Drools Expert User Guide

..... vii
1. The Rule Engine 1
1.1. What is a Rule Engine? 1
1.1.1. Introduction and Background 1
1.2. Why use a Rule Engine? 6
1.2.1. Advantages of a Rule Engine 6
1.2.2. When should you use a Rule Engine? 7
1.2.3. When not to use a Rule Engine 8
1.2.4. Scripting or Process Engines 8
1.2.5. Strong and Loose Coupling 9
2. Quick Start 11
2.1. The Basics 11
2.1.1. Stateless Knowledge Session 11
2.1.2. Stateful Knowledge Session 14
2.2. A Little Theory 19
2.2.1. Methods versus Rules 19
2.2.2. Cross Products 20
2.2.3. Activations, Agenda and Conflict Sets. 21
2.2.4. Inference 26
2.2.5. Inference and TruthMaintenance 28
2.3. More on building and deploying 30
2.3.1. Knowledge Base by Configuration Using Changesets 30
2.3.2. Knowledge Agent 31
3. Advanced Concepts and Theory 35
3.1. Truth Maintenance with Logical Objects 35
3.1.1. Example Scenario 37
3.1.2. Lazy Truth Maintenance 38
3.1.3. Important note: Equality for Java objects 38
3.2. Rete Algorithm 38
4. User Guide 45
4.1. Building 45
4.1.1. Building using Code 46
4.1.2. Building using Configuration and the ChangeSet XML 49
4.1.3. Changing default building result severity 53
4.2. Deploying 53
4.2.1. KnowledgePackage and Knowledge Definitions 53
4.2.2. KnowledgeBase 54
4.2.3. In-Process Building and Deployment 56
4.2.4. Building and Deployment in Separate Processes 57
4.2.5. StatefulknowledgeSessions and KnowledgeBase Modifications 58
4.2.6. KnowledgeAgent 58
4.3. Running 62
4.3.1. KnowledgeBase 62
4.3.2. StatefulKnowledgeSession 63

4.3.3. KnowledgeRuntime 63
4.3.4. Agenda 72
4.3.5. Event Model 77
4.3.6. KnowledgeRuntimeLogger 79
4.3.7. StatelessKnowledgeSession 80
4.3.8. Commands and the CommandExecutor 84
4.3.9. Marshalling 92
4.3.10. Persistence and Transactions 94
4.3.11. Drools Clips 96
5. The Rule Language 99
5.1. Overview 99
5.1.1. A rule file 99
5.1.2. What makes a rule 99
5.2. Keywords 100
5.3. Comments 102
5.3.1. Single line comment 102
5.3.2. Multi-line comment 103
5.4. Error Messages 103
5.4.1. Message format 103
5.4.2. Error Messages Description 104
5.4.3. Other Messages 108
5.5. Package 108
5.5.1. import 109
5.5.2. global 110
5.6. Function 111
5.7. Type Declaration 112
5.7.1. Declaring New Types 113
5.7.2. Declaring Metadata 115
5.7.3. Declaring Metadata for Existing Types 119
5.7.4. Parameterized constructors for declared types 120
5.7.5. Non Typesafe Classes 120
5.7.6. Accessing Declared Types from the Application Code 120
5.7.7. Type Declaration 'extends' 122
5.8. Rule 123
5.8.1. Rule Attributes 124
5.8.2. Timers and Calendars 128
5.8.3. Left Hand Side (when) syntax 129
5.8.4. The Right Hand Side (then) 177
5.8.5. A Note on Auto-boxing and Primitive Types 179
5.9. Query 180
5.10. Domain Specific Languages 183
5.10.1. When to Use a DSL 183
5.10.2. DSL Basics 183
5.10.3. Adding Constraints to Facts 186

5.10.4. Developing a DSL 188
5.10.5. DSL and DSLR Reference 188
5.11. XML Rule Language 192
5.11.1. When to use XML 192
5.11.2. The XML format 193
5.11.3. Legacy Drools 2.x XML rule format 197
5.11.4. Automatic transforming between formats (XML and DRL) 197
6. Authoring 199
6.1. Decision Tables in Spreadsheets 199
6.1.1. When to Use Decision Tables 199
6.1.2. Overview 199
6.1.3. How Decision Tables Work 202
6.1.4. Spreadsheet Syntax 205
6.1.5. Creating and integrating Spreadsheet based Decision Tables 214
6.1.6. Managing Business Rules in Decision Tables 215
6.1.7. Rule Templates 216
6.2. Templates 219
6.2.1. The Rule Template File 219
6.2.2. Expanding a Template 220
6.2.3. Example 222
7. The Java Rule Engine API 227
7.1. Introduction 227
7.2. How To Use 227
7.2.1. Building and Registering RuleExecutionSets 227
7.2.2. Using Stateful and Stateless RuleSessions 229
7.3. References 231
8. The Rule IDE (Eclipse) 233
8.1. Features Outline 234
8.2. Drools Runtimes 235
8.2.1. Defining a Drools Runtime 235
8.2.2. Selecting a runtime for your Drools project 239
8.3. Creating a Rule Project 241
8.4. Creating a New Rule and Wizards 244
8.5. Textual Rule Editor 245
8.6. Drools Views 247
8.6.1. The Working Memory View 247
8.6.2. The Agenda View 248
8.6.3. The Global Data View 248
8.6.4. The Audit View 249
8.7. Domain Specific Languages 251
8.7.1. Editing languages 251
8.8. The Rete View 252
8.9. Large DRL Files 253
8.10. Debugging Rules 254

8.10.1. Creating Breakpoints 255
8.10.2. Debugging Rules 255
9. Examples 259
9.1. Getting the Examples 259
9.2. Hello World 259
9.3. State Example 265
9.3.1. Understanding the State Example 265
9.4. Fibonacci Example 273
9.5. Banking Tutorial 280
9.6. Pricing Rule Decision Table Example 294
9.6.1. Executing the example 294
9.6.2. The decision table 295
9.7. Pet Store Example 297
9.8. Honest Politician Example 309
9.9. Sudoku Example 313
9.9.1. Sudoku Overview 314
9.9.2. Running the Example 314
9.9.3. Java Source and Rules Overview 318
9.9.4. Sudoku Validator Rules (validate.drl) 319
9.9.5. Sudoku Solving Rules (sudoku.drl) 320
9.10. Number Guess 321
9.11. Miss Manners and Benchmarking 328
9.11.1. Introduction 328
9.11.2. Indepth Discussion 331
9.11.3. Output Summary 337
9.12. Conway's Game Of Life 340
Index 349

Drools

Expert

Chapter 1. The Rule Engine

1.1. What is a Rule Engine?

1.1.1. Introduction and Background

Artificial Intelligence (A.I.) is a very broad research area that focuses on "Making computers think like people" and includes disciplines such as Neural Networks, Genetic Algorithms, Decision Trees, Frame Systems and Expert Systems. Knowledge representation is the area of A.I. concerned with how knowledge is represented and manipulated. Expert Systems use Knowledge representation to facilitate the codification of knowledge into a knowledge base which can be used for reasoning, i.e., we can process data with this knowledge base to infer conclusions. Expert Systems are also known as Knowledge-based Systems and Knowledge-based Expert Systems and are considered to be "applied artificial intelligence". The process of developing with an Expert System is Knowledge Engineering. EMYCIN was one of the first "shells" for an Expert System, which was created from the MYCIN medical diagnosis Expert System. Whereas early Expert Systems had their logic hard-coded, "shells" separated the logic from the system, providing an easy to use environment for user input. Drools is a Rule Engine that uses the rule-based approach to implement an Expert System and is more correctly classified as a Production Rule System.

The term "Production Rule" originates from formal grammars where it is described as "an abstract structure that describes a formal language precisely, i.e., a set of rules that mathematically delineates a (usually infinite) set of finite-length strings over a (usually finite) alphabet" (*Wikipedia [http://en.wikipedia.org/wiki/Formal_grammar]*).

Business Rule Management Systems build additional value on top of a general purpose Rule Engine by providing business user focused systems for rule creation, management, deployment, collaboration, analysis and end user tools. Further adding to this value is the fast evolving and popular methodology "Business Rules Approach", which is a helping to formalize the role of Rule Engines in the enterprise.

The term Rule Engine is quite ambiguous in that it can be any system that uses rules, in any form, that can be applied to data to produce outcomes. This includes simple systems like form validation and dynamic expression engines. The book "How to Build a Business Rules Engine (2004)" by Malcolm Chisholm exemplifies this ambiguity. The book is actually about how to build and alter a database schema to hold validation rules. The book then shows how to generate VB code from those validation rules to validate data entry. This, while a very valid and useful topic for some, caused quite a surprise to this author, unaware at the time in the subtleties of Rules Engines' differences, who was hoping to find some hidden secrets to help improve the Drools engine. JBoss jBPM uses expressions and delegates in its Decision nodes which control the transitions in a Workflow. At each node it evaluates ther is a rule set that dictates the transition to undertake, and so this is also a Rule Engine. While a Production Rule System is a kind of Rule Engine and also an Expert System, the validation and expression evaluation Rule Engines mentioned previously are not Expert Systems.

A Production Rule System is Turing complete, with a focus on knowledge representation to express propositional and first order logic in a concise, non-ambiguous and declarative manner. The brain of a Production Rules System is an Inference Engine that is able to scale to a large number of rules and facts. The Inference Engine matches facts and data against Production Rules - also called Productions or just Rules - to infer conclusions which result in actions. A Production Rule is a two-part structure using First Order Logic for reasoning over knowledge representation.

```
when
    <conditions>
then
    <actions>;
```

The process of matching the new or existing facts against Production Rules is called Pattern Matching, which is performed by the Inference Engine. There are a number of algorithms used for Pattern Matching by Inference Engines including:

- Linear
- Rete
- Treat
- Leaps

Drools implements and extends the Rete algorithm; Leaps used to be provided but was retired as it became unmaintained. The Drools Rete implementation is called ReteOO, signifying that Drools has an enhanced and optimized implementation of the Rete algorithm for object oriented systems. Other Rete based engines also have marketing terms for their proprietary enhancements to Rete, like RetePlus and Rete III. The most common enhancements are covered in "Production Matching for Large Learning Systems (Rete/UL)" (1995) by Robert B. Doorenbos.

The Rules are stored in the Production Memory and the facts that the Inference Engine matches against are kept in the Working Memory. Facts are asserted into the Working Memory where they may then be modified or retracted. A system with a large number of rules and facts may result in many rules being true for the same fact assertion; these rules are said to be in conflict. The Agenda manages the execution order of these conflicting rules using a Conflict Resolution strategy.

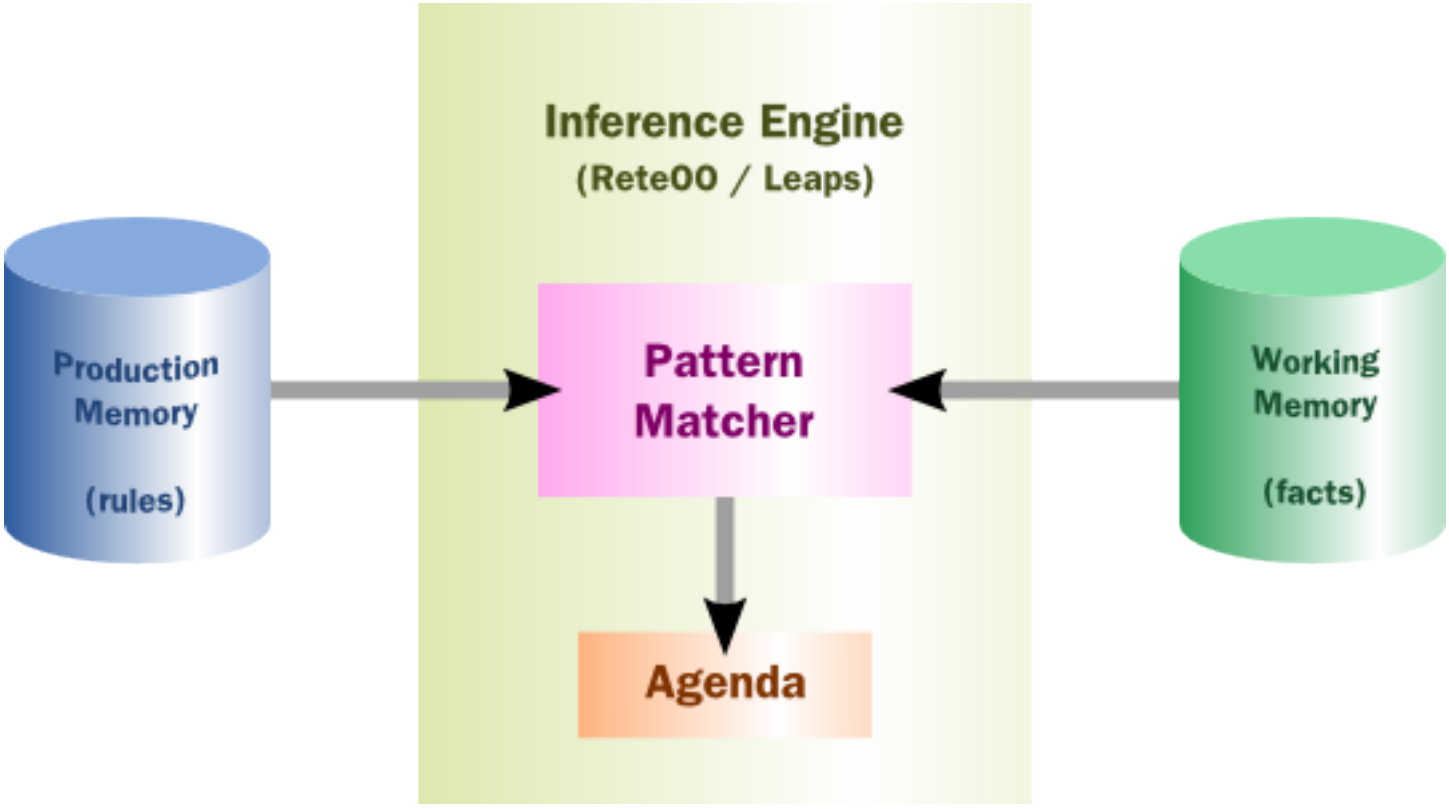


Figure 1.1. High-level View of a Rule Engine

There are two methods of execution for a rule system: Forward Chaining and Backward Chaining; systems that implement both are called Hybrid Chaining Systems. As of Drools 5.2 Drools provides seamless hybrid chaining, both forward and backwards. Understanding these two modes of operation is the key to understanding why a Production Rule System is different and how to get the best from it. Forward chaining is "data-driven" and thus reactionary, with facts being asserted into working memory, which results in one or more rules being concurrently true and scheduled for execution by the Agenda. In short, we start with a fact, it propagates and we end in a conclusion.

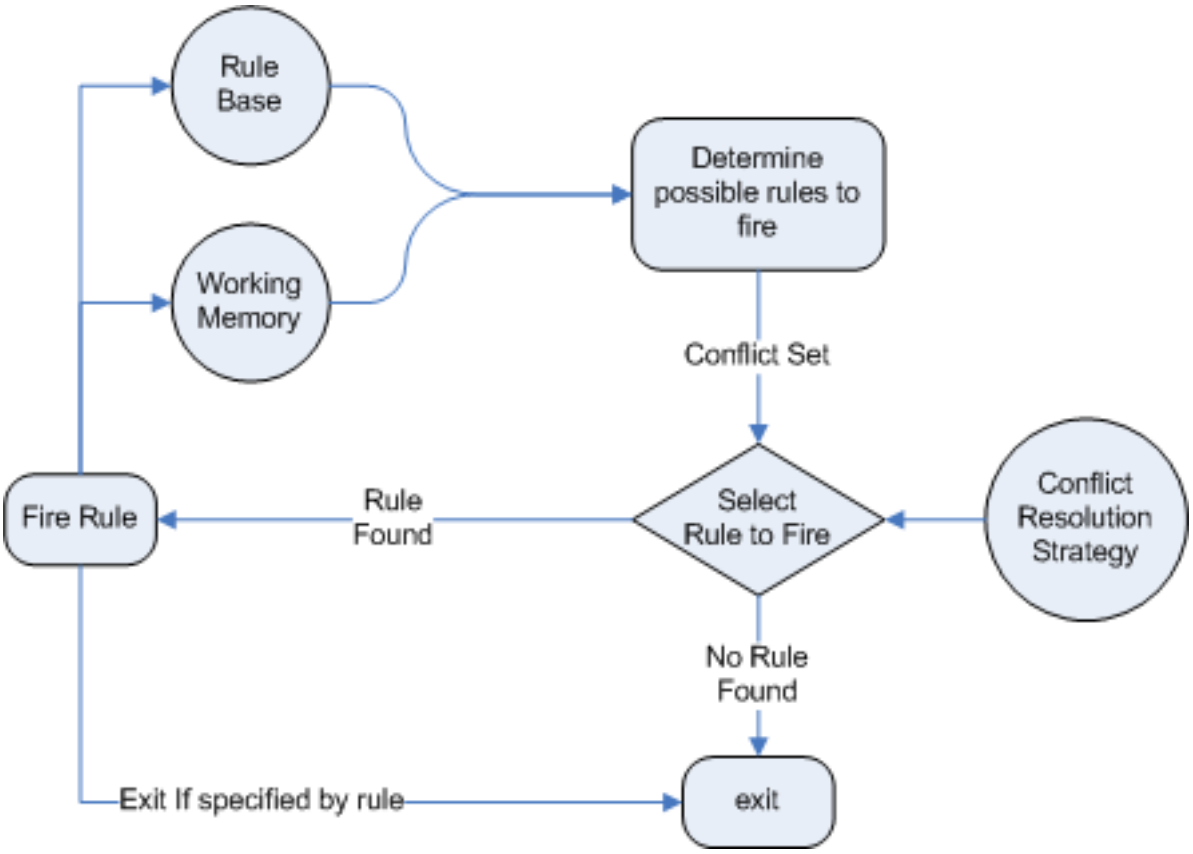


Figure 1.2. Forward Chaining

Backward chaining is "goal-driven", meaning that we start with a conclusion which the engine tries to satisfy. If it can't it then searches for conclusions that it can satisfy; these are known as subgoals, that will help satisfy some unknown part of the current goal. It continues this process until either the initial conclusion is proven or there are no more subgoals. Prolog is an example of a Backward Chaining engine. Drools can also do backward chaining, which we refer to as derivation queries.

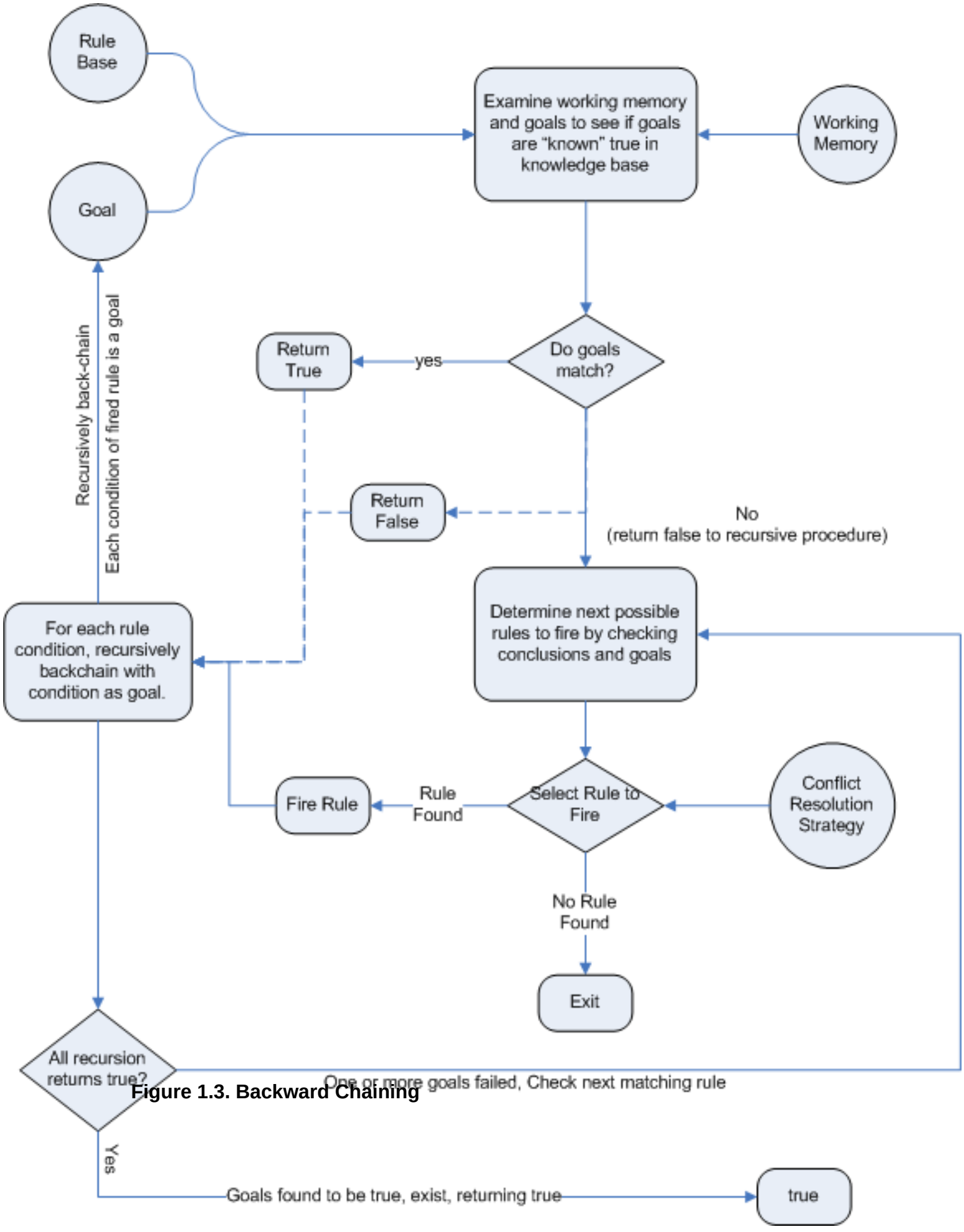


Figure 1.3. Backward Chaining

1.2. Why use a Rule Engine?

Some frequently asked questions:

1. When should you use a rule engine?
2. What advantage does a rule engine have over hand coded "if...then" approaches?
3. Why should you use a rule engine instead of a scripting framework, like BeanShell?

We will attempt to address these questions below.

1.2.1. Advantages of a Rule Engine

- Declarative Programming

  Rule engines allow you to say "What to do", not "How to do it".

  The key advantage of this point is that using rules can make it easy to express solutions to difficult problems and consequently have those solutions verified. Rules are much easier to read than code.

  Rule systems are capable of solving very, very hard problems, providing an explanation of how the solution was arrived at and why each "decision" along the way was made (not so easy with other of AI systems like neural networks or the human brain - I have no idea why I scratched the side of the car).

- Logic and Data Separation

  Your data is in your domain objects, the logic is in the rules. This is fundamentally breaking the OO coupling of data and logic, which can be an advantage or a disadvantage depending on your point of view. The upshot is that the logic can be much easier to maintain as there are changes in the future, as the logic is all laid out in rules. This can be especially true if the logic is cross-domain or multi-domain logic. Instead of the logic being spread across many domain objects or controllers, it can all be organized in one or more very distinct rules files.

- Speed and Scalability

  The Rete algorithm,the Leaps algorithm, and their descendants such as Drools' ReteOO, provide very efficient ways of matching rule patterns to your domain object data. These are especially efficient when you have datasets that change in small portions as the rule engine can remember past matches. These algorithms are battle proven.

- Centralization of Knowledge

  By using rules, you create a repository of knowledge (a knowledge base) which is executable. This means it's a single point of truth, for business policy, for instance. Ideally rules are so readable that they can also serve as documentation.

- Tool Integration

  Tools such as Eclipse (and in future, Web based user interfaces) provide ways to edit and manage rules and get immediate feedback, validation and content assistance. Auditing and debugging tools are also available.

- Explanation Facility

  Rule systems effectively provide an "explanation facility" by being able to log the decisions made by the rule engine along with why the decisions were made.

- Understandable Rules

  By creating object models and, optionally, Domain Specific Languages that model your problem domain you can set yourself up to write rules that are very close to natural language. They lend themselves to logic that is understandable to, possibly nontechnical, domain experts as they are expressed in their language, with all the program plumbing, the technical know-how being hidden away in the usual code.

1.2.2. When should you use a Rule Engine?

The shortest answer to this is "when there is no satisfactory traditional programming approach to solve the problem.". Given that short answer, some more explanation is required. The reason why there is no "traditional" approach is possibly one of the following:

- The problem is just too fiddle for traditional code.

  The problem may not be complex, but you can't see a non-fragile way of building a solution for it.

- The problem is beyond any obvious algorithmic solution.

  It is a complex problem to solve, there are no obvious traditional solutions, or basically the problem isn't fully understood.

- The logic changes often

  The logic itself may even be simple but the rules change quite often. In many organizations software releases are few and far between and pluggable rules can help provide the "agility" that is needed and expected in a reasonably safe way.

- Domain experts (or business analysts) are readily available, but are nontechnical.

  Domain experts often possess a wealth of knowledge about business rules and processes. They typically are nontechnical, but can be very logical. Rules can allow them to express the logic in their own terms. Of course, they still have to think critically and be capable of logical thinking. Many people in nontechnical positions do not have training in formal logic, so be careful and work with them, as by codifying business knowledge in rules, you will often expose holes in the way the business rules and processes are currently understood.

If rules are a new technology for your project teams, the overhead in getting going must be factored in. It is not a trivial technology, but this document tries to make it easier to understand.

Typically in a modern OO application you would use a rule engine to contain key parts of your business logic, *especially the really messy parts*. This is an inversion of the OO concept of encapsulating all the logic inside your objects. This is not to say that you throw out OO practices, on the contrary in any real world application, business logic is just one part of the application. If you ever notice lots of conditional statements such as "if" and "switch", an overabundance of strategy patterns and other messy logic in your code that just doesn't feel right: that would be a place for rules. If there is some such logic and you keep coming back to fix it, either because you got it wrong, or the logic or your understanding changes: think about using rules. If you are faced with tough problems for which there are no algorithms or patterns: consider using rules.

Rules could be used embedded in your application or perhaps as a service. Often a rule engine works best as "stateful" component, being an integral part of an application. However, there have been successful cases of creating reusable rule services which are stateless.

For your organization it is important to decide about the process you will use for updating rules in systems that are in production. The options are many, but different organizations have different requirements. Frequently, rules maintenance is out of the control of the application vendors or project developers.

1.2.3. When not to use a Rule Engine

To quote a Drools mailing list regular:

> It seems to me that in the excitement of working with rules engines, that people forget that a rules engine is only one piece of a complex application or solution. Rules engines are not really intended to handle workflow or process executions nor are workflow engines or process management tools designed to do rules. Use the right tool for the job. Sure, a pair of pliers can be used as a hammering tool in a pinch, but that's not what it's designed for.
>
> —Dave Hamu

As rule engines are dynamic (dynamic in the sense that the rules can be stored and managed and updated as data), they are often looked at as a solution to the problem of deploying software. (Most IT departments seem to exist for the purpose of preventing software being rolled out.) If this is the reason you wish to use a rule engine, be aware that rule engines work best when you are able to write declarative rules. As an alternative, you can consider data-driven designs (lookup tables), or script processing engines where the scripts are managed in a database and are able to be updated on the fly.

1.2.4. Scripting or Process Engines

Hopefully the preceding sections have explained when you may want to use a rule engine.

Alternatives are script-based engines that provide the drive for "changes on the fly", and there are many such solutions.

Alternatively Process Engines (also capable of workflow) such as jBPM allow you to graphically (or programmatically) describe steps in a process. Those steps can also involve decision points which are in themselves a simple rule. Process engines and rules often can work nicely together, so they are not mutually exclusive.

One key point to note with rule engines is that some rule engines are really scripting engines. The downside of scripting engines is that you are tightly coupling your application to the scripts. If they are rules, you are effectively calling rules directly and this may cause more difficulty in future maintenance, as they tend to grow in complexity over time. The upside of scripting engines is that they can be easier to implement initially, producing results quickly, and are conceptually simpler for imperative programmers.

Many people have also implemented data-driven systems successfully in the past (where there are control tables that store meta-data that changes your applications behavior) - these can work well when the control can remain very limited. However, they can quickly grow out of control if extended too much (such that only the original creators can change the applications behavior) or they cause the application to stagnate as they are too inflexible.

1.2.5. Strong and Loose Coupling

No doubt you have heard terms like "tight coupling" and "loose coupling" in systems design. Generally people assert that "loose" or "weak" coupling is preferable in design terms, due to the added flexibility it affords. Similarly, you can have "strongly coupled" and "weakly coupled" rules. Strongly coupled in this sense means that one rule "firing" will clearly result in another rule firing, and so on; in other words, there is a clear (probably obvious) chain of logic. If your rules are all strongly coupled, the chances are that the will turn out to be inflexible, and, more significantly, that a rule engine is an overkill. A clear chain can be hard coded, or implemented using a Decision Tree. This is not to say that strong coupling is inherently bad, but it is a point to keep in mind when considering a rule engine and the way you capture the rules. "Loosely" coupled rules should result in a system that allows rules to be changed, removed and added without requiring changes to other, unrelated rules.

Chapter 2. Quick Start

2.1. The Basics

2.1.1. Stateless Knowledge Session

So where do we get started, there are so many use cases and so much functionality in a rule engine such as Drools that it becomes beguiling. Have no fear my intrepid adventurer, the complexity is layered and you can ease yourself into with simple use cases.

Stateless session, not utilising inference, forms the simplest use case. A stateless session can be called like a function passing it some data and then receiving some results back. Some common use cases for stateless sessions are, but not limited to:

- Validation
  - Is this person eligible for a mortgage?
- Calculation
  - Compute a mortgage premium.
- Routing and Filtering
  - Filter incoming messages, such as emails, into folders.
  - Send incoming messages to a destination.

So let's start with a very simple example using a driving license application.

```
public class Applicant {
    private String name;
    private int age;
    private boolean valid;
    // getter and setter methods here
}
```

Now that we have our data model we can write our first rule. We assume that the application uses rules to refute invalid applications. As this is a simple validation use case we will add a single rule to disqualify any applicant younger than 18.

```
package com.company.license

rule "Is of valid age"
```

```
when
    $a : Applicant( age < 18 )
then
    $a.setValid( false );
end
```

To make the engine aware of data, so it can be processed against the rules, we have to *insert* the data, much like with a database. When the Applicant instance is inserted into the engine it is evaluated against the constraints of the rules, in this case just two constraints for one rule. We say *two* because the type Applicant is the first object type constraint, and `age < 18` is the second field constraint. An object type constraint plus its zero or more field constraints is referred to as a pattern. When an inserted instance satisfies both the object type constraint and all the field constraints, it is said to be matched. The `$a` is a binding variable which permits us to reference the matched object in the consequence. There its properties can be updated. The dollar character ('$') is optional, but it helps to differentiate variable names from field names. The process of matching patterns against the inserted data is, not surprisingly, often referred to as *pattern matching*.

Let's assume that the rules are in the same folder as the classes, so we can use the classpath resource loader to build our first `KnowledgeBase`. A Knowledge Base is what we call our collection of compiled definitions, such as rules and processes, which are compiled using the `KnowledgeBuilder`. Both the KnowledgeBuilder and KnowledgeBase can be created from the factories KnowledeBuilderFactory and KnowledgeBaseFactory.

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kbuilder.add( ResourceFactory.newClassPathResource( "licenseApplication.drl", getClass() ),
              ResourceType.DRL );
if ( kbuilder.hasErrors() ) {
    System.err.println( kbuilder.getErrors().toString() );
}
KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
kbase.addKnowledgePackages( kbuilder.getKnowledgePackages() );
```

The above code snippet looks on the classpath for the `licenseApplication.drl` file, using the method `newClassPathResource()`. The resource type is DRL, short for "Drools Rule Language". Once the DRL file has been added we can check the Knowledge Builder object for any errors. If there are no errors, we can add the resulting packages to our Knowledge Base. Now we are ready to build our session and execute against some data:

```
StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();
Applicant applicant = new Applicant( "Mr John Smith", 16 );
assertTrue( applicant.isValid() );
ksession.execute( applicant );
assertFalse( applicant.isValid() );
```

The preceding code executes the data against the rules. Since the applicant is under the age of 18, the application is marked as invalid.

So far we've only used a single instance, but what if we want to use more than one? We can execute against any object implementing Iterable, such as a collection. Let's add another class called `Application`, which has the date of the application, and we'll also move the boolean valid field to the `Application` class.

```
public class Applicant {
    private String name;
    private int age;
    // getter and setter methods here
}

public class Application {
    private Date dateApplied;
    private boolean valid;
    // getter and setter methods here
}
```

We can also add another rule to validate that the application was made within a period of time.

```
package com.company.license

rule "Is of valid age"
when
    Applicant( age < 18 )
    $a : Application()
then
    $a.setValid( false );
end

rule "Application was made this year"
when
    $a : Application( dateApplied > "01-jan-2009" )
then
    $a.setValid( false );
end
```

Unfortunately a Java array does not implement the `Iterable` interface, so we have to use the JDK converter method `Arrays.asList(...)`. The code shown below executes against an iterable list, where all collection elements are inserted before any matched rules are fired.

```
StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();
```

```
Applicant applicant = new Applicant( "Mr John Smith", 16 );
Application application = new Application();
assertTrue( application() );
ksession.execute( Arrays.asList( new Object[] { application, applicant } ) );
assertFalse( application() );
```

The two execute methods `execute(Object object)` and `execute(Iterable objects)` are actually convenience methods for the interface `BatchExecutor`'s method `execute(Command command)`.

A `CommandFactory` is used to create commands, so that the following is equivalent to `execute(Iterable it)`:

```
ksession.execute( CommandFactory.newInsertIterable( new Object[] { application, applicant } ) )
```

Batch Executor and Command Factory are particularly useful when working with multiple Commands and with output identifiers for obtaining results.

```
List<Command> cmds = new ArrayList<Command>();
cmds.add( CommandFactory.newInsert( new Person( "Mr John Smith" ), "mrSmith" );
cmds.add( CommandFactory.newInsert( new Person( "Mr John Doe" ), "mrDoe" );
BatchExecutionResults results = ksession.execute( CommandFactory.newBatchExecution( cmds ) );
assertEquals( new Person( "Mr John Smith" ), results.getValue( "mrSmith" ) );
```

`CommandFactory` supports many other Commands that can be used in the `BatchExecutor` like `StartProcess`, `Query`, and `SetGlobal`.

2.1.2. Stateful Knowledge Session

Stateful Sessions are longer lived and allow iterative changes over time. Some common use cases for Stateful Sessions are, but not limited to:

- Monitoring
  - Stock market monitoring and analysis for semi-automatic buying.
- Diagnostics
  - Fault finding, medical diagnostics
- Logistics
  - Parcel tracking and delivery provisioning
- Compliance

- Validation of legality for market trades.

In contrast to a Stateless Session, the `dispose()` method must be called afterwards to ensure there are no memory leaks, as the Knowledge Base contains references to Stateful Knowledge Sessions when they are created. `StatefulKnowledgeSession` also supports the `BatchExecutor` interface, like `StatelessKnowledgeSession`, the only difference being that the `FireAllRules` command is not automatically called at the end for a Stateful Session.

We illustrate the monitoring use case with an example for raising a fire alarm. Using just four classes, we represent rooms in a house, each of which has one sprinkler. If a fire starts in a room, we represent that with a single `Fire` instance.

```
public class Room {
    private String name
    // getter and setter methods here
}
public classs Sprinkler {
    private Room room;
    private boolean on;
    // getter and setter methods here
}
public class Fire {
    private Room room;
    // getter and setter methods here
}
public class Alarm {
}
```

In the previous section on Stateless Sessions the concepts of inserting and matching against data was introduced. That example assumed that only a single instance of each object type was ever inserted and thus only used literal constraints. However, a house has many rooms, so rules must express relationships between objects, such as a sprinkler being in a certain room. This is best done by using a binding variable as a constraint in a pattern. This "join" process results in what is called cross products, which are covered in the next section.

When a fire occurs an instance of the `Fire` class is created, for that room, and inserted into the session. The rule uses a binding on the `room` field of the `Fire` object to constrain matching to the sprinkler for that room, which is currently off. When this rule fires and the consequence is executed the sprinkler is turned on.

```
rule "When there is a fire turn on the sprinkler"
when
    Fire($room : room)
    $sprinkler : Sprinkler( room == $room, on == false )
then
```

```
    modify( $sprinkler ) { setOn( true ) };
    System.out.println( "Turn on the sprinkler for room " + $room.getName() );
end
```

Whereas the Stateless Session uses standard Java syntax to modify a field, in the above rule we use the `modify` statement, which acts as a sort of "with" statement. It may contain a series of comma separated Java expressions, i.e., calls to setters of the object selected by the `modify` statement's control expression. This modifies the data, and makes the engine aware of those changes so it can reason over them once more. This process is called inference, and it's essential for the working of a Stateful Session. Stateless Sessions typically do not use inference, so the engine does not need to be aware of changes to data. Inference can also be turned off explicitly by using the *sequential mode*.

So far we have rules that tell us when matching data exists, but what about when it does *not* exist? How do we determine that a fire has been extinguished, i.e., that there isn't a `Fire` object any more? Previously the constraints have been sentences according to Propositional Logic, where the engine is constraining against individual intances. Drools also has support for First Order Logic that allows you to look at sets of data. A pattern under the keyword `not` matches when something does not exist. The rule given below turns the sprinkler off as soon as the fire in that room has disappeared.

```
rule "When the fire is gone turn off the sprinkler"
when
    $room : Room( )
    $sprinkler : Sprinkler( room == $room, on == true )
    not Fire( room == $room )
then
    modify( $sprinkler ) { setOn( false ) };
    System.out.println( "Turn off the sprinkler for room " + $room.getName() );
end
```

While there is one sprinkler per room, there is just a single alarm for the building. An `Alarm` object is created when a fire occurs, but only one `Alarm` is needed for the entire building, no matter how many fires occur. Previously `not` was introduced to match the absence of a fact; now we use its complement `exists` which matches for one or more instances of some category.

```
rule "Raise the alarm when we have one or more fires"
when
    exists Fire()
then
    insert( new Alarm() );
    System.out.println( "Raise the alarm" );
end
```

Likewise, when there are no fires we want to remove the alarm, so the `not` keyword can be used again.

```
rule "Cancel the alarm when all the fires have gone"
when
    not Fire()
    $alarm : Alarm()
then
    retract( $alarm );
    System.out.println( "Cancel the alarm" );
end
```

Finally there is a general health status message that is printed when the application first starts and after the alarm is removed and all sprinklers have been turned off.

```
rule "Status output when things are ok"
when
    not Alarm()
    not Sprinkler( on == true )
then
    System.out.println( "Everything is ok" );
end
```

The above rules should be placed in a single DRL file and saved to some directory on the classpath and using the file name `fireAlarm.drl`, as in the Stateless Session example. We can then build a Knowledge Base, as before, just using the new name `fireAlarm.drl`. The difference is that this time we create a Stateful Session from the Knowledge Base, whereas before we created a Stateless Session.

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kbuilder.add( ResourceFactory.newClassPathResource( "fireAlarm.drl", getClass() ),
              ResourceType.DRL );
if ( kbuilder.hasErrors() ) {
    System.err.println( builder.getErrors().toString() );
}
kbase.addKnowledgePackages( kbuilder.getKnowledgePackages() );
StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();
```

With the session created it is now possible to iteratvely work with it over time. Four `Room` objects are created and inserted, as well as one `Sprinkler` object for each room. At this point the engine has done all of its matching, but no rules have fired yet. Calling `ksession.fireAllRules()` allows the matched rules to fire, but without a fire that will just produce the health message.

```
String[] names = new String[]{"kitchen", "bedroom", "office", "livingroom"};
Map<String,Room> name2room = new HashMap<String,Room>();
for( String name: names ){
    Room room = new Room( name );
    name2room.put( name, room );
    ksession.insert( room );
    Sprinkler sprinkler = new Sprinkler( room );
    ksession.insert( sprinkler );
}

ksession.fireAllRules()
```

```
> Everything is ok
```

We now create two fires and insert them; this time a reference is kept for the returned `FactHandle`. A Fact Handle is an internal engine reference to the inserted instance and allows instances to be retracted or modified at a later point in time. With the fires now in the engine, once `fireAllRules()` is called, the alarm is raised and the respective sprinklers are turned on.

```
Fire kitchenFire = new Fire( name2room.get( "kitchen" ) );
Fire officeFire = new Fire( name2room.get( "office" ) );

FactHandle kitchenFireHandle = ksession.insert( kitchenFire );
FactHandle officeFireHandle = ksession.insert( officeFire );

ksession.fireAllRules();
```

```
> Raise the alarm
> Turn on the sprinkler for room kitchen
> Turn on the sprinkler for room office
```

After a while the fires will be put out and the `Fire` instances are retracted. This results in the sprinklers being turned off, the alarm being cancelled, and eventually the health message is printed again.

```
ksession.retract( kitchenFireHandle );
ksession.retract( officeFireHandle );

ksession.fireAllRules();
```

```
> Turn on the sprinkler for room office
> Turn on the sprinkler for room kitchen
> Cancel the alarm
> Everything is ok
```

Everyone still with me? That wasn't so hard and already I'm hoping you can start to see the value and power of a declarative rule system.

2.2. A Little Theory

2.2.1. Methods versus Rules

People often confuse methods and rules, and new rule users regular ask, "How do I call a rule?" After the last section, you are now feeling like a rule expert and the answer to that is obvious, but let's summarize the differences nonetheless.

```
public void helloWorld(Person person) {
    if ( person.getName().equals( "Chuck" ) ) {
        System.out.println( "Hello Chuck" );
    }
}
```

- Methods are called directly.
- Specific instances are passed.
- One call results in a single execution.

```
rule "Hello World"
    when
        Person( name == "Chuck" )
    then
        System.out.println( "Hello Chuck" );
        end
```

- Rules execute by matching against any data as long it is inserted into the engine.
- Rules can never be called directly.
- Specific instances cannot be passed to a rule.
- Depending on the matches, a rule may fire once or several times, or not at all.

2.2.2. Cross Products

Earlier the term "cross product" was mentioned, which is the result of a join. Imagine for a moment that the data from the fire alarm example were used in combination with the following rule where there ar no field constraints:

```
rule
when
    $room : Room()
    $sprinkler : Sprinkler()
then
    System.out.println( "room:" + $room.getName() +
                        " sprinkler:" + $sprinkler.getRoom().getName() );
end
```

In SQL terms this would be like doing `select * from Room, Sprinkler` and every row in the Room table would be joined with every row in the Sprinkler table resulting in the following output:

```
room:office sprinker:office
room:office sprinkler:kitchen
room:office sprinkler:livingroom
room:office sprinkler:bedroom
room:kitchen sprinkler:office
room:kitchen sprinkler:kitchen
room:kitchen sprinkler:livingroom
room:kitchen sprinkler:bedroom
room:livingroom sprinkler:office
room:livingroom sprinkler:kitchen
room:livingroom sprinkler:livingroom
room:livingroom sprinkler:bedroom
room:bedroom sprinkler:office
room:bedroom sprinkler:kitchen
room:bedroom sprinkler:livingroom
room:bedroom sprinkler:bedroom
```

These cross products can obviously become huge, and they may very well contain spurious data. The size of cross products is often the source of performance problems for new rule authors. From this it can be seen that it's always desirable to constrain the cross products, which is done with the variable constraint.

```
rule
when
    $room : Room()
    $sprinkler : Sprinkler( room == $room )
```

```
then
    System.out.println( "room:" + $room.getName() +
                        " sprinkler:" + $sprinkler.getRoom().getName() );
end
```

This results in just four rows of data, with the correct Sprinkler for each Room. In SQL (actually HQL) the corresponding query would be `select * from Room, Sprinkler where Room == Sprinkler.room`.

```
room:office sprinkler:office
room:kitchen sprinkler:kitchen
room:livingroom sprinkler:livingroom
room:bedroom sprinkler:bedroom
```

2.2.3. Activations, Agenda and Conflict Sets.

So far the data and the matching process has been simple and small. To mix things up a bit a new example will be explored that handles cashflow calculations over date periods. The state of the engine will be illustratively shown at key stages to help get a better understanding of what is actually going on under the hood. Three classes will be used, as shown below.

```
public class CashFlow {
    private Date   date;
    private double amount;
    private int    type;
    long           accountNo;
    // getter and setter methods here
}

public class Account {
    private long   accountNo;
    private double balance;
    // getter and setter methods here
}

public AccountPeriod {
    private Date start;
    private Date end;
    // getter and setter methods here
}
```

By now you already know how to create Knowledge Bases and how to instantiate facts to populate the `StatefulKnowledgeSession`, so tables will be used to show the state of the inserted data, as it makes things clearer for illustration purposes. The tables below show that a single fact was

inserted for the `Account`. Also inserted are a series of debits and credits as `CashFlow` objects for that account, extending over two quarters.

CashFlow

date	amount	type	accountNo
12-Jan-07	100	CREDIT	1
2-Feb-07	200	DEBIT	1
18-May-07	50	CREDIT	1
9-Mar-07	75	CREDIT	1

Account

accountNo	balance
1	0

Figure 2.1. CashFlows and Account

Two rules can be used to determine the debit and credit for that quarter and update the Account balance. The two rules below constrain the cashflows for an account for a given time period. Notice the "&&" which use short cut syntax to avoid repeating the field name twice.

```
rule "increase balance for credits"
when
  ap : AccountPeriod()
     acc   :   Account(   $accountNo
 accountNo )
  CashFlow( type == CREDIT,
            accountNo == $accountNo,
         date >= ap.start && <= ap.end,
            $amount : amount )
then
  acc.balance  += $amount;
end
```

```
rule "decrease balance for debits"
when
  ap : AccountPeriod()
     acc   :   Account(   $accountNo   :
 accountNo )
  CashFlow( type == DEBIT,
            accountNo == $accountNo,
               date >= ap.start && <=
 ap.end,
            $amount : amount )
then
  acc.balance -= $amount;
end
```

If the `AccountPeriod` is set to the first quarter we constrain the rule "increase balance for credits" to fire on two rows of data and "decrease balance for debits" to act on one row of data.

AccountingPeriod

start	end
01-Jan-07	31-Mar-07

CashFlow

date	amount	type
12-Jan-07	100	CREDIT
9-Mar-07	75	CREDIT

CashFlow

date	amount
2-Feb-07	

Figure 2.2. AccountingPeriod, CashFlows and Account

The two cashflow tables above represent the matched data for the two rules. The data is matched during the insertion stage and, as you discovered in the previous chapter, does not fire straight away, but only after `fireAllRules()` is called. Meanwhile, the rule plus its matched data is placed on the Agenda and referred to as an Activation. The Agenda is a table of Activations that are able to fire and have their consequences executed, as soon as fireAllRules() is called. Activations on the Agenda are executed in turn. Notice that the order of execution so far is considered arbitrary.

Agenda		
1	increase balance	arbitrary
2	decrease balance	
3	increase balance	

Figure 2.3. CashFlows and Account

After all of the above activations are fired, the account has a balance of -25.

Account	
accountNo	balance
1	-25

Figure 2.4. CashFlows and Account

If the `AccountPeriod` is updated to the second quarter, we have just a single matched row of data, and thus just a single Activation on the Agenda.

AccountingPeriod	
start	end
01-Apr-07	30-Jun-07

CashFlow		
date	amount	type
18-May-07	50	CREDIT

Figure 2.5. CashFlows and Account

The firing of that Activation results in a balance of 25.

accountNo	balance
1	25

Figure 2.6. CashFlows and Account

What if you don't want the order of Activation execution to be arbitrary? When there is one or more Activations on the Agenda they are said to be in conflict, and a conflict resolver strategy is used to determine the order of execution. At the simplest level the default strategy uses salience to determine rule priority. Each rule has a default value of 0, the higher the value the higher the priority. To illustrate this we add a rule to print the account balance, where we want this rule to be executed after all the debits and credits have been applied for all accounts. We achieve this by assigning a negative salience to this rule so that it fires after all rules with the default salience 0.

Table 2.1.

```
rule "Print balance for AccountPeriod"
        salience -50
    when
        ap : AccountPeriod()
        acc : Account()
    then
        System.out.println( acc.accountNo + " : " + acc.balance );
end
```

The table below depicts the resulting Agenda. The three debit and credit rules are shown to be in arbitrary order, while the print rule is ranked last, to execute afterwards.

Agenda		
1	increase balance	arbitrary
2	decrease balance	
3	increase balance	
4	print balance	

Figure 2.7. CashFlows and Account

Earlier we showed how rules would equate to SQL, which can often help people with an SQL background to understand rules. The two rules above can be represented with two views and a trigger for each view, as below:

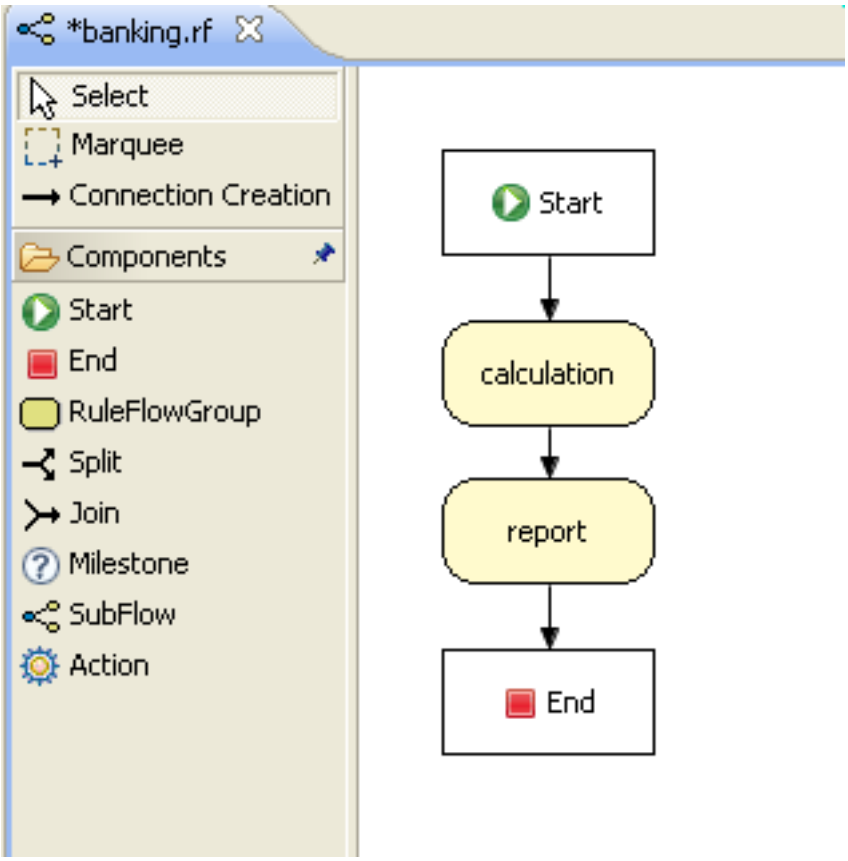
Table 2.2.

```
select * from Account acc,
              Cashflow cf,
              AccountPeriod ap
where  acc.accountNo  ==  cf.accountN
 and
      cf.type == CREDIT and
      cf.date >= ap.start and
      cf.date <= ap.end
```

```
select * from Account acc,
              Cashflow cf,
              AccountPeriod ap
where  acc.accountNo  ==  cf.accountNo
 and
      cf.type == DEBIT and
      cf.date >= ap.start and
      cf.date <= ap.end
```

`trigger : acc.balance += cf.amount`	`trigger : acc.balance -= cf.amount`

Drools also features ruleflow-group attributes which allows workflow diagrams to declaratively specify when rules are allowed to fire. The screenshot below is taken from Eclipse using the Drools plugin. It has two ruleflow-group nodes which ensures that the calculation rules are executed before the reporting rules.



The use of the ruleflow-group attribute in a rule is shown below.

Table 2.3.

```
rule "increase balance for credits"
  ruleflow-group "calculation"
when
  ap : AccountPeriod()
     acc   :   Account(   $accountNo
 accountNo )
  CashFlow( type == CREDIT,
            accountNo == $accountNo,
          date >= ap.start && <= ap.end
            $amount : amount )
then
  acc.balance  += $amount;
```

```
rule "Print balance for AccountPeriod"
  ruleflow-group "report"
when
  ap : AccountPeriod()
  acc : Account()
then
  System.out.println( acc.accountNo +
                                  " : " +
 acc.balance );
end
```

```
end
```

2.2.4. Inference

Inference has a bad names these days, as something not relevant to business use cases and just too complicated to be useful. It is true that contrived and complicated examples occur with inference, but that should not detract from the fact that simple and useful ones exist too. But more than this, correct use of inference can crate more agile and less error prone businesses with easier to maintain software.

So what is inference? Something is inferred when we gain knowledge of something from using previous knowledge. For example given a Person fact with an age field and a rule that provides age policy control, we can infer whether a Person is an adult or a child and act on this.

```
rule "Infer Adult"
when
  $p : Person( age >= 18 )
then
  insert( new IsAdult( $p ) )
end
```

So in the above every Person who is 18 or over will have an instance of IsAdult inserted for them. This fact is special in that it is known as a relation. We can use this inferred relation in any rule:

```
$p : Person()
IsAdult( person == $p )
```

So now we know what inference is, and have a basic example, how does this facilitate good rule design and maintenance?

Let's take a government department that are responsible for issuing ID cards when children become adults, hence forth referred to as ID department. They might have a decision table that includes logic like this, which says when an adult living in london is 18 or over, issue the card:

	RuleTable ID Card		
	CONDITION	CONDITION	ACTION
	p : Person		
	location	age >= $1	issueIdCard($1)
	Select Person	Select Adults	Issue ID Car
Issue ID Card to Adults	London	18	p

However the ID department does not set the policy on who an adult is. That's done at a central government level. If the central government where to change that age to 21 there is a change management process. Someone has to liaise with the ID department and make sure their systems are updated, in time for the law going live.

This change management process and communication between departments is not ideal for an agile environment and change become costly and error prone. Also the card department is managing more information than it needs to be aware of with its "monolothic" approach to rules management which is "leaking" information better placed else where. By this I mean that it doesn't care what explicit "age >= 18" information determines whether someone is an adult, only that they are an adult.

Instead what if we were to split (de-couple) the authoring responsibility, so the central government maintains its rules and the ID department maintains its.

So its the central governments job to determine who is an adult and if they change the law they just update their central repository with the new rules, which others use:

	RuleTable Age Policy	
	CONDITION	ACTION
	p : Person	
	age >= $1	insert($1)
	Adult Age Policy	**Add Adult Relation**
Infer Adult	**18**	**new IsAdult(p)**

The IsAdult fact, as discussed previously, is inferred from the policy rules. It encapsulates the seemingly arbitrary piece of logic "age >= 18" and provides semantic abstractions for it's meaning. Now if anyone uses the above rules, they no longer need to be aware of explicit information that determines whether someone is an adult or not. They can just use the inferred fact:

	RuleTable ID Card		
	CONDITION	CONDITION	ACTION
	p : Person	IsAdult	
	location	person == $1	issueIdCard($1)
	Select Person	**Select Adults**	**Issue ID Card**
Issue ID Card to Adults	**London**	**p**	**p**

While the example is very minimal and trivial it illustrates some important points. We started with a monolithic and leaky approach to our knowledge engineering. We create a single decision table that had all possible information in it that leaks information from central government that the ID department did not care about and did not want to manage.

We first de-coupled the knowledge process so each department was responsible for only what it needed to know. We then encapsulated this leaky knowledge using an inferred fact IsAdult. The use of the term IsAdult also gave a semantic abstraction to the previously arbitrary logic "age >= 18".

So a general rule or thumb when doing your knowledge engineering is:

- **Bad**
  - Monolithic
  - Leaky
- **Good**
  - De-couple knowledge responsibilities
  - Encapsulate knowledge
  - Provide semantic abstractions for those encapsulations

2.2.5. Inference and TruthMaintenance

The previous example was issuing ID cards to over 18s, in this example we now issue bus passes, either a child or adult pass.

```
rule "Issue Child Bus Pass" when
  $p : Person( age < 16 )
then
  insert(new ChildBusPass( $p ) );
end

rule "Issue Adult Bus Pass" when
  $p : Person( age >= 16 )
then
  insert(new AdultBusPass( $p ) );
end
```

As before the above example is considered monolithic, leaky and providing poor separation of concerns.

As before we can provide a more robust application with a separation of concerns using inference. Notice this time we don't just insert the inferred object, we use "logicalInsert":

```
rule "Infer Child" when
  $p : Person( age < 16 )
```

```
then
    logicalInsert( new IsChild( $p ) )
end
rule "Infer Adult" when
  $p : Person( age >= 16 )
then
    logicalInsert( new IsAdult( $p ) )
end
```

A "logicalInsert" is part of the Drools Truth Maintenance System (TMS). Here the fact is logically inserted, this fact is dependant on the truth of the "when" clause. It means that when the rule becomes false the fact is automatically retracted. This works particularly well as the two rules are mutually exclusive. So in the above rules if the person is under 16 it inserts an IsChild fact, once the person is 16 or over the IsChild fact is automatically retracted and the IsAdult fact inserted.

We can now bring back in the code to issue the passes, these two can also be logically inserted, as the TMS supports chaining of logical insertions for a cascading set of retracts.

```
rule "Issue Child Bus Pass" when
  $p : Person( )
       IsChild( person == $p )
then
  logicalInsert(new ChildBusPass( $p ) );
end

rule "Issue Adult Bus Pass" when
  $p : Person( age >= 16 )
       IsAdult( person =$p )
then
  logicalInsert(new AdultBusPass( $p ) );
end
```

Now when the person changes from being 15 to 16, not only is the IsChild fact automatically retracted, so is the person's ChildBusPass fact. For bonus points we can combine this with the 'not' conditional element to handle notifications, in this situation a request for the returning of the pass. So when the TMS automatically retracts the ChildBusPass object, this rule triggers and sends a request to the person:

```
rule "Return ChildBusPass Request "when
  $p : Person( )
       not( ChildBusPass( person == $p ) )
then
    requestChildBusPass( $p );
end
```

2.3. More on building and deploying

2.3.1. Knowledge Base by Configuration Using Changesets

So far, the programmatic API has been used to build a Knowledge Base. Quite often it's more desirable to do this via configuration. To facilitate this, Drools supports the "Changeset" feature. The file `changeset.xml` contains a list of resources, and it may also point recursively to another changeset XML file. Currently there is no XML schema for the changeset XML, but we hope to add one soon. A few examples will be shown to give you the gist of things. A resource approach is employed that uses a prefix to indicate the protocol. All the protocols provided by `java.net.URL`, such as "file" and "http", are supported, as well as an additional "classpath". Currently the type attribute must always be specified for a resource, as it is not inferred from the file name extension. Here is a simple example that points to a http location for some rules.

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
            xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
                      xs:schemaLocation='http://drools.org/drools-5.0/change-
set   http://anonsvn.jboss.org/repos/labs/labs/jbossrules/trunk/drools-api/src/
main/resources/change-set-1.0.0.xsd' >
   <add>
       <resource source='http:org/domain/myrules.drl' type='DRL' />
   </add>
 </change-set>
```

To use the above XML, the code is almost identical as before, except we change the resource type to `CHANGE_SET`.

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kbuilder.add( ResourceFactory.newClasspathResource( "myChangeSet.xml", getClass() ),
              ResourceType.CHANGE_SET );
if ( kbuilder.hasErrors() ) {
    System.err.println( builder.getErrors().toString() );
}
```

Changesets can include any number of resources, and they even support additional configuration information, which currently is only needed for decision tables. The example below is expanded to load the rules from a http URL location, and an Excel decision table from the classpath.

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
            xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
                      xs:schemaLocation='http://drools.org/drools-5.0/change-
set.xsd   http://anonsvn.jboss.org/repos/labs/labs/jbossrules/trunk/drools-api/
src/main/resources/change-set-1.0.0.xsd' >
```

```
   <add>
       <resource source='http:org/domain/myrules.drl' type='DRL' />
                                          <resource      source='classpath:data/
IntegrationExampleTest.xls' type="DTABLE">
           <decisiontable-conf input-type="XLS" worksheet-name="Tables_2" />
       </resource>
   </add>
 </change-set>
```

It is also possible to specify a directory, to add the contents of that directory. It is expected that all the files are of the specified type, since type is not yet inferred from the file name extensions.

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
            xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
                       xs:schemaLocation='http://drools.org/drools-5.0/change-
set.xsd   http://anonsvn.jboss.org/repos/labs/labs/jbossrules/trunk/drools-api/
src/main/resources/change-set-1.0.0.xsd' >
   <add>
       <resource source='file://myfolder/' type='DRL' />
   </add>
 </change-set>
```

2.3.2. Knowledge Agent

The Knowlege Agent provides automatic loading, caching and re-loading of resources and is configured from a properties files. The Knowledge Agent can update or rebuild this Knowlege Base as the resources it uses are changed. The strategy for this is determined by the configuration given to the factory, but it is typically pull-based using regular polling. We hope to add push-based updates and rebuilds in future versions.

```
KnowledgeAgent kagent = KnowledgeAgentFactory.newKnowledgeAgent( "MyAgent" );
kagent.applyChangeSet( ResourceFactory.newUrlResource( url ) );
KnowledgeBase kbase = kagent.getKnowledgeBase();
```

A `KnowledgeAgent` object will continuously scan all the added resources, using a default polling interval of 60 seconds and, when some last modification date is updated, it will applied the changes into the cached Knowledge Base using the new resources. Note that the previous `KnowledgeBase` reference will still exist and you'll have to call `getKnowledgeBase()` to access the newly built `KnowledgeBase`. If a directory is specified as part of the change set, the entire contents of that directory will be scanned for changes. The way modifications are applied depends on `drools.agent.newInstance` property present in the KnowledgeAgentConfiguration object passed to the agent.

For polling to occur, the polling and notifier services must be started:

```
ResourceFactory.getResourceChangeNotifierService().start();
ResourceFactory.getResourceChangeScannerService().start();
```

2.3.2.1. Knowledge Agent and Custom ClassLoaders

Because Knowledge Agent could scan and process remote resources, it could ends up failing when compiling or executing rules, queries, functions, etc. that use classes outside the agent's classloader. If this is your case, you could take 2 approach: use a custom classloader for agent's kbuilder or force the agent to use the same classloader that its kbase has.

2.3.2.1.1. Custom ClassLoaders for KnowledgeBuilder

Knowledge Agent uses KnowledgeBuilder internally in order to compile managed resources. If you need to pass custom configuration to these compilers you could pass a KnowledgeBuilderConfiguration object to KnowledgeAgentFactory.newKnowledgeAgent(). This object will be used in every builder the agent creates. Using a KnowledgeBuilderConfiguration you can specify a custom classloader.

2.3.2.1.2. Reuse KnowledgeBase ClassLoader

Most of the times, the classloader you wan't to use in the compilation process of remote resources is the same needed in the agent's kbase, so the rules could be executed. If you want to use this approach, you will need to setup the desired ClassLoader to the agen't kbase and use the "drools.agent.useKBaseClassLoaderForCompiling" property of KnowledgeAgentConfiguration object.

This approach lets you modify agent's kbuilder classloader in runtime by modifying the classloader the agent's kbase uses. This will serve also when not using incremental change set processing (see the section below). When the kbase is recreated its configuration is reused, so the classloader is maintained.

```
KnowledgeBaseConfiguration kbaseConfig =
   KnowledgeBaseFactory.newKnowledgeBaseConfiguration(null, customClassLoader);
KnowledgeBase kbase =
      KnowledgeBaseFactory.newKnowledgeBase(kbaseConfig); //kbase with custom
 classloader
KnowledgeAgentConfiguration aconf =
    KnowledgeAgentFactory.newKnowledgeAgentConfiguration();
aconf.setProperty("drools.agent.newInstance", "false"); //incremental change set
 processing enabled
aconf.setProperty("drools.agent.useKBaseClassLoaderForCompiling", "true");
KnowledgeAgent kagent = KnowledgeAgentFactory.newKnowledgeAgent(
                "test agent", kbase, aconf);
```

2.3.2.2. Incremental Change Set Processing

Knowledge Agent can process change sets in two different ways: recreating the knowledge base every time a new change set is processed or applying the change set in the cached knowledge base without destroying it. This behavior is controlled by the "newInstance" property of the KnowledgeAgentConfiguration object passed to the Agent's constructor.

When "newInstace" is set to true (the default value), the agent will destroy the cached Knowledge Base it contains and populate a new one containing the change set modifications. When "newInstance" is set to "false" change sets are applied directly to the cached Knowledge Base. The rule that were not modified in the change sets' resources are not replaced in the Knowledge Base, the modified or deleted rules are modified or deleted from the cached Knowledge Base. Functions, Queries and Definition Types are always replaced in the cached Knowledge Base whether they are modified or not.

The following code snippet creates a new Knowledge Agent with its "newInstace" property set to false

```
KnowledgeAgentConfiguration aconf = KnowledgeAgentFactory.newKnowledgeAgentConfiguration();
aconf.setProperty("drools.agent.newInstance", "false");
KnowledgeAgent kagent = KnowledgeAgentFactory.newKnowledgeAgent("test
 agent", null, aconf);
```

2.3.2.3. Remote HTTP resource caching

A note on remote HTTP Url Resources: if your knowledge agent is "pulling" resources from a http(s) URL, then you might rightly be concerned if that resource (remote web server) suddenly disappears. To survive a restart when a resource is no longer available remotely (eg the remote server is being restarted) then you can set a System Property: drools.resource.urlcache to a directory that has write permissions for the application: the Knowledge Agent will cache copies of the remote resources in that local directory.

For example, using the java command line: -Ddrools.resource.urlcache=/users/someone/KnowledgeCache - will keep local copies of the resources (rules, packages etc) in that directory, for the agent to use should it be restarted (when a remote resource becomes available, and is updated, it will automatically update the local cache copy).

Chapter 3. Advanced Concepts and Theory

3.1. Truth Maintenance with Logical Objects

After regular inserts you have to retract facts explicitly. With *logical* assertions, the fact that was asserted will be automatically retracted when the conditions that asserted it in the first place are no longer true. Actually, it's even cleverer then that, because it will be retracted only if there isn't any single condition that supports the logical assertion.

Normal insertions are said to be *stated*, i.e., just like the intuitive meaning of "stating a fact" implies. Using a `HashMap` and a counter, we track how many times a particular equality is *stated*; this means we count how many different instances are equal.

When we *logically* insert an object during a RHS execution we are said to *justify* it, and it is considered to be justified by the firing rule. For each logical insertion there can only be one equal object, and each subsequent equal logical insertion increases the justification counter for this logical assertion. A justification is removed by the LHS of the creating rule becoming untrue, and the counter is decreased accordingly. As soon as we have no more justifications the logical object is automatically retracted.

If we try to *logically* insert an object when there is an equal *stated* object, this will fail and return null. If we *state* an object that has an existing equal object that is *justified* we override the Fact; how this override works depends on the configuration setting `WM_BEHAVIOR_PRESERVE`. When the property is set to discard we use the existing handle and replace the existing instance with the new Object, which is the default behavior; otherwise we override it to *stated* but we create an new `FactHandle`.

This can be confusing on a first read, so hopefully the flow charts below help. When it says that it returns a new `FactHandle`, this also indicates the `Object` was propagated through the network.

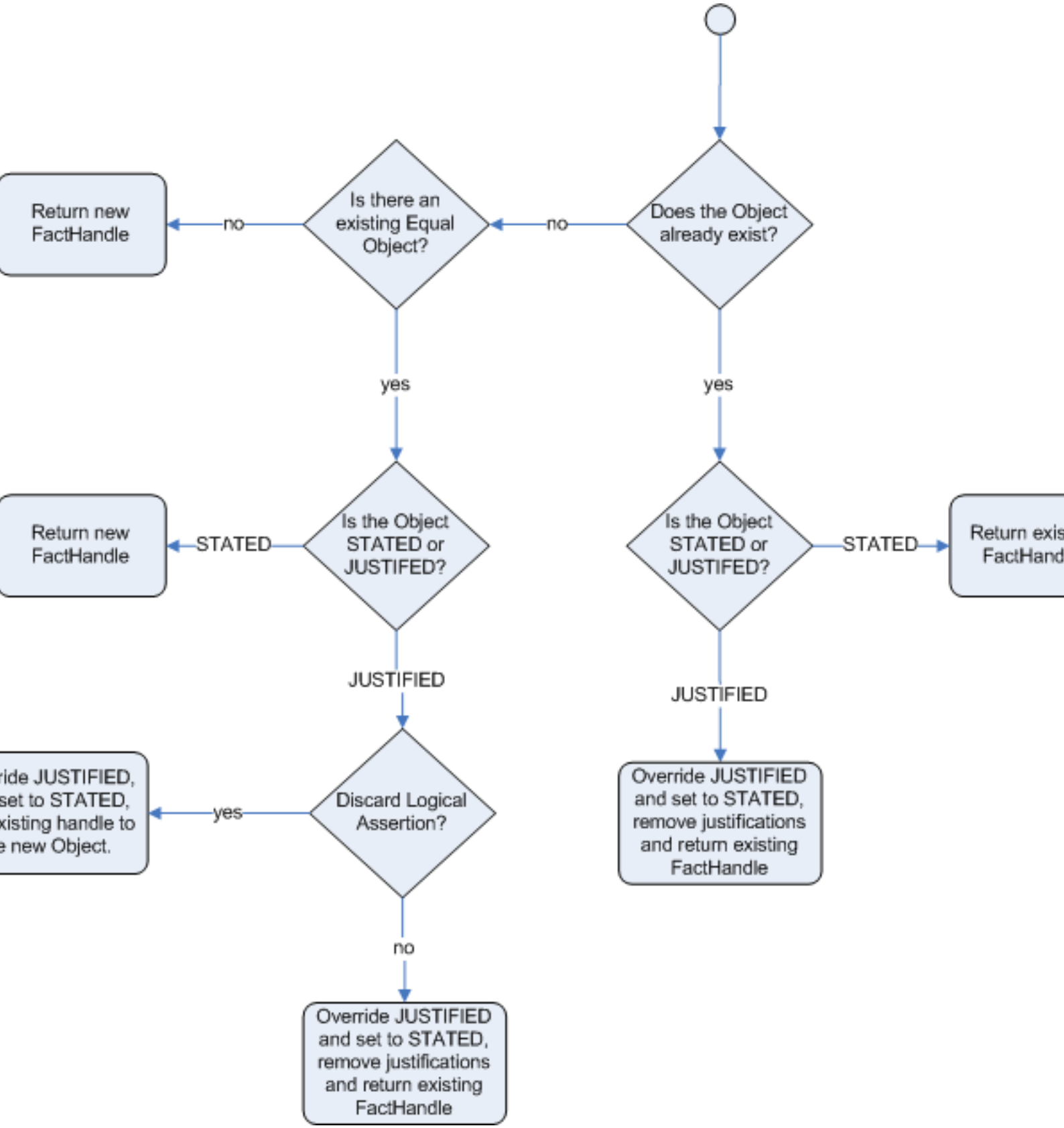


Figure 3.1. Stated Insertion

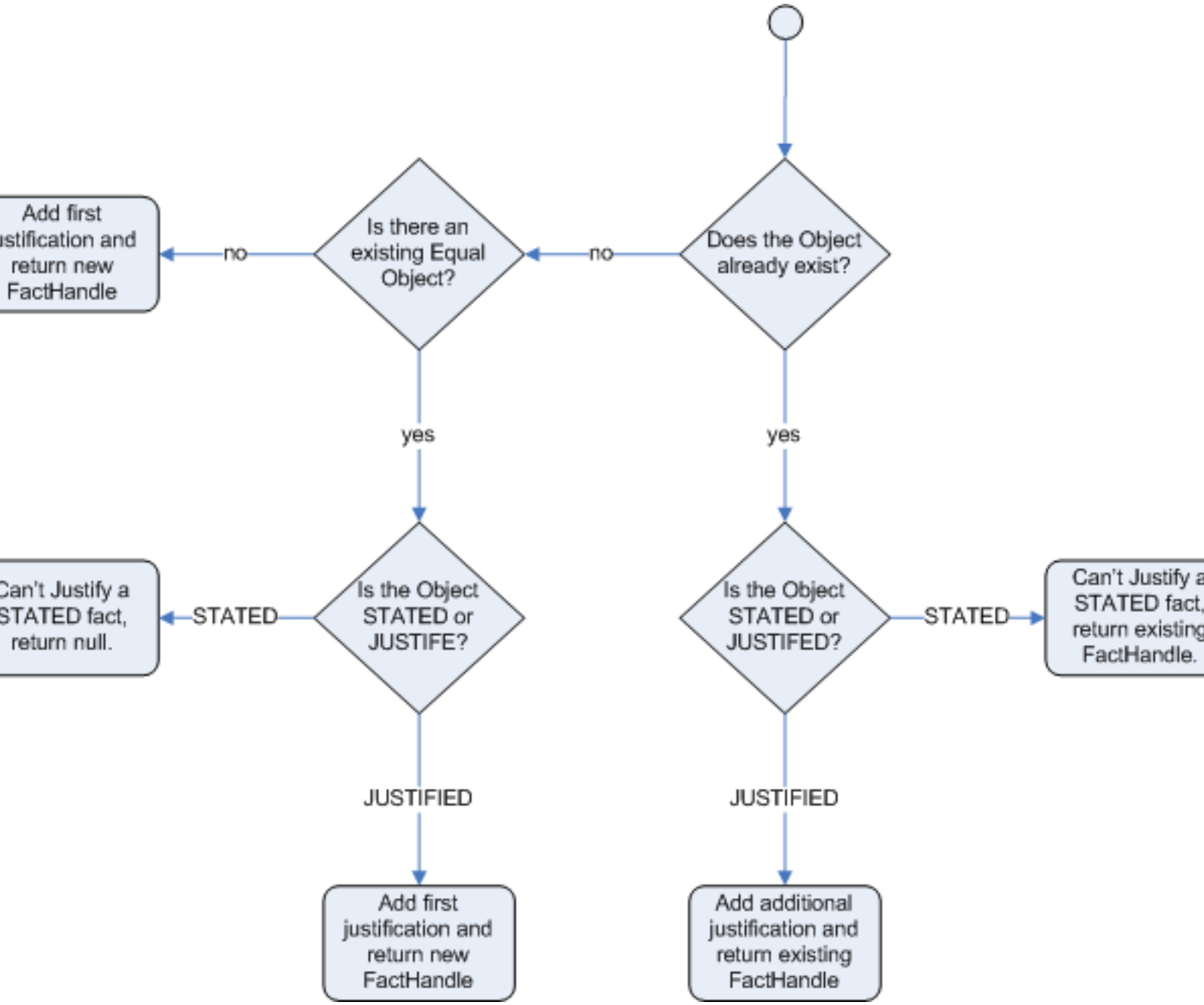


Figure 3.2. Logical Insertion

3.1.1. Example Scenario

An example may make things clearer. Imagine a credit card processing application, processing transactions for a given account and we have a working memory accumulating knowledge about a single account transaction. The rule engine is doing its best to decide whether transactions are possibly fraudulent or not. Imagine that this rule base basically has rules that kick in when there is "reason to be suspicious" and when "everything is normal".

Of course there are many rules that operate no matter what, performing standard calculations, etc. Now there are possibly many reasons as to what could trigger a "reason to be suspicious": someone notifying the bank, a sequence of large transactions, transactions for geographically disparate locations, or even reports of credit card theft. Rather then smattering all the little conditions in lots of rules, imagine there is a fact class called "SuspiciousAccount".

Then there can be a series of rules whose job is to look for things that may raise suspicion, and if they fire, they *logically* insert a new SuspiciousAccount() instance. All the other rules just have conditions like "not SuspiciousAccount()" or "SuspiciousAccount()" depending on their needs. Note that this has the advantage of allowing there to be many rules around raising suspicion, without touching the other rules. After all the facts causing the SuspiciousAccount() insertion are removed, the account handling reverts to a normal mode of operation where, for instance, a rule with "not SuspiciousAccount()" may kick in, which flushes through any blocked transactions.

If you have followed this far, you will note that truth maintenance, like logical assertions, allows rules to behave a little like a human would, and can certainly make the rules more manageable.

3.1.2. Lazy Truth Maintenance

You no longer need to enable or disable truth maintenance, via the kbase configuration. It is now handled automatically and turned on only when needed. This was done along with the code changes so that all entry points use the same code, previous to this the default entry point and named entry points used different code, to avoid TMS overhead for event processing.

3.1.3. Important note: Equality for Java objects

It is important to note that for Truth Maintenance (and logical assertions) to work at all, your Fact objects (which may be JavaBeans) must override equals and hashCode methods (from java.lang.Object) correctly. As the truth maintenance system needs to know when two different physical objects are equal in value, *both* equals and hashCode must be overridden correctly, as per the Java standard.

Two objects are equal if and only if their equals methods return true for each other and if their hashCode methods return the same values. See the Java API for more details (but do keep in mind you *MUST* override both equals and hashCode).

3.2. Rete Algorithm

The *Rete* algorithm was invented by Dr. Charles Forgy and documented in his PhD thesis in 1978-79. A simplified version of the paper was published in 1982 (*http://citeseer.ist.psu.edu/context/505087/0*). The latin word "rete" means "net" or "network". The Rete algorithm can be broken into 2 parts: rule compilation and runtime execution.

The compilation algorithm describes how the Rules in the Production Memory are processed to generate an efficient discrimination network. In non-technical terms, a discrimination network is used to filter data as it propagates through the network. The nodes at the top of the network would

have many matches, and as we go down the network, there would be fewer matches. At the very bottom of the network are the terminal nodes. In Dr. Forgy's 1982 paper, he described 4 basic nodes: root, 1-input, 2-input and terminal.

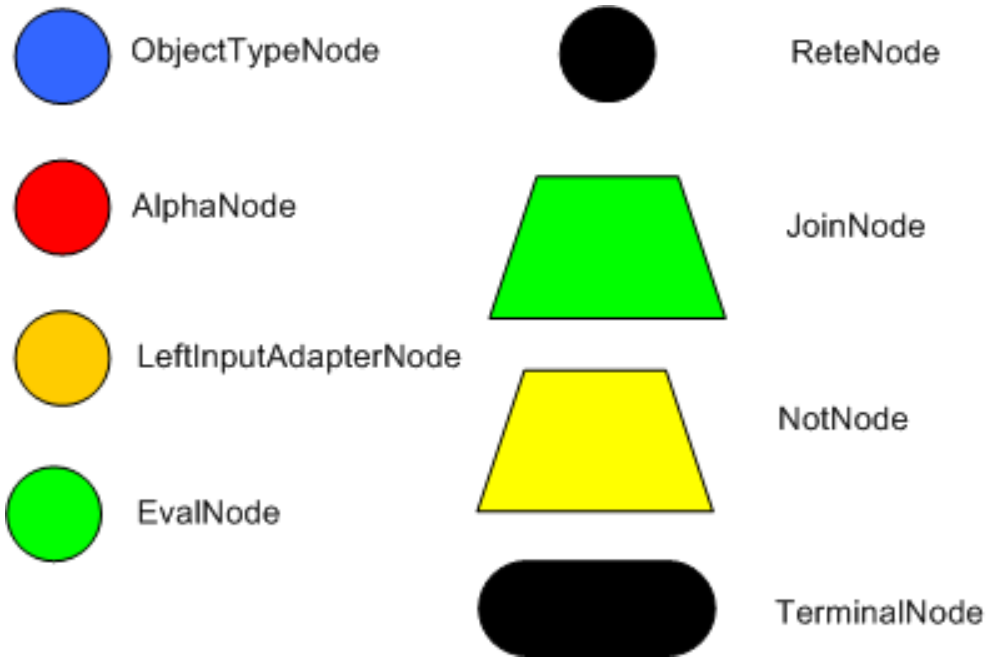


Figure 3.3. Rete Nodes

The root node is where all objects enter the network. From there, it immediately goes to the ObjectTypeNode. The purpose of the ObjectTypeNode is to make sure the engine doesn't do more work than it needs to. For example, say we have 2 objects: Account and Order. If the rule engine tried to evaluate every single node against every object, it would waste a lot of cycles. To make things efficient, the engine should only pass the object to the nodes that match the object type. The easiest way to do this is to create an ObjectTypeNode and have all 1-input and 2-input nodes descend from it. This way, if an application asserts a new Account, it won't propagate to the nodes for the Order object. In Drools when an object is asserted it retrieves a list of valid ObjectTypesNodes via a lookup in a HashMap from the object's Class; if this list doesn't exist it scans all the ObjectTypeNodes finding valid matches which it caches in the list. This enables Drools to match against any Class type that matches with an `instanceof` check.

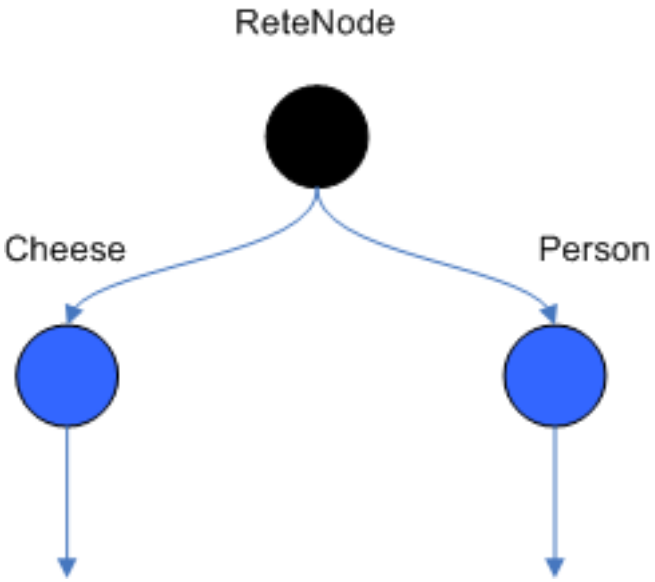


Figure 3.4. ObjectTypeNodes

ObjectTypeNodes can propagate to AlphaNodes, LeftInputAdapterNodes and BetaNodes. AlphaNodes are used to evaluate literal conditions. Although the 1982 paper only covers equality conditions, many RETE implementations support other operations. For example, `Account.name == "Mr Trout"` is a literal condition. When a rule has multiple literal conditions for a single object type, they are linked together. This means that if an application asserts an Account object, it must first satisfy the first literal condition before it can proceed to the next AlphaNode. In Dr. Forgy's paper, he refers to these as IntraElement conditions. The following diagram shows the AlphaNode combinations for Cheese(name == "cheddar", strength == "strong"):

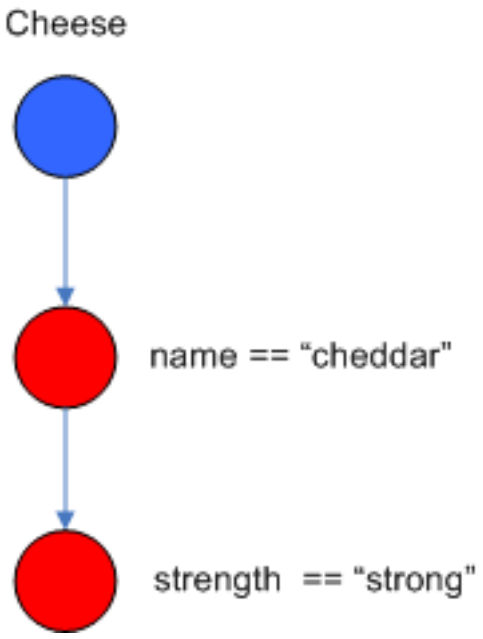


Figure 3.5. AlphaNodes

Drools extends Rete by optimizing the propagation from ObjectTypeNode to AlphaNode using hashing. Each time an AlphaNode is added to an ObjectTypeNode it adds the literal value as a key to the HashMap with the AlphaNode as the value. When a new instance enters the ObjectType node, rather than propagating to each AlphaNode, it can instead retrieve the correct AlphaNode from the HashMap,thereby avoiding unnecessary literal checks.

There are two two-input nodes, JoinNode and NotNode, and both are types of BetaNodes. BetaNodes are used to compare 2 objects, and their fields, to each other. The objects may be the same or different types. By convention we refer to the two inputs as left and right. The left input for a BetaNode is generally a list of objects; in Drools this is a Tuple. The right input is a single object. Two Nodes can be used to implement 'exists' checks. BetaNodes also have memory. The left input is called the Beta Memory and remembers all incoming tuples. The right input is called the Alpha Memory and remembers all incoming objects. Drools extends Rete by performing indexing on the BetaNodes. For instance, if we know that a BetaNode is performing a check on a String field, as each object enters we can do a hash lookup on that String value. This means when facts enter from the opposite side, instead of iterating over all the facts to find valid joins, we do a lookup returning potentially valid candidates. At any point a valid join is found the Tuple is joined with the Object; which is referred to as a partial match; and then propagated to the next node.

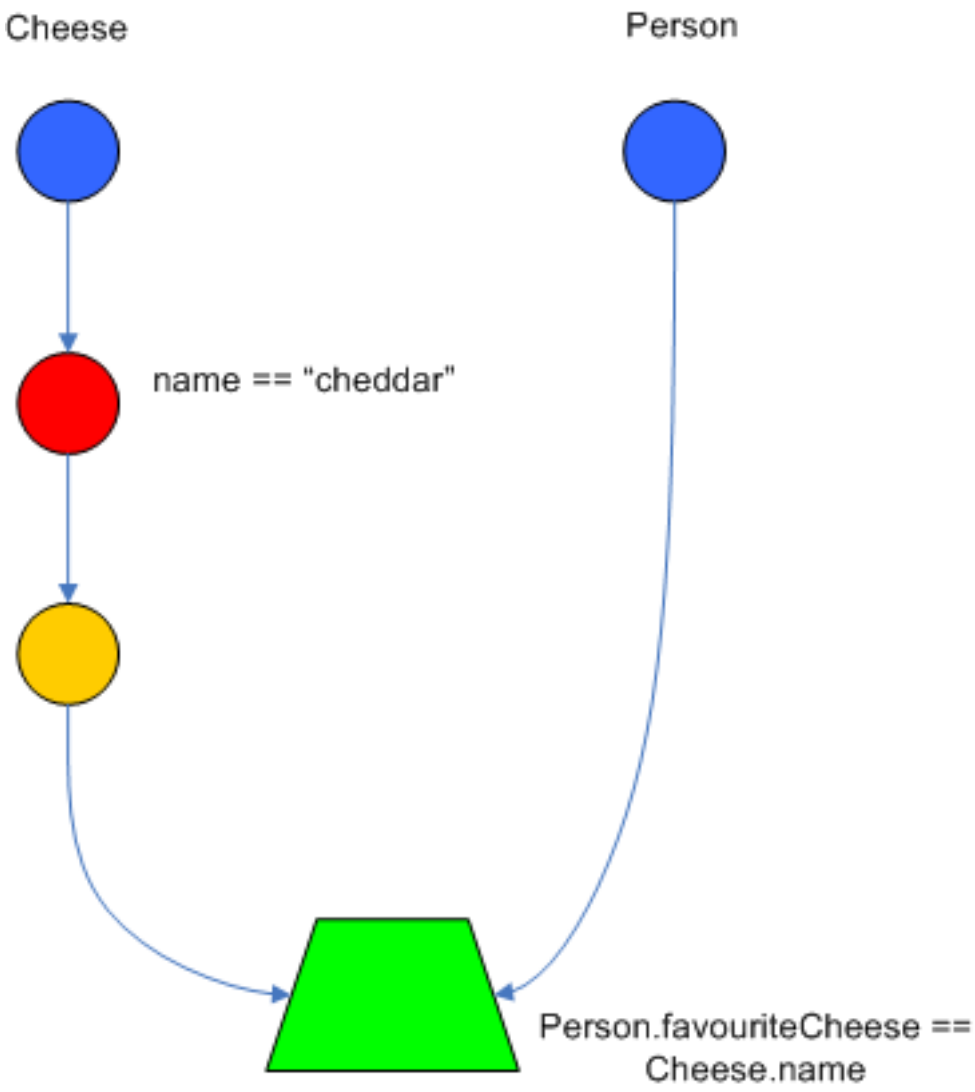


Figure 3.6. JoinNode

To enable the first Object, in the above case Cheese, to enter the network we use a LeftInputNodeAdapter - this takes an Object as an input and propagates a single Object Tuple.

Terminal nodes are used to indicate a single rule having matched all its conditions; at this point we say the rule has a full match. A rule with an 'or' conditional disjunctive connective results in subrule generation for each possible logically branch; thus one rule can have multiple terminal nodes.

Drools also performs node sharing. Many rules repeat the same patterns, and node sharing allows us to collapse those patterns so that they don't have to be re-evaluated for every single instance. The following two rules share the first pattern, but not the last:

```
rule
when
```

```
        Cheese( $chedddar : name == "cheddar" )
        $person : Person( favouriteCheese == $cheddar )
    then
        System.out.println( $person.getName() + " likes cheddar" );
    end
```

```
    rule
    when
        Cheese( $chedddar : name == "cheddar" )
        $person : Person( favouriteCheese != $cheddar )
    then
        System.out.println( $person.getName() + " does not like cheddar" );
    end
```

As you can see below, the compiled Rete network shows that the alpha node is shared, but the beta nodes are not. Each beta node has its own TerminalNode. Had the second pattern been the same it would have also been shared.

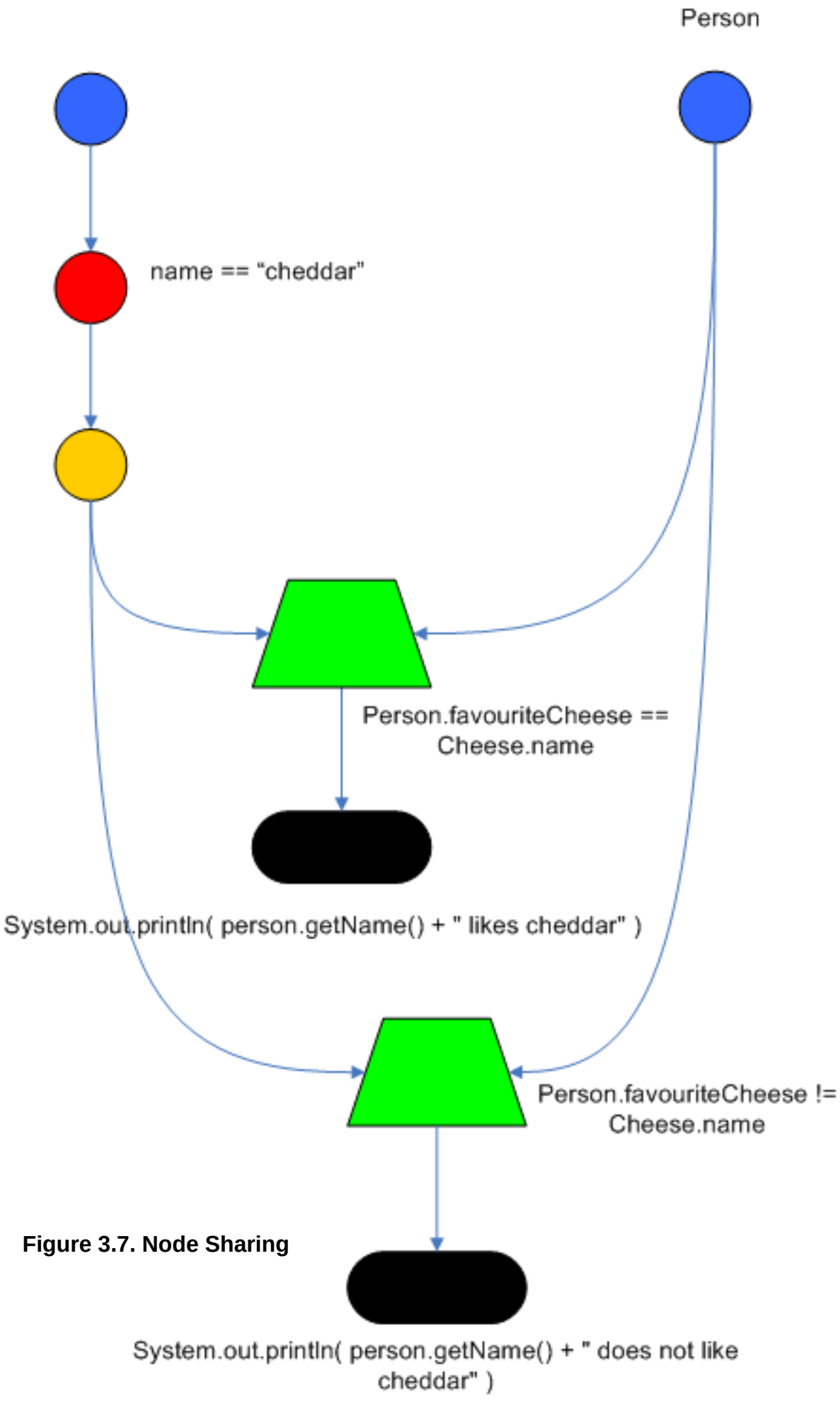


Figure 3.7. Node Sharing

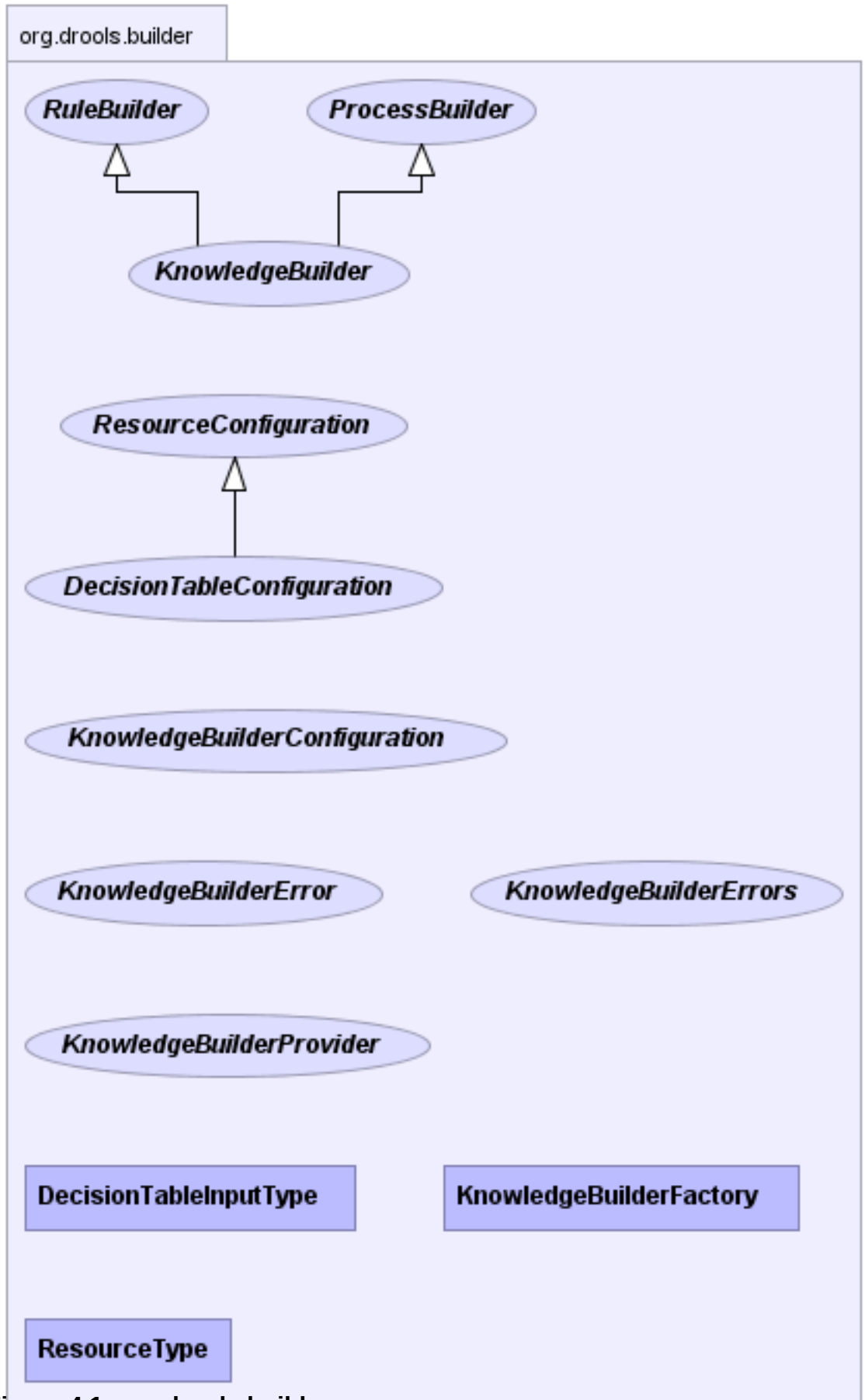


Figure 4.1. org.drools.builder

4.1.1. Building using Code

The KnowledgeBuilder is responsible for taking source files, such as a DRL file or an Excel file, and turning them into a Knowledge Package of rule and process definitions which a Knowledge Base can consume. An object of the class `ResourceType` indicates the type of resource it is being asked to build.

The `ResourceFactory` provides capabilities to load resources from a number of sources, such as Reader, ClassPath, URL, File, or ByteArray. Binaries, such as decision tables (Excel .xls files), should not use a Reader based resource handler, which is only suitable for text based resources.

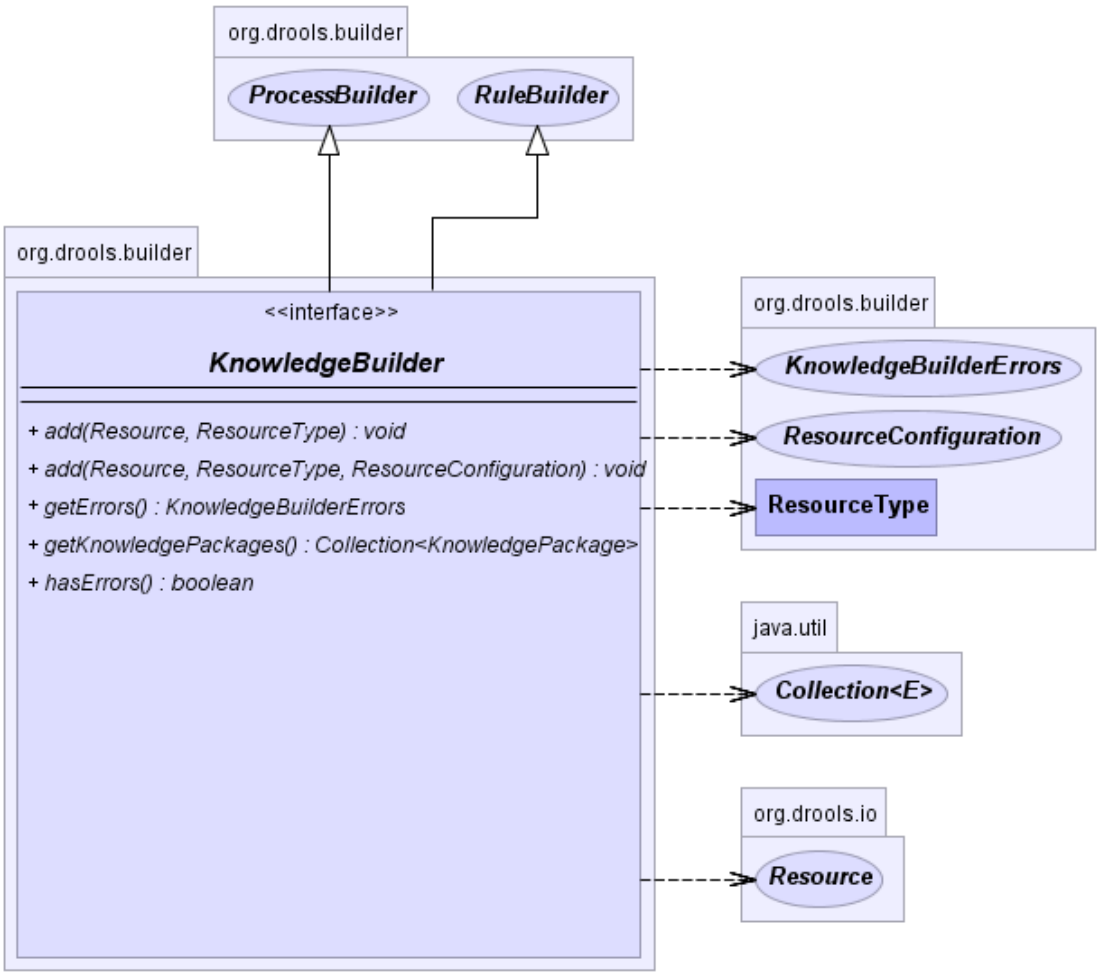


Figure 4.2. KnowledgeBuilder

The KnowlegeBuilder is created using the KnowledgeBuilderFactory.

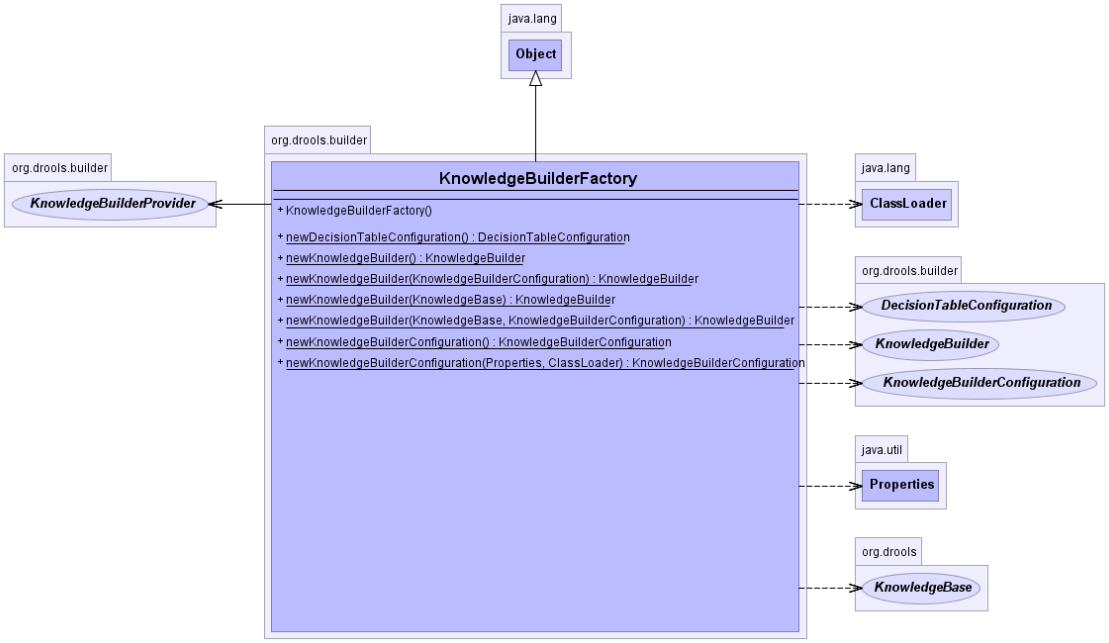


Figure 4.3. KnowledgeBuilderFactory

A KnowledgeBuilder can be created using the default configuration.

Example 4.1. Creating a new KnowledgeBuilder

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
```

A configuration can be created using the `KnowledgeBuilderFactory`. This allows the behavior of the Knowledge Builder to be modified. The most common usage is to provide a custom class loader so that the `KnowledgeBuilder` object can resolve classes that are not in the default classpath. The first parameter is for properties and is optional, i.e., it may be left null, in which case the default options will be used. The options parameter can be used for things like changing the dialect or registering new accumulator functions.

Example 4.2. Creating a new KnowledgeBuilder with a custom ClassLoader

```
KnowledgeBuilderConfiguration kbuilderConf = KnowledgeBuilderFactory.newKnowledgeBuilderConfigu
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder(kbuilderConf);
```

Resources of any type can be added iteratively. Below, a DRL file is added. Unlike Drools 4.0 Package Builder, the Knowledge Builder can now handle multiple namespaces, so you can just keep adding resources regardless of namespace.

Example 4.3. Adding DRL Resources

```
kbuilder.add( ResourceFactory.newFileResource( "/project/myrules.drl" ),
              ResourceType.DRL);
```

It is a best practice to always check the compilation results after a change an addition. The KnowledgeBuilder can report compilation results of 3 different severities: ERROR, WARNING and INFO.

An ERROR indicates that the compilation of the resources failed and you should not add more resources or retrieve the Knowledge Packages if there are errors. `getKnowledgePackages()` returns an empty list if there are errors.

WARNING and INFO results can be ignored, but are available for inspection nonetheless. `hasErrors()` method after an addition.

To check and retrieve the building results for a list of severities, the KnowledgeBuilder interface offers a couple methods:

Example 4.4. KnowledgeBuilder result inspection methods

```
    /**
     * Return the knowledge builder results for the listed severities.
     *
     * @param severities
     * @return
     */
    KnowledgeBuilderResults getResults(ResultSeverity...severities );


    /**
     * Checks if the builder generated any results of the listed severities
     * @param severities
     * @return
     */
    boolean hasResults(ResultSeverity...severities );
```

The KnowledgeBuilder interface also has two helper methods to inspect for errors only: `hasErrors()` and `getErrors()`:

Example 4.5. Validating

```
if( kbuilder.hasErrors() ) {
    System.out.println( kbuilder.getErrors() );
```

```
    return;
}
```

When all the resources have been added and there are no errors the collection of Knowledge Packages can be retrieved. It is a Collection because there is one Knowledge Package per package namespace. These Knowledge Packages are serializable and often used as a unit of deployment.

Example 4.6. Getting the KnowledgePackages

```
Collection<KnowledgePackage> kpkgs = kbuilder.getKnowledgePackages();
```

The final example puts it all together.

Example 4.7. Putting it all together

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
if( kbuilder.hasErrors() ) {
    System.out.println( kbuilder.getErrors() );
    return;
}

KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kbuilder.add( ResourceFactory.newFileResource( "/project/myrules1.drl" ),
              ResourceType.DRL);
kbuilder.add( ResourceFactory.newFileResource( "/project/myrules2.drl" ),
              ResourceType.DRL);

if( kbuilder.hasErrors() ) {
    System.out.println( kbuilder.getErrors() );
    return;
}

Collection<KnowledgePackage> kpkgs = kbuilder.getKnowledgePackages();
```

4.1.2. Building using Configuration and the ChangeSet XML

Instead of adding the resources to create definitions programmatically it is also possible to do it by configuration, via the ChangeSet XML. The simple XML file supports three elements: add, remove, and modify, each of which has a sequence of <resource> subelements defining a configuration entity. The following XML schema is *not* normative and intended for illustration only.

Example 4.8. XML Schema for ChangeSet XML (not normative)

```
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
           xmlns="http://drools.org/drools-5.0/change-set"
           targetNamespace="http://drools.org/drools-5.0/change-set">

  <xs:element name="change-set" type="ChangeSet"/>

  <xs:complexType name="ChangeSet">
    <xs:choice maxOccurs="unbounded">
      <xs:element name="add"    type="Operation"/>
      <xs:element name="remove" type="Operation"/>
      <xs:element name="modify" type="Operation"/>
    </xs:choice>
  </xs:complexType>

  <xs:complexType name="Operation">
    <xs:sequence>
      <xs:element name="resource" type="Resource"
                  maxOccurs="unbounded"/>
    </xs:sequence>
  </xs:complexType>

  <xs:complexType name="Resource">
    <xs:sequence>

      <xs:element name="decisiontable-conf" type="DecTabConf"
                  minOccurs="0"/>
    </xs:sequence>

    <xs:attribute name="source" type="xs:string"/>
    <xs:attribute name="type"   type="ResourceType"/>
  </xs:complexType>

  <xs:complexType name="DecTabConf">
    <xs:attribute name="input-type"     type="DecTabInpType"/>
    <xs:attribute name="worksheet-name" type="xs:string"
                  use="optional"/>
  </xs:complexType>


  <xs:simpleType name="ResourceType">
    <xs:restriction base="xs:string">
      <xs:enumeration value="DRL"/>
      <xs:enumeration value="XDRL"/>
      <xs:enumeration value="DSL"/>
      <xs:enumeration value="DSLR"/>
      <xs:enumeration value="DRF"/>
```

```
      <xs:enumeration value="DTABLE"/>
      <xs:enumeration value="PKG"/>
      <xs:enumeration value="BRL"/>
      <xs:enumeration value="CHANGE_SET"/>
    </xs:restriction>
  </xs:simpleType>


  <xs:simpleType name="DecTabInpType">
    <xs:restriction base="xs:string">
      <xs:enumeration value="XLS"/>
      <xs:enumeration value="CSV"/>
    </xs:restriction>
  </xs:simpleType>

</xs:schema>
```

Currently only the add element is supported, but the others will be implemented to support iterative changes. The following example loads a single DRL file.

Example 4.9. Simple ChangeSet XML

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
             xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
                         xs:schemaLocation='http://drools.org/drools-5.0/change-
set.xsd   http://anonsvn.jboss.org/repos/labs/labs/jbossrules/trunk/drools-api/
src/main/resources/change-set-1.0.0.xsd' >
   <add>
      <resource source='file:/project/myrules.drl' type='DRL' />
   </add>
</change-set>
```

Notice the `file:` prefix, which signifies the protocol for the resource. The Change Set supports all the protocols provided by java.net.URL, such as "file" and "http", as well as an additional "classpath". Currently the type attribute must always be specified for a resource, as it is not inferred from the file name extension. Using the ClassPath resource loader in Java allows you to specify the Class Loader to be used to locate the resource but this is not possible from XML. Instead, the Class Loader will default to the one used by the Knowledge Builder unless the ChangeSet XML is itself loaded by the ClassPath resource, in which case it will use the Class Loader specified for that resource.

Currently you still need to use the API to load that ChangeSet, but we will add support for containers such as Spring in the future, so that the process of creating a Knowledge Base can be done completely by XML configuration. Loading resources using an XML file couldn't be simpler, as it's just another resource type.

Example 4.10. Loading the ChangeSet XML

```
kbuilder.add( ResourceFactory.newUrlResource( url ), ResourceType.CHANGE_SET );
```

ChangeSets can include any number of resources, and they even support additional configuration information, which currently is only needed for decision tables. Below, the example is expanded to load rules from a http URL location, and an Excel decision table from the classpath.

Example 4.11. ChangeSet XML with resource configuration

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
            xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
                      xs:schemaLocation='http://drools.org/drools-5.0/change-
set.xsd   http://anonsvn.jboss.org/repos/labs/labs/jbossrules/trunk/drools-api/
src/main/resources/change-set-1.0.0.xsd' >
  <add>
       <resource source='http:org/domain/myrules.drl' type='DRL' />
                                          <resource      source='classpath:data/
IntegrationExampleTest.xls' type="DTABLE">
           <decisiontable-conf input-type="XLS" worksheet-name="Tables_2" />
       </resource>
   </add>
 </change-set>
```

The ChangeSet is especially useful when working with a Knowledge Agent, as it allows for change notification and automatic rebuilding of the Knowledge Base, which is covered in more detail in the section on the Knowledge Agent, under Deploying.

Directories can also be specified, to add all resources in that folder. Currently it is expected that all resources in that folder are of the same type. If you use the Knowledge Agent it will provide a continous scanning for added, modified or removed resources and rebuild the cached Knowledge Base. The KnowledgeAgent provides more information on this.

Example 4.12. ChangeSet XML which adds a directory's contents

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
            xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
                      xs:schemaLocation='http://drools.org/drools-5.0/change-
set.xsd   http://anonsvn.jboss.org/repos/labs/labs/jbossrules/trunk/drools-api/
src/main/resources/change-set-1.0.0.xsd' >
   <add>
      <resource source='file:/projects/myproject/myrules' type='DRL' />
   </add>
```

```
</change-set>
```

4.1.3. Changing default building result severity

In some cases, it is possible to change the default severity of a type of building result. For instance, when a new rule with the same name of an existing rule is added to a package, the default behavior is to replace the old rule by the new rule and report it as an INFO. This is probably ideal for most use cases, but in some deployements, the user might want to prevent the rule update and report it as an error.

Changing the default severity for a result type is the same as configuring any other option in Drools and can be done either by API calls, system properties or configuration files. As of this version, Drools supports configurable result severity for rule updates and function updates. To configure it using system properties or configuration files, the user has to use the following properties:

Example 4.13. Setting the severity using properties

```
// sets the severity of rule updates
drools.kbuilder.severity.duplicateRule = <INFO|WARNING|ERROR>
// sets the severity of function updates
drools.kbuilder.severity.duplicateFunction = <INFO|WARNING|ERROR>
```

To configure it through the API:

Example 4.14. Setting the severity using the API

```
KnowledgeBuilderConfiguration kbconf = ...

// sets the severity of rule updates to error
kbconf.setOption( KBuilderSeverityOption.get( "drools.kbuilder.severity.duplicateRule",
 ResultSeverity.ERROR ) );
// sets the severity of function updates to error
kbconf.setOption( KBuilderSeverityOption.get( "drools.kbuilder.severity.duplicateFunction",
 ResultSeverity.ERROR ) );
```

4.2. Deploying

4.2.1. KnowledgePackage and Knowledge Definitions

A Knowledge Package is a collection of Knowledge Definitions, such as rules and processes. It is created by the Knowledge Builder, as described in the chapter "Building". Knowledge Packages are self-contained and serializable, and they currently form the basic deployment unit.

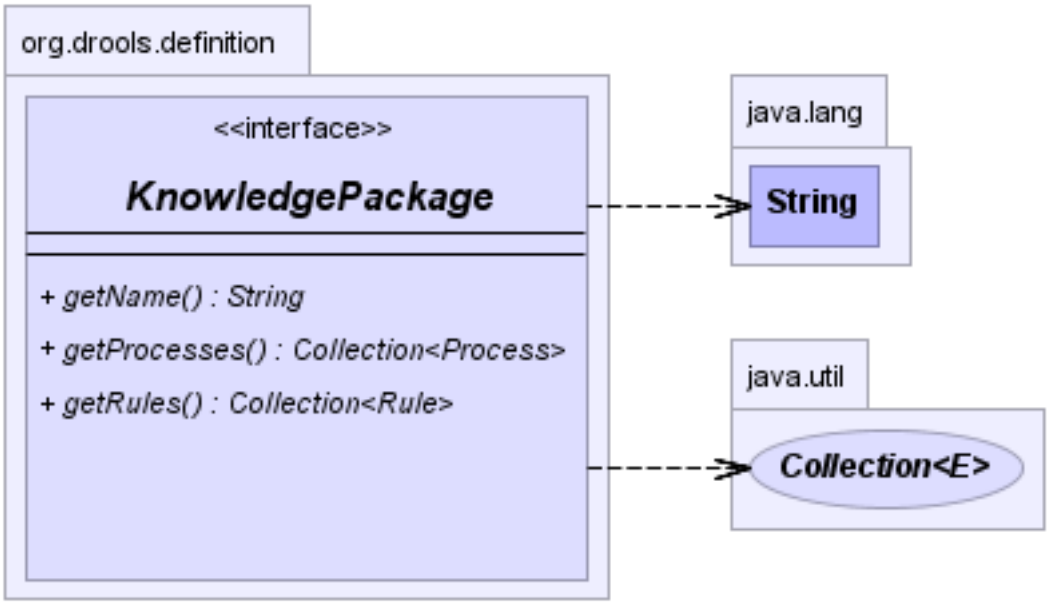


Figure 4.4. KnowledgePackage

Knowledge Packages are added to the Knowledge Base. However, a Knowledge Package instance cannot be reused once it's added to the Knowledge Base. If you need to add it to another Knowledge Base, try serializing it first and using the "cloned" result. We hope to fix this limitation in future versions of Drools.

4.2.2. KnowledgeBase

The Knowlege Base is a repository of all the application's knowledge definitions. It may contain rules, processes, functions, and type models. The Knowledge Base itself does not contain instance data, known as facts; instead, sessions are created from the Knowledge Base into which data can be inserted and where process instances may be started. Creating the Knowlege Base can be heavy, whereas session creation is very light, so it is recommended that Knowledge Bases be cached where possible to allow for repeated session creation.

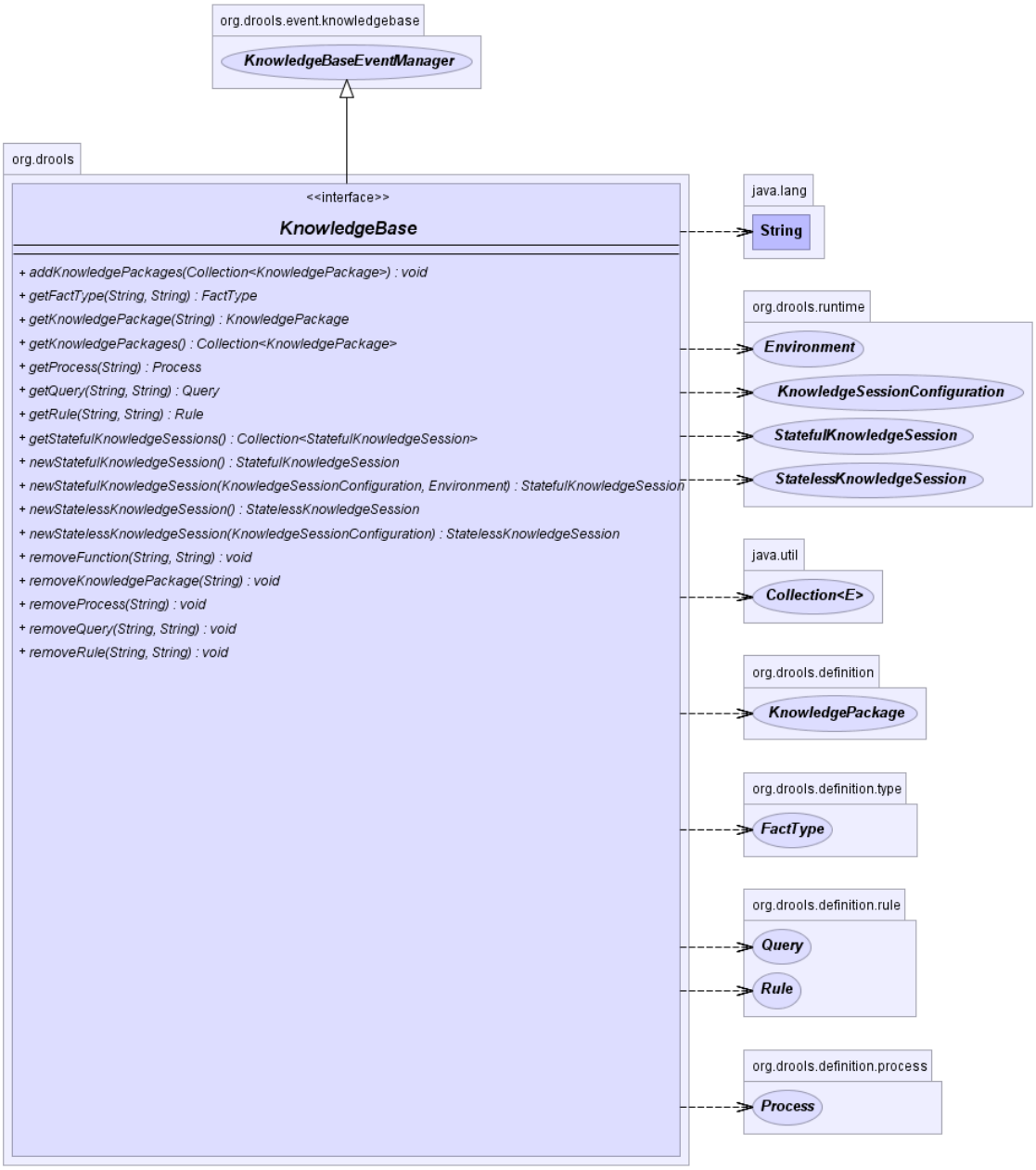


Figure 4.5. KnowledgeBase

A `KnowledgeBase` object is also serializable, and some people may prefer to build and then store a `KnowledgeBase`, treating it also as a unit of deployment, instead of the Knowledge Packages.

The KnowlegeBase is created using the KnowledgeBaseFactory.

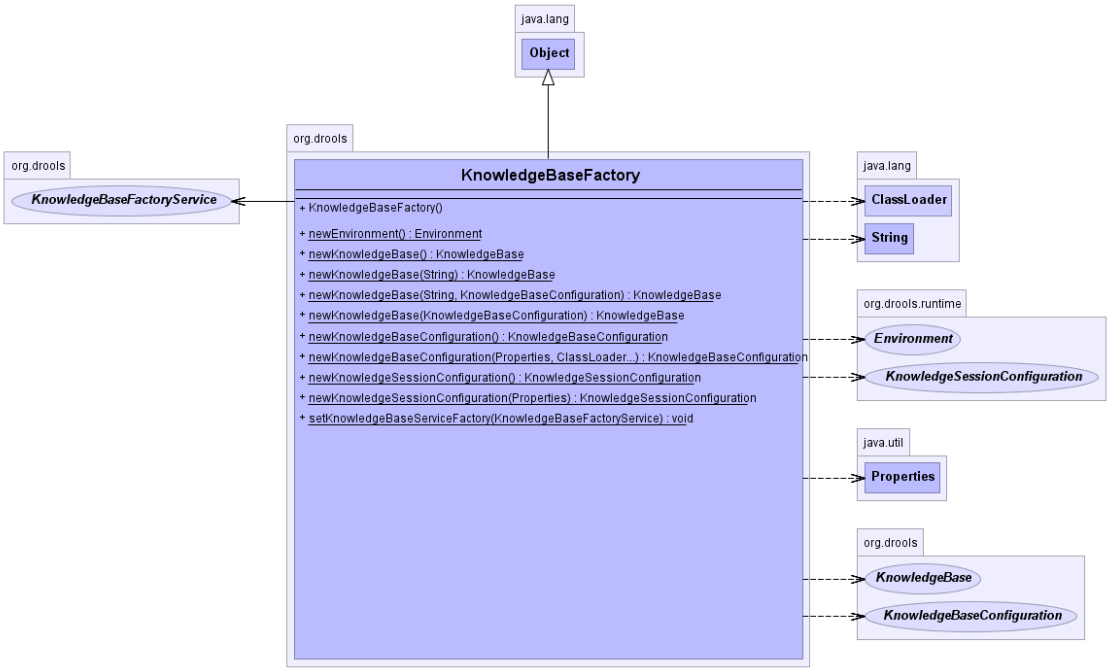


Figure 4.6. KnowledgeBaseFactory

A KnowledgeBase can be created using the default configuration.

Example 4.15. Creating a new KnowledgeBase

```
KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
```

If a custom class loader was used with the `KnowledgeBuilder` to resolve types not in the default class loader, then that must also be set on the `KnowledgeBase`. The technique for this is the same as with the `KnowledgeBuilder`.

Example 4.16. Creating a new KnowledgeBase with a custom ClassLoader

```
KnowledgeBaseConfiguration kbaseConf =
    KnowledgeBaseFactory.createKnowledgeBaseConfiguration( null, cl );
KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase( kbaseConf );
```

4.2.3. In-Process Building and Deployment

This is the simplest form of deployment. It compiles the knowledge definitions and adds them to the Knowledge Base in the same JVM. This approach requires drools-core.jar and drools-compiler.jar to be on the classpath.

Example 4.17. Add KnowledgePackages to a KnowledgeBase

```
Collection<KnowledgePackage> kpkgs = kbuilder.getKnowledgePackages();

KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
kbase.addKnowledgePackages( kpkgs );
```

Note that the `addKnowledgePackages(kpkgs)` method can be called iteratively to add additional knowledge.

4.2.4. Building and Deployment in Separate Processes

Both the `KnowledgeBase` and the `KnowledgePackage` are units of deployment and serializable. This means you can have one machine do any necessary building, requiring `drools-compiler.jar`, and have another machine deploy and execute everything, needing only `drools-core.jar`.

Although serialization is standard Java, we present an example of how one machine might write out the deployment unit and how another machine might read in and use that deployment unit.

Example 4.18. Writing the KnowledgePackage to an OutputStream

```
ObjectOutputStream out = new ObjectOutputStream( new FileOutputStream( fileName ) );
out.writeObject( kpkgs );
out.close();
```

Example 4.19. Reading the KnowledgePackage from an InputStream

```
ObjectInputStream in = new ObjectInputStream( new FileInputStream( fileName ) );
// The input stream might contain an individual
// package or a collection.
@SuppressWarnings( "unchecked" )
Collection<KnowledgePackage> kpkgs =
    ()in.readObject( Collection<KnowledgePackage> );
in.close();

KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
kbase.addKnowledgePackages( kpkgs );
```

The `KnowledgeBase` is also serializable and some people may prefer to build and then store the `KnowledgeBase` itself, instead of the Knowledge Packages.

Drools Guvnor, our server side management system, uses this deployment approach. After Guvnor has compiled and published serialized Knowledge Packages on a URL, Drools can use the URL resource type to load them.

4.2.5. StatefulknowledgeSessions and KnowledgeBase Modifications

Stateful Knowledge Sessions will be discussed in more detail in section "Running". The `KnowledgeBase` creates and returns `StatefulKnowledgeSession` objects, and it may optionally keep references to those. When `KnowledgeBase` modifications occur those modifications are applied against the data in the sessions. This reference is a weak reference and it is also optional, which is controlled by a boolean flag.

4.2.6. KnowledgeAgent

The `KnowlegeAgent` provides automatic loading, caching and re-loading of resources and is configured from a properties files. The Knowledge Agent can update or rebuild this Knowlege Base as the resources it uses are changed. The strategy for this is determined by the configuration given to the factory, but it is typically pull-based using regular polling. We hope to add push-based updates and rebuilds in future versions. The Knowledge Agent will continuously scan all the added resources, using a default polling interval of 60 seconds. If their date of the last modification is updated it will rebuild the cached Knowledge Base using the new resources.

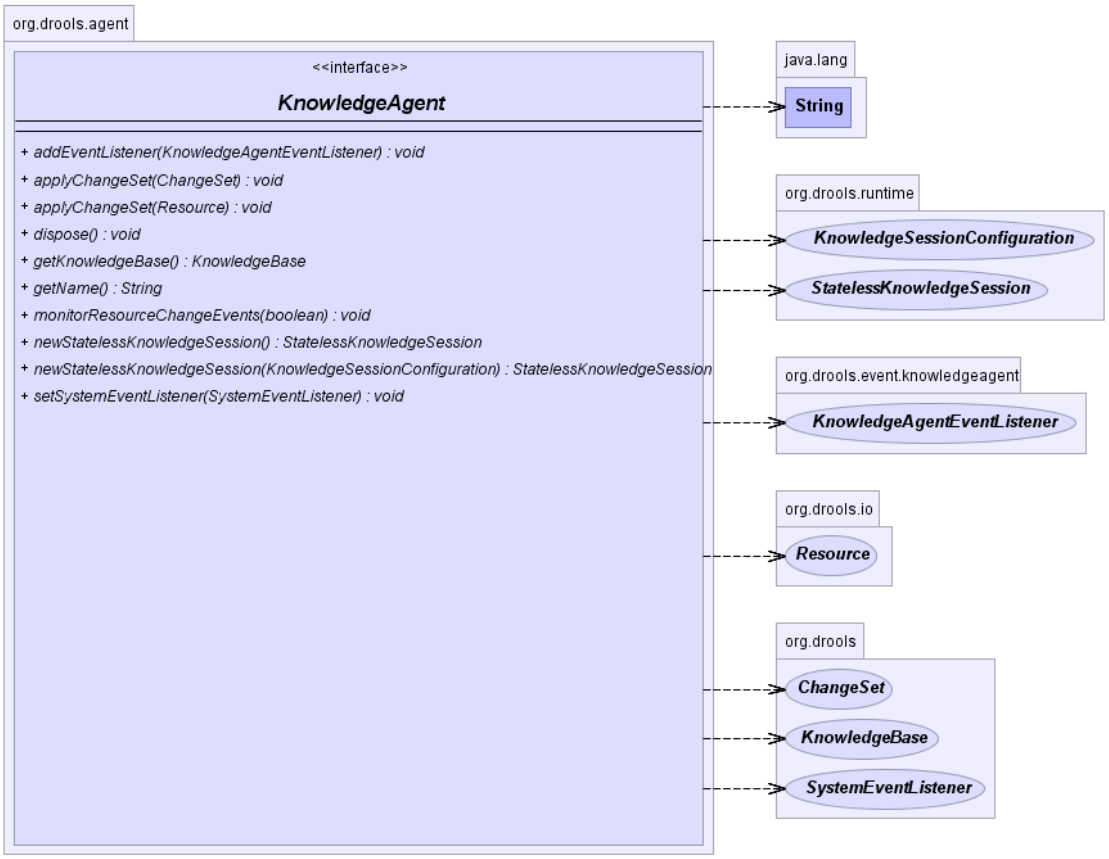


Figure 4.7. KnowledgeAgent

The `KnowlegeBuilder` is created using a `KnowledgeBuilderFactory` object. The agent must specify a name, which is used in the log files to associate a log entry with the corresponding agent.

Example 4.20. Creating the KnowledgeAgent

```
KnowledgeAgent kagent = KnowledgeAgentFactory.newKnowledgeAgent( "MyAgent" );
```

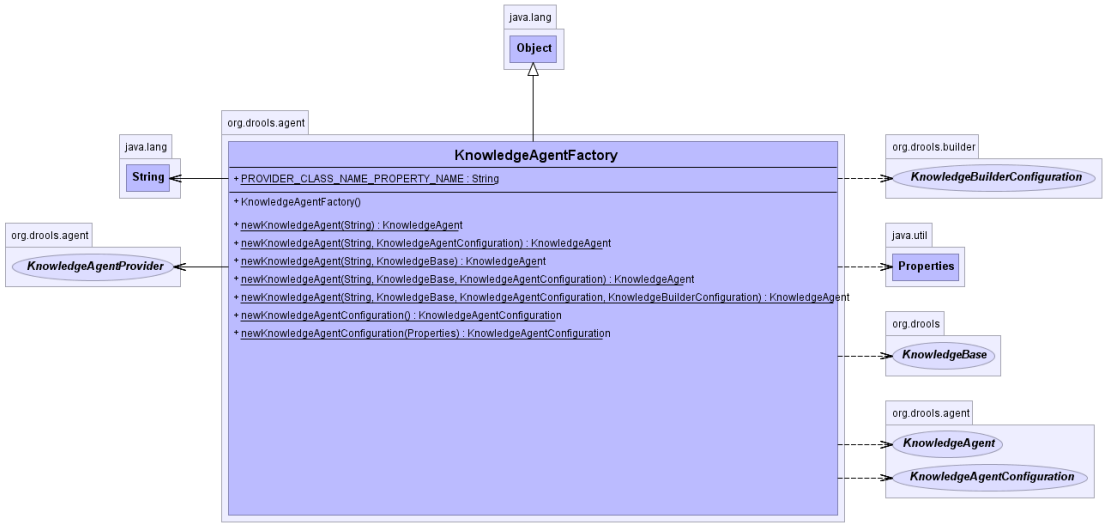


Figure 4.8. KnowledgeAgentFactory

The following example constructs an agent that will build a new KnowledgeBase from the specified ChangeSet. (See section "Building" for more details on the ChangeSet format.) Note that the method can be called iteratively to add new resources over time. The Knowledge Agent polls the resources added from the ChangeSet every 60 seconds, the default interval, to see if they are updated. Whenever changes are found it will construct a new Knowledge Base or apply the modifications to the existing Knowledge Base according to its configuration. If the change set specifies a resource that is a directory its contents will be scanned for changes, too.

Example 4.21. Writing the KnowledgePackage to an OutputStream

```
KnowledgeAgent kagent = KnowledgeAgentFactory.newKnowledgeAgent( "MyAgent" );
kagent.applyChangeSet( ResourceFactory.newUrlResource( url ) );
KnowledgeBase kbase = kagent.getKnowledgeBase();
```

Resource scanning is not on by default, it's a service and must be started, and the same is true for notification. Both can be done via the ResourceFactory.

Example 4.22. Starting the Scanning and Notification Services

```
ResourceFactory.getResourceChangeNotifierService().start();
ResourceFactory.getResourceChangeScannerService().start();
```

The default resource scanning period may be changed via the `ResourceChangeScannerService`. A suitably updated `ResourceChangeScannerConfiguration` object is passed to the service's `configure()` method, which allows for the service to be reconfigured on demand.

Example 4.23. Changing the Scanning Intervals

```
ResourceChangeScannerConfiguration sconf =
    ResourceFactory.getResourceChangeScannerService().newResourceChangeScannerConfiguration();
// Set the disk scanning interval to 30s, default is 60s.
sconf.setProperty( "drools.resource.scanner.interval", "30" );
ResourceFactory.getResourceChangeScannerService().configure( sconf );
```

Knowledge Agents can take an empty Knowledge Base or a populated one. If a populated Knowledge Base is provided, the Knowledge Agent will run an iterator from Knowledge Base and subscribe to the resources that it finds. While it is possible for the Knowledge Builder to build all resources found in a directory, that information is lost by the Knowledge Builder so that those directories will not be continuously scanned. Only directories specified as part of the `applyChangeSet(Resource)` method are monitored.

One of the advantages of providing `KnowledgeBase` as the starting point is that you can provide it with a `KnowledgeBaseConfiguration`. When resource changes are detected and a new `KnowledgeBase` object is instantiated, it will use the `KnowledgeBaseConfiguration` of the previous `KnowledgeBase` object.

Example 4.24. Using an existing KnowledgeBase

```
KnowledgeBaseConfiguration kbaseConf =
    KnowledgeBaseFactory.createKnowledgeBaseConfiguration( null, cl );
KnowledgeBase kbase KnowledgeBaseFactory.newKnowledgeBase( kbaseConf );
// Populate kbase with resources here.

KnowledgeAgent kagent =
    KnowledgeAgentFactory.newKnowledgeAgent( "MyAgent", kbase );
KnowledgeBase kbase = kagent.getKnowledgeBase();
```

In the above example `getKnowledgeBase()` will return the same provided kbase instance until resource changes are detected and a new Knowledge Base is built. When the new Knowledge Base is built, it will be done with the `KnowledgeBaseConfiguration` that was provided to the previous `KnowledgeBase`.

As mentioned previously, a ChangeSet XML can specify a directory and all of its contents will be added. If this ChangeSet XML is used with the `applyChangeSet()` method it will also add any directories to the scanning process. When the directory scan detects an additional file, it will be added to the Knowledge Base; any removed file is removed from the Knowledge Base, and modified files will be removed from the Knowledge Base.

Example 4.25. ChangeSet XML which adds a directories contents

```
<change-set xmlns='http://drools.org/drools-5.0/change-set'
            xmlns:xs='http://www.w3.org/2001/XMLSchema-instance'
            xs:schemaLocation='http://drools.org/drools-5.0/change-set.xsd' >
   <add>
      <resource source='file:/projects/myproject/myrules' type='PKG' />
   </add>
</change-set>
```

Note that for the resource type PKG the drools-compiler dependency is not needed as the Knowledge Agent is able to handle those with just drools-core.

The `KnowledgeAgentConfiguration` can be used to modify a Knowledge Agent's default behavior. You could use this to load the resources from a directory, while inhibiting the continuous scan for changes of that directory.

Example 4.26. Change the Scanning Behavior

```
KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();

KnowledgeAgentConfiguration kaconf =
    KnowledgeAgentFactory.newKnowledgeAgentConfiguation();
// Do not scan directories, just files.
kaconf.setProperty( "drools.agent.scanDirectories", "false" );
KnowledgeAgent kagent =
    KnowledgeAgentFactory.newKnowledgeAgent( "test agent", kaconf );
```

Previously we mentioned Drools Guvnor and how it can build and publish serialized Knowledge Packages on a URL, and that the ChangeSet XML can handle URLs and Packages. Taken together, this forms an importanty deployment scenario for the Knowledge Agent.

4.3. Running

4.3.1. KnowledgeBase

The `KnowlegeBase` is a repository of all the application's knowledge definitions. It will contain rules, processes, functions, and type models. The Knowledge Base itself does not contain data; instead, sessions are created from the `KnowledgeBase` into which data can be inserted and from which process instances may be started. Creating the `KnowlegeBase` can be heavy, whereas session creation is very light, so it is recommended that Knowle Bases be cached where possible to allow for repeated session creation.

Example 4.27. Creating a new KnowledgeBase

```
KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
```

4.3.2. StatefulKnowledgeSession

The `StatefulKnowledgeSession` stores and executes on the runtime data. It is created from the `KnowledgeBase`.

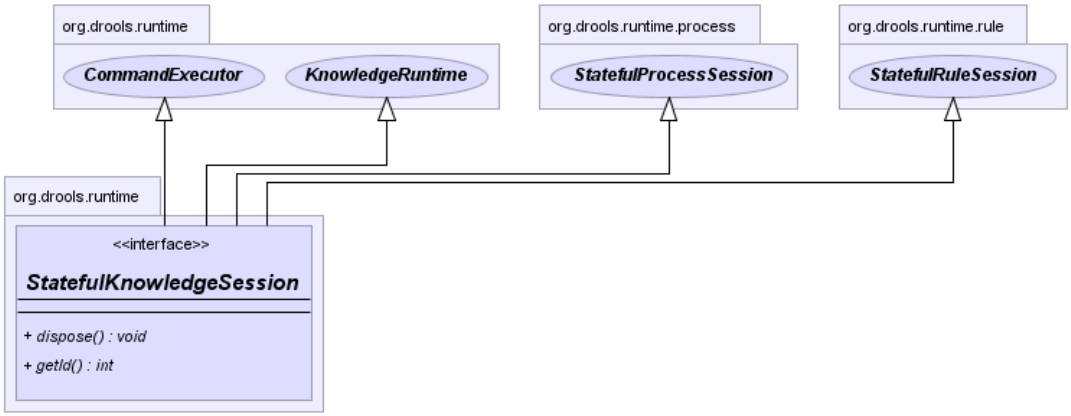


Figure 4.9. StatefulKnowledgeSession

Example 4.28. Create a StatefulKnowledgeSession from a KnowledgeBase

```
StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();
```

4.3.3. KnowledgeRuntime

4.3.3.1. WorkingMemoryEntryPoint

The `WorkingMemoryEntryPoint` provides the methods around inserting, updating and retrieving facts. The term "entry point" is related to the fact that we have multiple partitions in a Working Memory and you can choose which one you are inserting into, although this use case is aimed at event processing and covered in more detail in the Fusion manual. Most rule based applications will work with the default entry point alone.

The `KnowledgeRuntime` interface provides the main interaction with the engine. It is available in rule consequences and process actions. In this manual the focus is on the methods and interfaces related to rules, and the methods pertaining to processes will be ignored for now. But you'll notice that the `KnowledgeRuntime` inherits methods from both the `WorkingMemory` and

the `ProcessRuntime`, thereby providing a unified API to work with processes and rules. When working with rules, three interfaces form the `KnowledgeRuntime`: `WorkingMemoryEntryPoint`, `WorkingMemory` and the `KnowledgeRuntime` itself.

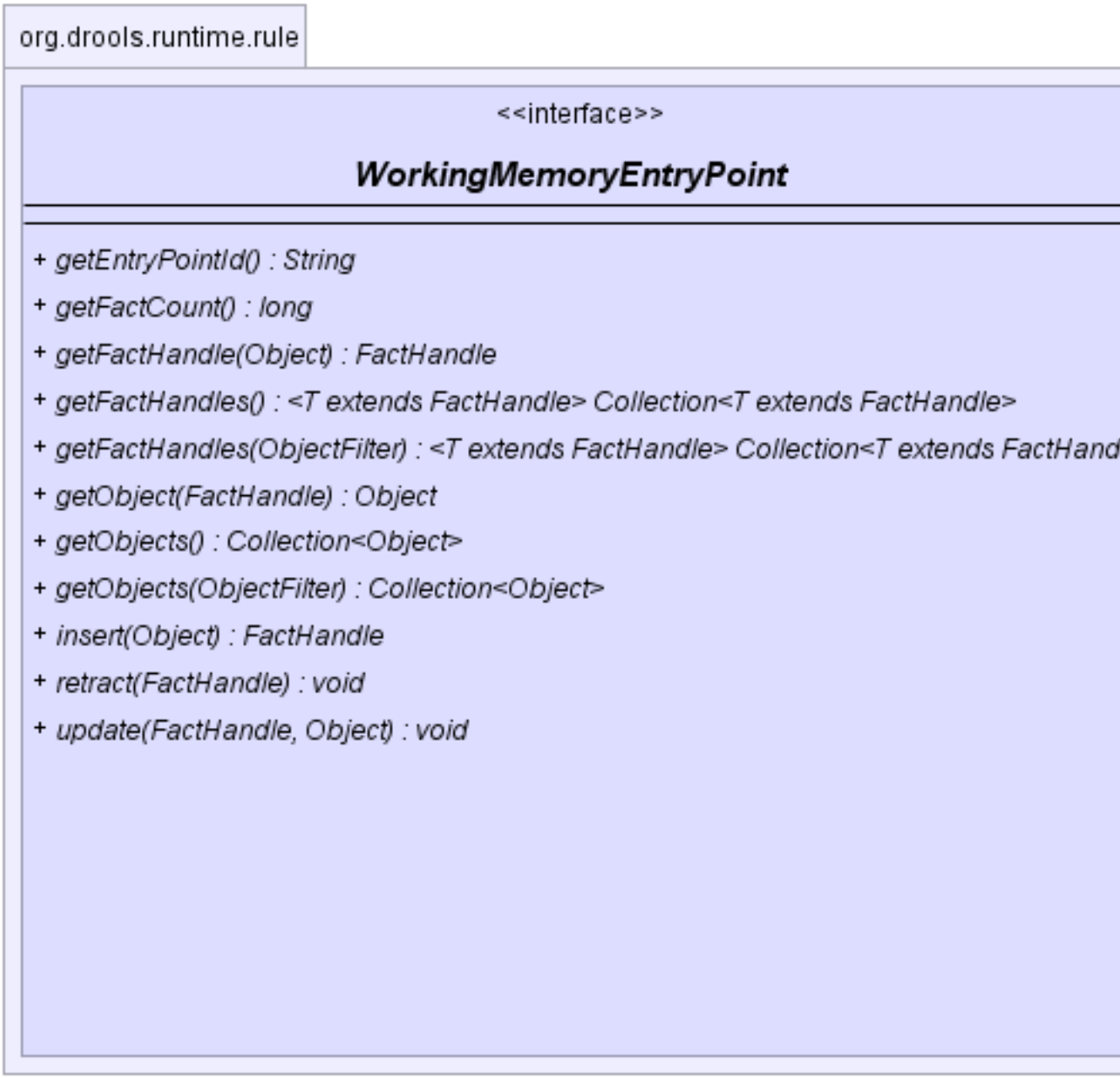


Figure 4.10. WorkingMemoryEntryPoint

4.3.3.1.1. Insertion

Insertion is the act of telling the `WorkingMemory` about a fact, which you do by `ksession.insert(yourObject)`, for example. When you insert a fact, it is examined for matches

against the rules. This means *all* of the work for deciding about firing or not firing a rule is done during insertion; no rule, however, is executed until you call `fireAllRules()`, which you call after you have finished inserting your facts. It is a common misunderstanding for people to think the condition evaluation happens when you call `fireAllRules()`. Expert systems typically use the term *assert* or *assertion* to refer to facts made available to the system. However, due to "assert" being a keyword in most languages, we have decided to use the `insert` keyword; so expect to hear the two used interchangeably.

When an Object is inserted it returns a `FactHandle`. This `FactHandle` is the token used to represent your inserted object within the `WorkingMemory`. It is also used for interactions with the `WorkingMemory` when you wish to retract or modify an object.

```
Cheese stilton = new Cheese("stilton");
FactHandle stiltonHandle = ksession.insert( stilton );
```

As mentioned in the Knowledge Base section, a Working Memory may operate in two assertion modes, i.e., equality or identity, with identity being the default.

Identity means that the Working Memory uses an `IdentityHashMap` to store all asserted objects. New instance assertions always result in the return of a new `FactHandle`, but if an instance is asserted again then it returns the original fact handle, i.e., it ignores repeated insertions for the same fact.

Equality means that the Working Memory uses a `HashMap` to store all asserted Objects. New instance assertions will only return a new `FactHandle` if no equal objects have been asserted.

4.3.3.1.2. Retraction

Retraction is the removal of a fact from Working Memory, which means that it will no longer track and match that fact, and any rules that are activated and dependent on that fact will be cancelled. Note that it is possible to have rules that depend on the nonexistence of a fact, in which case retracting a fact may cause a rule to activate. (See the `not` and `exist` keywords.) Retraction is done using the `FactHandle` that was returned by the insert call.

```
Cheese stilton = new Cheese("stilton");
FactHandle stiltonHandle = ksession.insert( stilton );
....
ksession.retract( stiltonHandle );
```

4.3.3.1.3. Update

The Rule Engine must be notified of modified facts, so that they can be reprocessed. You must use the `update()` method to notify the `WorkingMemory` of changed objects for those objects that are not able to notify the `WorkingMemory` themselves. Notice that `update()` always takes the modified

object as a second parameter, which allows you to specify new instances for immutable objects. On the right hand side of a rule the `modify` statement is recommended, as it makes the changes and notifies the engine in a single statement. After a fact's field values have changed you must call update before changing another fact, or you will cause problems with the indexing within the rule engine. The modify keyword avoids this problem.

```
Cheese stilton = new Cheese("stilton");
FactHandle stiltonHandle = workingMemory.insert( stilton );
...
stilton.setPrice( 100 );
workingMemory.update( stiltonHandle, stilton );
```

4.3.3.2. WorkingMemory

The WorkingMemory provides access to the Agenda, permits query executions, and lets you access named Enty Points.

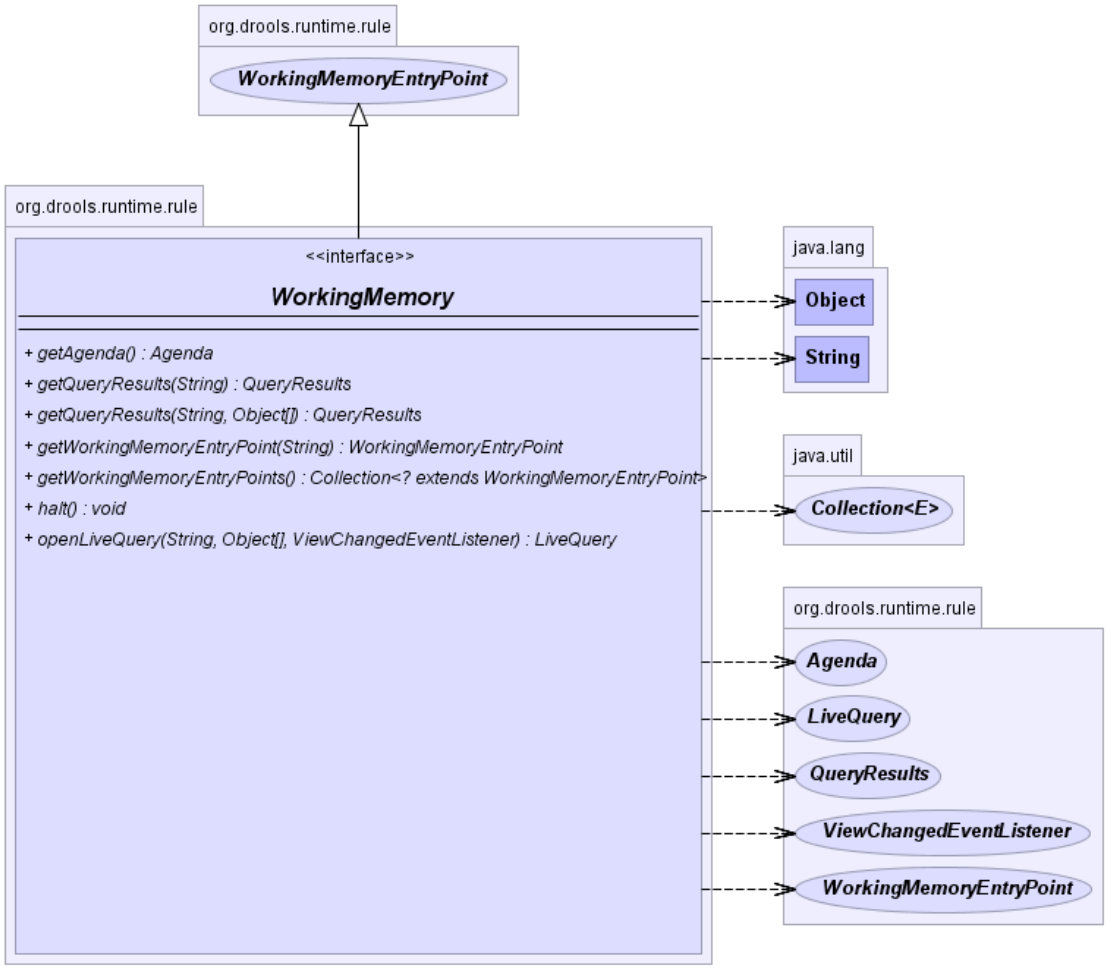


Figure 4.11. WorkingMemory

4.3.3.2.1. Query

Queries are used to retrieve fact sets based on patterns, as they are used in rules. Patterns may make use of optional parameters. Queries can be defined in the Knowlege Base, from where they are called up to return the matching results. While iterating over the result collection, any bound identifier in the query can be accessed using the get(String identifier) method and any FactHandle for that identifier can be retrieved using getFactHandle(String identifier).

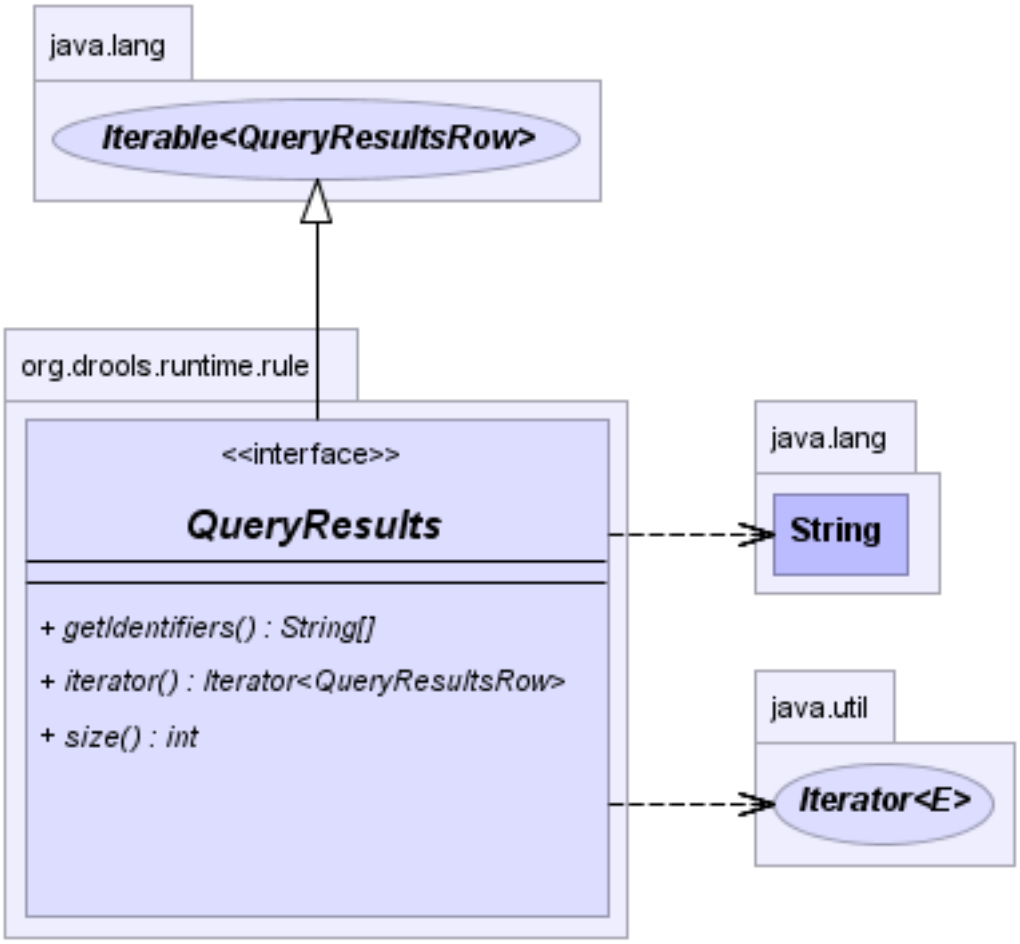


Figure 4.12. QueryResults

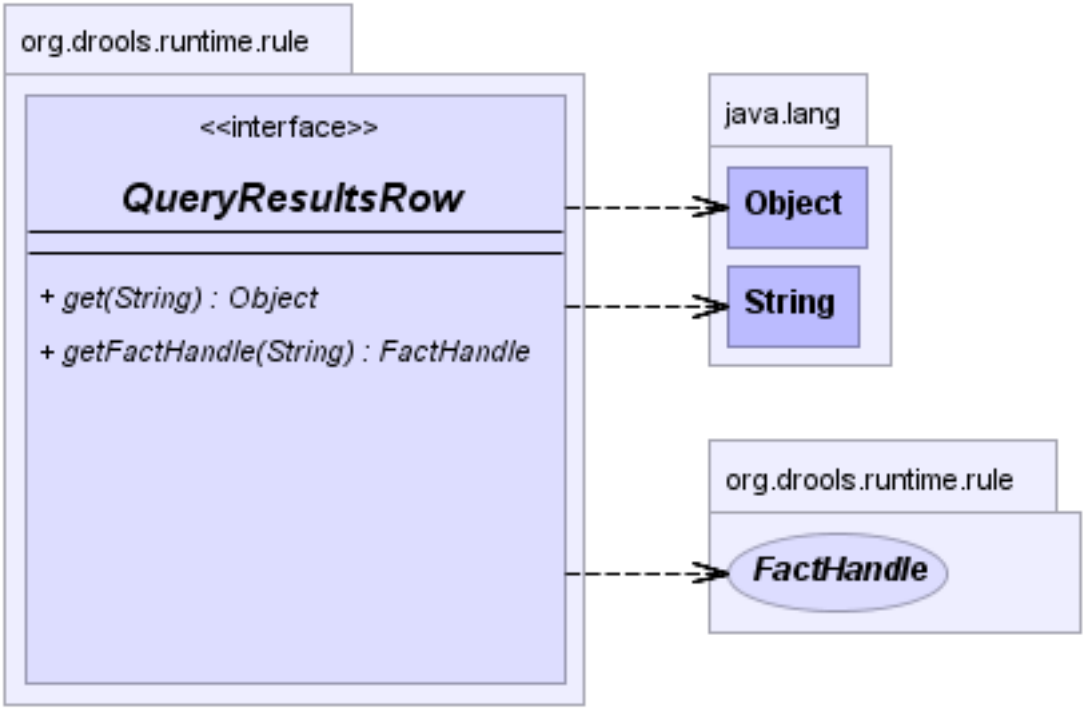


Figure 4.13. QueryResultsRow

Example 4.29. Simple Query Example

```
QueryResults results =
    ksession.getQueryResults( "my query", new Object[] { "string" } );
for ( QueryResultsRow row : results ) {
    System.out.println( row.get( "varName" ) );
}
```

4.3.3.2.2. Live Querries

Drools has always had query support, but the result was returned as an iterable set; this makes it hard to monitor changes over time.

We have now complimented this with Live Querries, which has a listener attached instead of returning an iterable result set. These live querries stay open creating a view and publish change events for the contents of this view. So now you can execute your query, with parameters and listen to changes in the resulting view.

Example 4.30. Implementing ViewChangedEventListener

```
final List updated = new ArrayList();
```

```
final List removed = new ArrayList();
final List added = new ArrayList();

ViewChangedEventListener listener = new ViewChangedEventListener() {
 public void rowUpdated(Row row) {
  updated.add( row.get( "$price" ) );
 }

 public void rowRemoved(Row row) {
  removed.add( row.get( "$price" ) );
 }

 public void rowAdded(Row row) {
  added.add( row.get( "$price" ) );
 }
};

// Open the LiveQuery
LiveQuery query = ksession.openLiveQuery( "cheeses",
                                          new Object[] { "cheddar", "stilton" },
                                           listener );
...
...
query.dispose() // make sure you call dispose when you want the query to close
```

A Drools blog article contains an example of Glazed Lists integration for live queries,

http://blog.athico.com/2010/07/glazed-lists-examples-for-drools-live.html

4.3.3.3. KnowledgeRuntime

The `KnowledgeRuntime` provides further methods that are applicable to both rules and processes, such as setting globals and registering `Channels` (previously exit points, some references may remain in docs for a while).

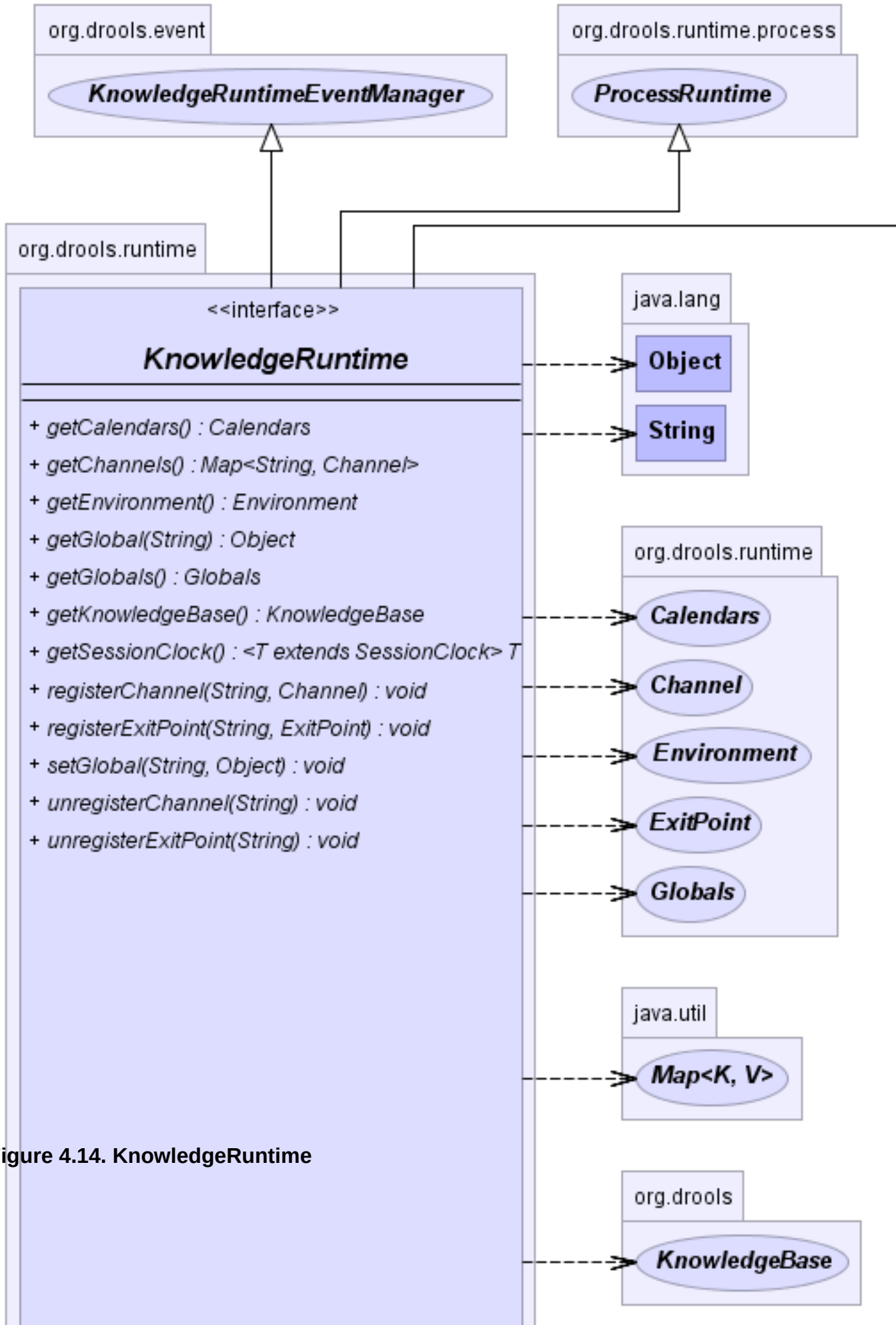


Figure 4.14. KnowledgeRuntime

4.3.3.3.1. Globals

Globals are named objects that can be passed to the rule engine, without needing to insert them. Most often these are used for static information, or for services that are used in the RHS of a rule, or perhaps as a means to return objects from the rule engine. If you use a global on the LHS of a rule, make sure it is immutable. A global must first be declared in a rules file before it can be set on the session.

```
global java.util.List list
```

With the Knowledge Base now aware of the global identifier and its type, it is now possible to call `ksession.setGlobal()` for any session. Failure to declare the global type and identifier first will result in an exception being thrown. To set the global on the session use `ksession.setGlobal(identifier, value)`:

```
List list = new ArrayList();
ksession.setGlobal("list", list);
```

If a rule evaluates on a global before you set it you will get a `NullPointerException`.

4.3.3.4. StatefulRuleSession

The `StatefulRuleSession` is inherited by the `StatefulKnowledgeSession` and provides the rule related methods that are relevant from outside of the engine.

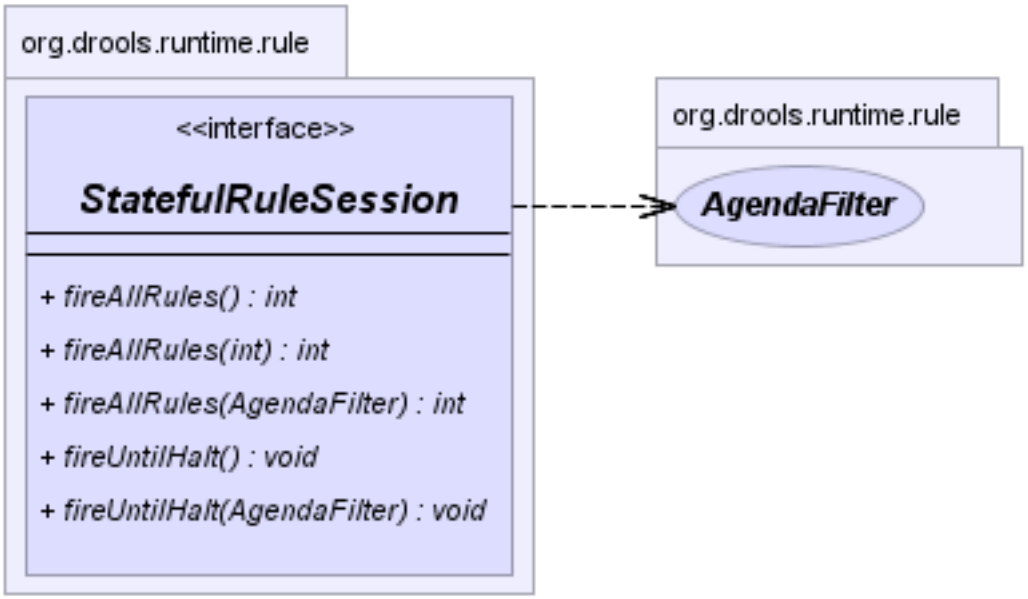


Figure 4.15. StatefulRuleSession

4.3.3.4.1. Agenda Filters

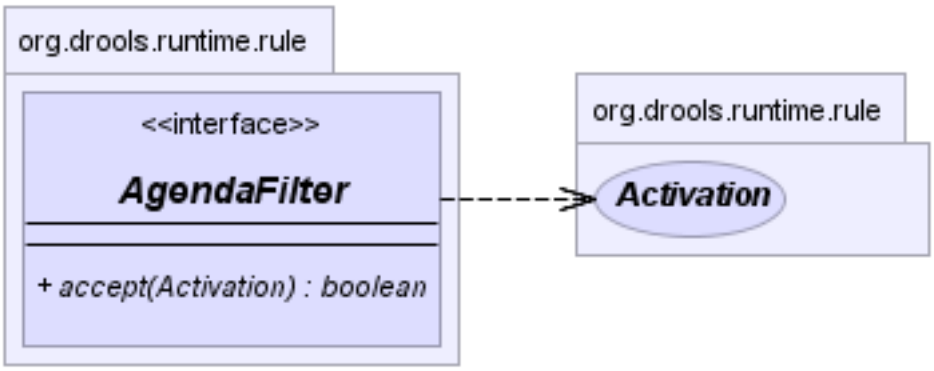


Figure 4.16. AgendaFilters

`AgendaFilter` objects are optional implementations of the filter interface which are used to allow or deny the firing of an activation. What you filter on is entirely up to the implementation. Drools 4.0 used to supply some out of the box filters, which have not be exposed in drools 5.0 knowledge-api, but they are simple to implement and the Drools 4.0 code base can be referred to.

To use a filter specify it while calling `fireAllRules()`. The following example permits only rules ending in the string `"Test"`. All others will be filtered out.

```
ksession.fireAllRules( new RuleNameEndsWithAgendaFilter( "Test" ) );
```

4.3.4. Agenda

The Agenda is a *Rete* feature. During actions on the `WorkingMemory`, rules may become fully matched and eligible for execution; a single Working Memory Action can result in multiple eligible rules. When a rule is fully matched an Activation is created, referencing the rule and the matched facts, and placed onto the Agenda. The Agenda controls the execution order of these Activations using a Conflict Resolution strategy.

The engine cycles repeatedly through two phases:

1. Working Memory Actions. This is where most of the work takes place, either in the Consequence (the RHS itself) or the main Java application process. Once the Consequence has finished or the main Java application process calls `fireAllRules()` the engine switches to the Agenda Evaluation phase.

2. Agenda Evaluation. This attempts to select a rule to fire. If no rule is found it exits, otherwise it fires the found rule, switching the phase back to Working Memory Actions.

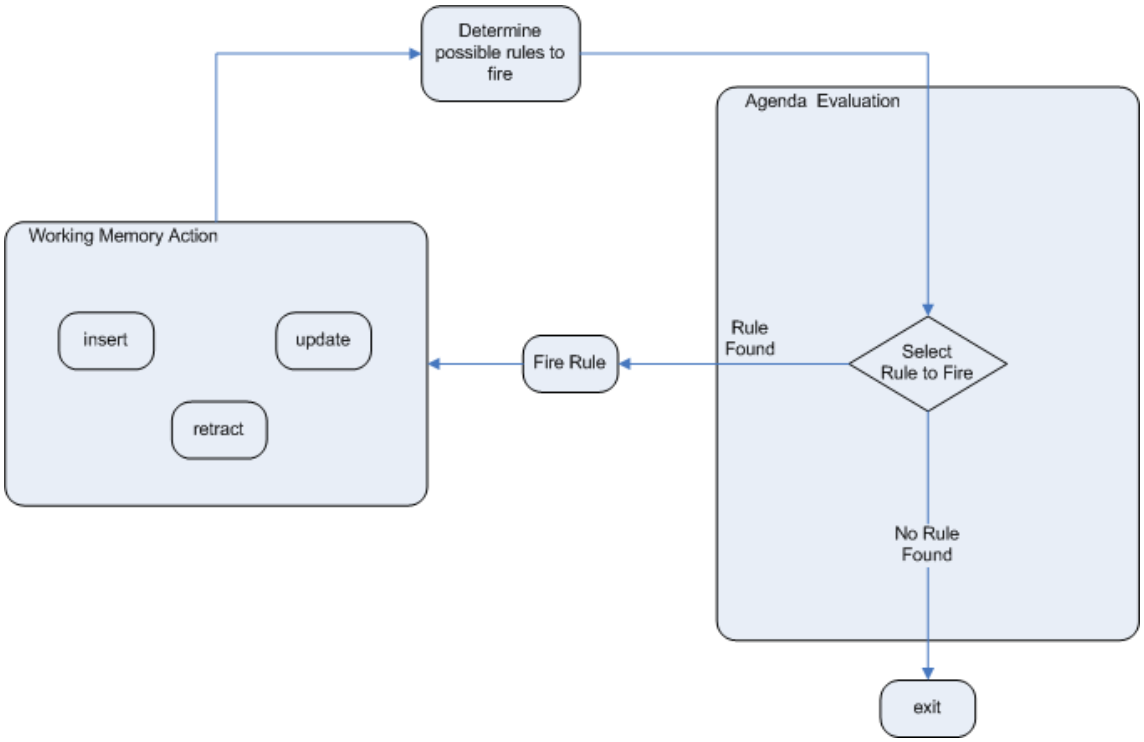


Figure 4.17. Two Phase Execution

The process repeats until the agenda is clear, in which case control returns to the calling application. When Working Memory Actions are taking place, no rules are being fired.

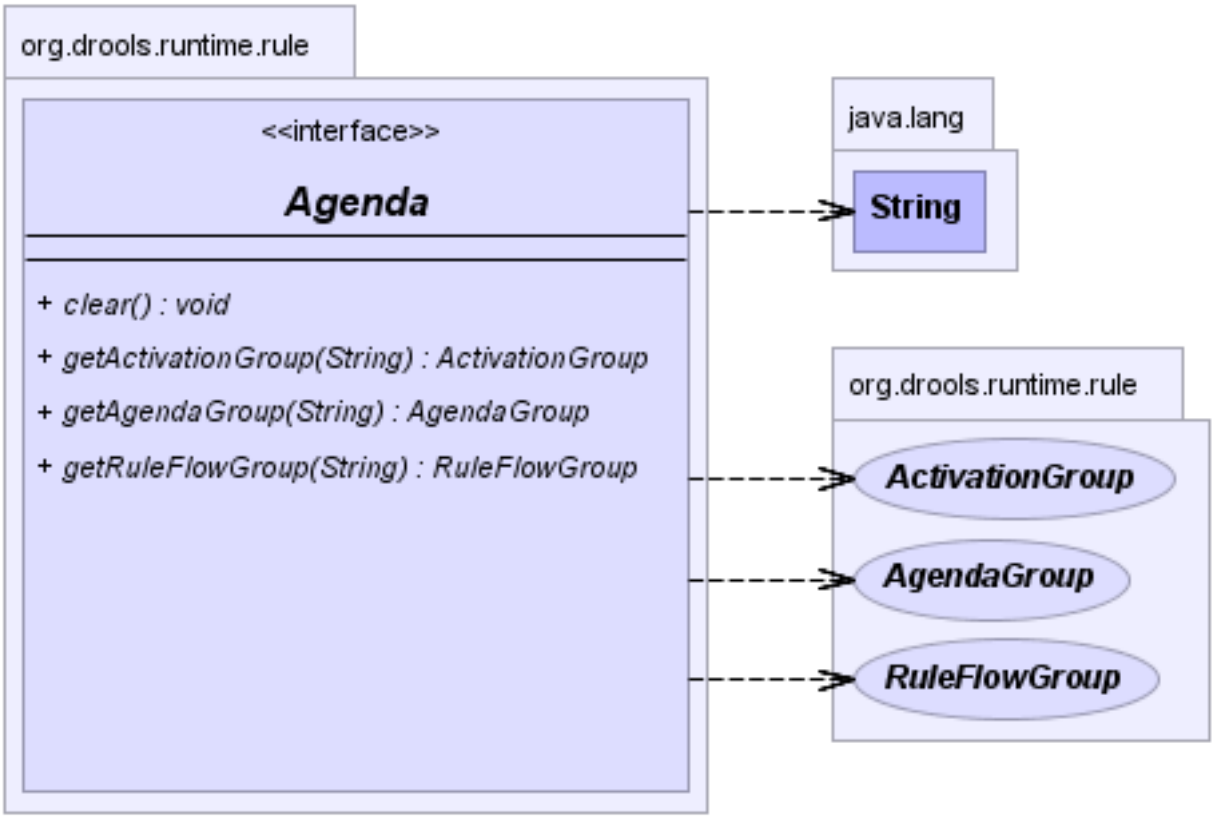


Figure 4.18. Agenda

4.3.4.1. Conflict Resolution

Conflict resolution is required when there are multiple rules on the agenda. (The basics to this are covered in chapter "Quick Start".) As firing a rule may have side effects on the working memory, the rule engine needs to know in what order the rules should fire (for instance, firing ruleA may cause ruleB to be removed from the agenda).

The default conflict resolution strategies employed by Drools are: Salience and LIFO (last in, first out).

The most visible one is *salience* (or priority), in which case a user can specify that a certain rule has a higher priority (by giving it a higher number) than other rules. In that case, the rule with higher salience will be preferred. LIFO priorities are based on the assigned Working Memory Action counter value, with all rules created during the same action receiving the same value. The execution order of a set of firings with the same priority value is arbitrary.

As a general rule, it is a good idea not to count on rules firing in any particular order, and to author the rules without worrying about a "flow". However when a flow is needed a number of possibilities exist, including but not limited to: agenda groups, rule flow groups, activation groups, control/semaphore facts. These are discussed in later sections.

Drools 4.0 supported custom conflict resolution strategies; while this capability still exists in Drools it has not yet been exposed to the end user via knowledge-api in Drools 5.0.

4.3.4.2. AgendaGroup

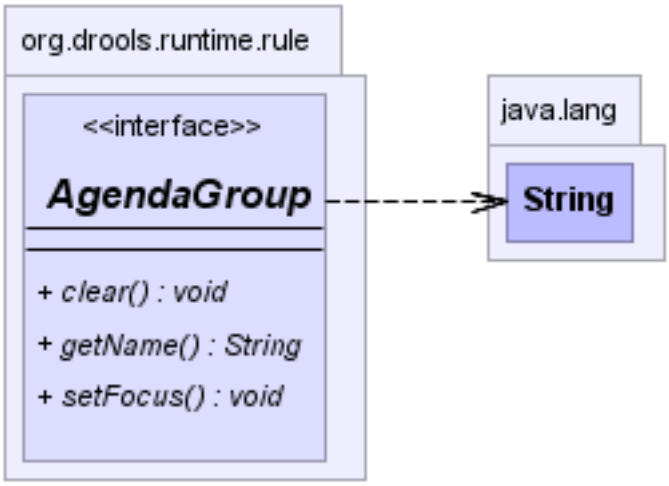


Figure 4.19. AgendaGroup

Agenda groups are a way to partition rules (activations, actually) on the agenda. At any one time, only one group has "focus" which means that activations for rules in that group only will take effect. You can also have rules with "auto focus" which means that the focus is taken for its agenda group when that rule's conditions are true.

Agenda groups are known as "modules" in CLIPS terminology. While it best to design rules that do not need control flow, this is not always possible. Agenda groups provide a handy way to create a "flow" between grouped rules. You can switch the group which has focus either from within the rule engine, or via the API. If your rules have a clear need for multiple "phases" or "sequences" of processing, consider using agenda-groups for this purpose.

Each time `setFocus()` is called it pushes that Agenda Group onto a stack. When the focus group is empty it is popped from the stack and the focus group that is now on top evaluates. An Agenda Group can appear in multiple locations on the stack. The default Agenda Group is "MAIN", with all rules which do not specify an Agenda Group being in this group. It is also always the first group on the stack, given focus initially, by default.

```
ksession.getAgenda().getAgendaGroup( "Group A" ).setFocus();
```

4.3.4.3. ActivationGroup

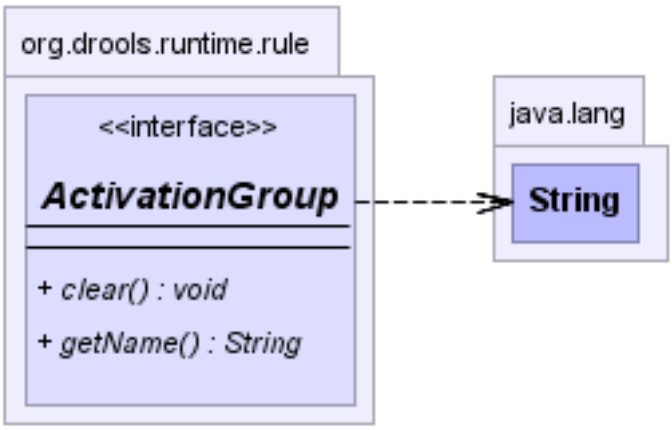


Figure 4.20. ActivationGroup

An activation group is a set of rules bound together by the same "activation-group" rule attribute. In this group only one rule can fire, and after that rule has fired all the other rules are cancelled from the agenda. The `clear()` method can be called at any time, which cancels all of the activations before one has had a chance to fire.

```
ksession.getAgenda().getActivationGroup( "Group B" ).clear();
```

4.3.4.4. RuleFlowGroup

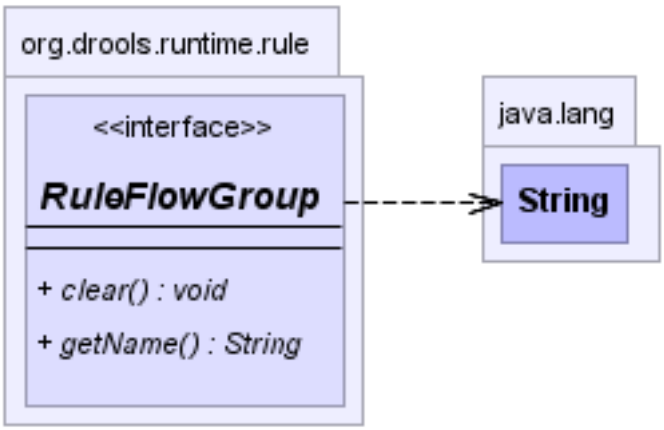


Figure 4.21. RuleFlowGroup

A rule flow group is a group of rules associated by the "ruleflow-group" rule attribute. These rules can only fire when the group is activate. The group itself can only become active when

the elaboration of the ruleflow diagram reaches the node representing the group. Here too, the `clear()` method can be called at any time to cancels all activations still remaining on the Agenda.

```
ksession.getAgenda().getRuleFlowGroup( "Group C" ).clear();
```

4.3.5. Event Model

The event package provides means to be notified of rule engine events, including rules firing, objects being asserted, etc. This allows you, for instance, to separate logging and auditing activities from the main part of your application (and the rules).

The `KnowlegeRuntimeEventManager` interface is implemented by the `KnowledgeRuntime` which provides two interfaces, `WorkingMemoryEventManager` and `ProcessEventManager`. We will only cover the `WorkingMemoryEventManager` here.

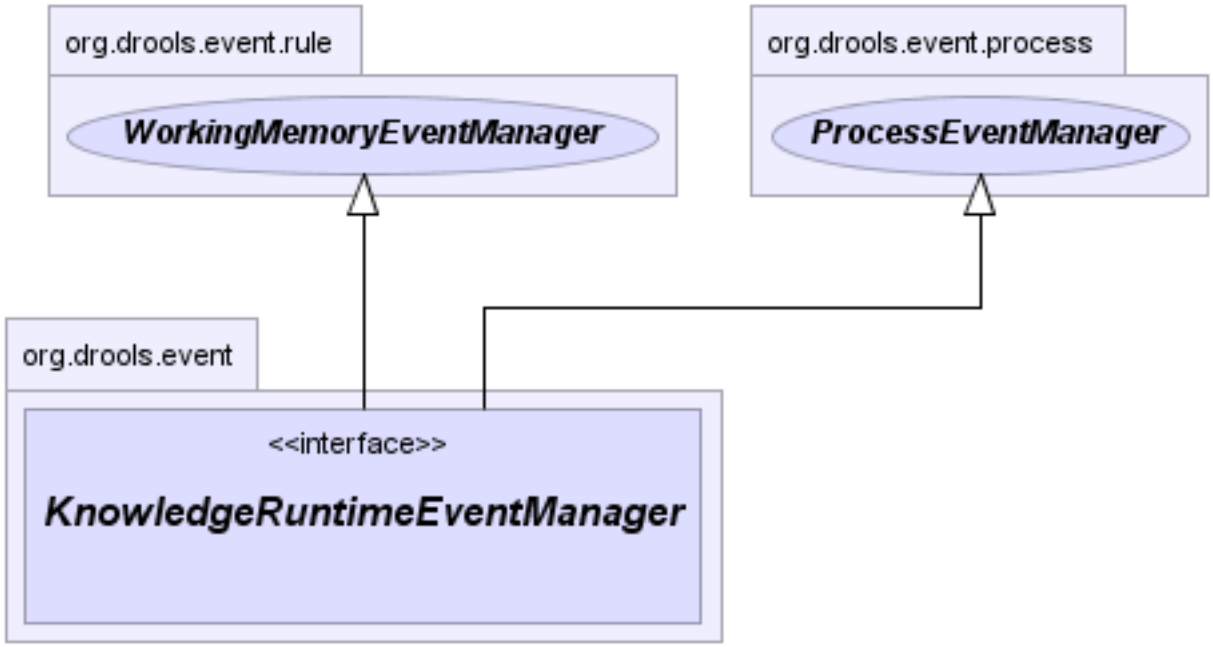


Figure 4.22. KnowledgeRuntimeEventManager

The `WorkingMemoryEventManager` allows for listeners to be added and removed, so that events for the working memory and the agenda can be listened to.

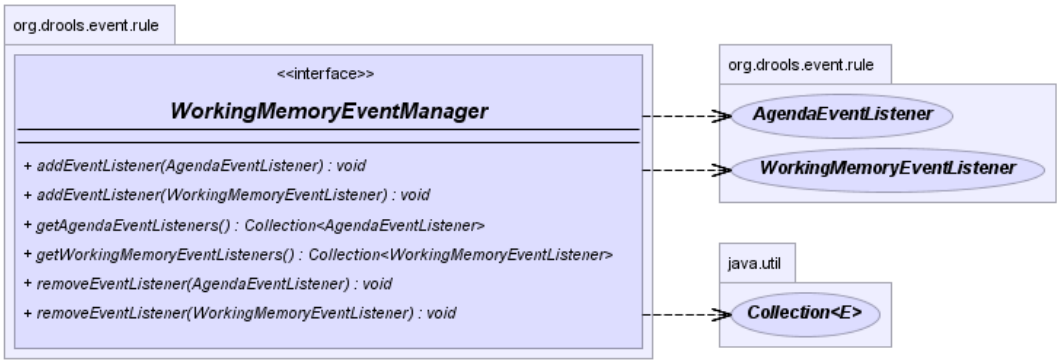


Figure 4.23. WorkingMemoryEventManager

The following code snippet shows how a simple agenda listener is declared and attached to a session. It will print activations after they have fired.

Example 4.31. Adding an AgendaEventListener

```
ksession.addEventListener( new DefaultAgendaEventListener() {
   public void afterActivationFired(AfterActivationFiredEvent event) {
       super.afterActivationFired( event );
       System.out.println( event );
   }
});
```

Drools also provides `DebugWorkingMemoryEventListener` and `DebugAgendaEventListener` which implement each method with a debug print statement. To print all Working Memory events, you add a listener like this:

Example 4.32. Creating a new KnowledgeBuilder

```
ksession.addEventListener( new DebugWorkingMemoryEventListener() );
```

All emitted events implement the `KnowlegeRuntimeEvent` interface which can be used to retrieve the actual `KnowlegeRuntime` the event originated from.

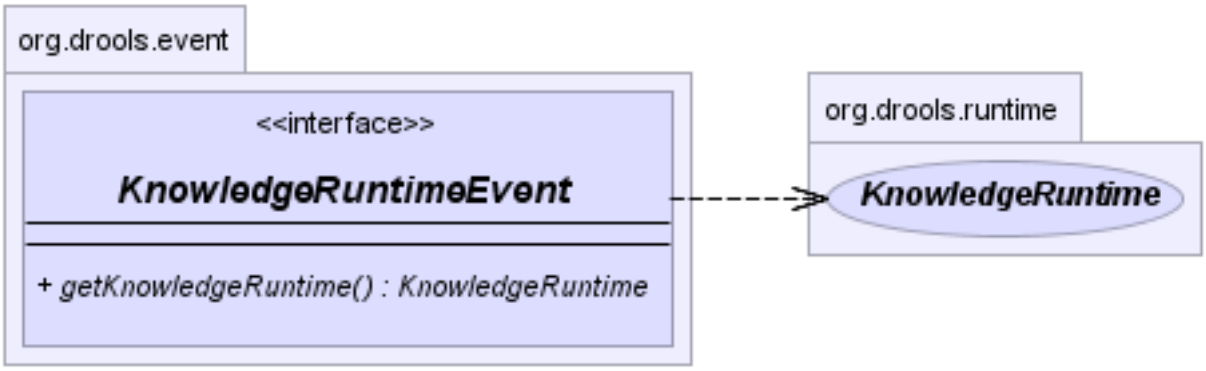


Figure 4.24. KnowlegeRuntimeEvent

The events currently supported are:

- ActivationCreatedEvent
- ActivationCancelledEvent
- BeforeActivationFiredEvent
- AfterActivationFiredEvent
- AgendaGroupPushedEvent
- AgendaGroupPoppedEvent
- ObjectInsertEvent
- ObjectRetractedEvent
- ObjectUpdatedEvent
- ProcessCompletedEvent
- ProcessNodeLeftEvent
- ProcessNodeTriggeredEvent
- ProcessStartEvent

4.3.6. KnowledgeRuntimeLogger

The KnowledgeRuntimeLogger uses the comprehensive event system in Drools to create an audit log that can be used to log the execution of an application for later inspection, using tools such as the Eclipse audit viewer.

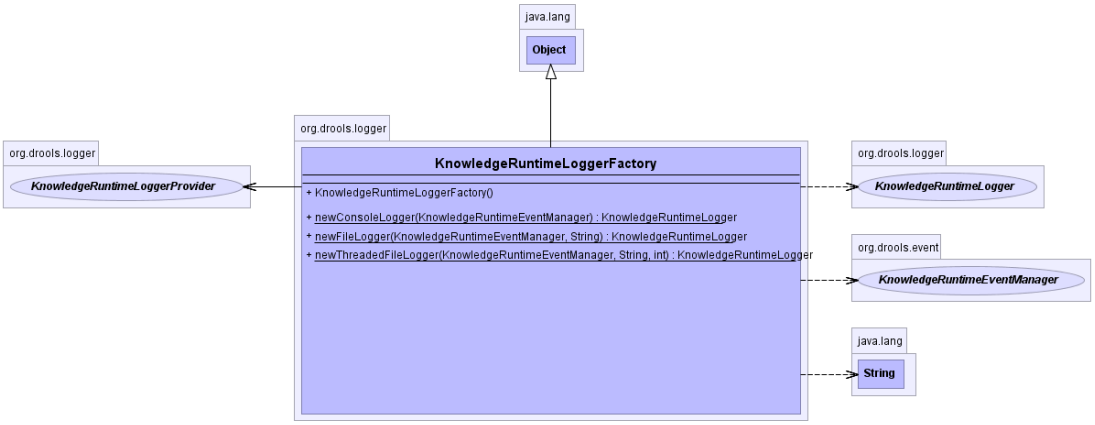


Figure 4.25. KnowledgeRuntimeLoggerFactory

Example 4.33. FileLogger

```
KnowledgeRuntimeLogger logger =
  KnowledgeRuntimeLoggerFactory.newFileLogger(ksession, "logdir/mylogfile");
...
logger.close();
```

4.3.7. StatelessKnowledgeSession

The `StatelessKnowledgeSession` wraps the `StatefulKnowledgeSession`, instead of extending it. Its main focus is on decision service type scenarios. It avoids the need to call `dispose()`. Stateless sessions do not support iterative insertions and the method call `fireAllRules()` from Java code; the act of calling `execute()` is a single-shot method that will internally instantiate a `StatefulKnowledgeSession`, add all the user data and execute user commands, call `fireAllRules()`, and then call `dispose()`. While the main way to work with this class is via the `BatchExecution` (a subinterface of `Command`) as supported by the `CommandExecutor` interface, two convenience methods are provided for when simple object insertion is all that's required. The `CommandExecutor` and `BatchExecution` are talked about in detail in their own section.

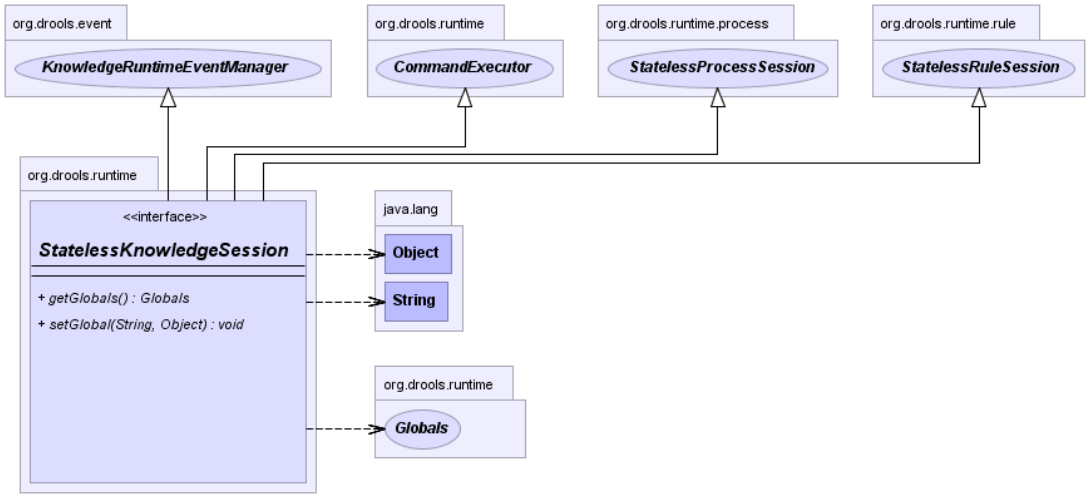


Figure 4.26. StatelessKnowledgeSession

Our simple example shows a stateless session executing a given collection of Java objects using the convenience API. It will iterate the collection, inserting each element in turn.

Example 4.34. Simple StatelessKnowledgeSession execution with a Collection

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kbuilder.add( ResourceFactory.newFileSystemResource( fileName ), ResourceType.DRL );
if (kbuilder.hasErrors() ) {
    System.out.println( kbuilder.getErrors() );
} else {
    KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
    kbase.addKnowledgePackages( kbuilder.getKnowledgePackages() );
    StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();
    ksession.execute( collection );
}
```

If this was done as a single Command it would be as follows:

Example 4.35. Simple StatelessKnowledgeSession execution with InsertElements Command

```
ksession.execute( CommandFactory.newInsertElements( collection ) );
```

If you wanted to insert the collection itself, and the collection's individual elements, then `CommandFactory.newInsert(collection)` would do the job.

Methods of the `CommandFactory` create the supported commands, all of which can be marshalled using XStream and the `BatchExecutionHelper`. `BatchExecutionHelper` provides details on the XML format as well as how to use Drools Pipeline to automate the marshalling of `BatchExecution` and `ExecutionResults`.

`StatelessKnowledgeSession` supports globals, scoped in a number of ways. I'll cover the non-command way first, as commands are scoped to a specific execution call. Globals can be resolved in three ways.

- The Stateless Knowledge Session method `getGlobals()` returns a Globals instance which provides access to the session's globals. These are shared for *all* execution calls. Exercise caution regarding mutable globals because execution calls can be executing simultaneously in different threads.

Example 4.36. Session scoped global

```
StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();
// Set a global hbnSession, that can be used for DB interactions in the rules.
ksession.setGlobal( "hbnSession", hibernateSession );
// Execute while being able to resolve the "hbnSession" identifier.
ksession.execute( collection );
```

- Using a delegate is another way of global resolution. Assigning a value to a global (with `setGlobal(String, Object)`) results in the value being stored in an internal collection mapping identifiers to values. Identifiers in this internal collection will have priority over any supplied delegate. Only if an identifier cannot be found in this internal collection, the delegate global (if any) will be used.

- The third way of resolving globals is to have execution scoped globals. Here, a `Command` to set a global is passed to the `CommandExecutor`.

The `CommandExecutor` interface also offers the ability to export data via "out" parameters. Inserted facts, globals and query results can all be returned.

Example 4.37. Out identifiers

```
// Set up a list of commands
List cmds = new ArrayList();
cmds.add( CommandFactory.newSetGlobal( "list1", new ArrayList(), true ) );
cmds.add( CommandFactory.newInsert( new Person( "jon", 102 ), "person" ) );
cmds.add( CommandFactory.newQuery( "Get People" "getPeople" );

// Execute the list
ExecutionResults results =
```

```
  ksession.execute( CommandFactory.newBatchExecution( cmds ) );

// Retrieve the ArrayList
results.getValue( "list1" );
// Retrieve the inserted Person fact
results.getValue( "person" );
// Retrieve the query as a QueryResults instance.
results.getValue( "Get People" );
```

4.3.7.1. Sequential Mode

With Rete you have a stateful session where objects can be asserted and modified over time, and where rules can also be added and removed. Now what happens if we assume a stateless session, where after the initial data set no more data can be asserted or modified and rules cannot be added or removed? Certainly it won't be necessary to re-evaluate rules, and the engine will be able to operate in a simplified way.

1. Order the Rules by salience and position in the ruleset (by setting a sequence attribute on the rule terminal node).
2. Create an array, one element for each possible rule activation; element position indicates firing order.
3. Turn off all node memories, except the right-input Object memory.
4. Disconnect the Left Input Adapter Node propagation, and let the Object plus the Node be referenced in a Command object, which is added to a list on the Working Memory for later execution.
5. Assert all objects, and, when all assertions are finished and thus right-input node memories are populated, check the Command list and execute each in turn.
6. All resulting Activations should be placed in the array, based upon the determined sequence number of the Rule. Record the first and last populated elements, to reduce the iteration range.
7. Iterate the array of Activations, executing populated element in turn.
8. If we have a maximum number of allowed rule executions, we can exit our network evaluations early to fire all the rules in the array.

The `LeftInputAdapterNode` no longer creates a Tuple, adding the Object, and then propagate the Tuple – instead a Command object is created and added to a list in the Working Memory. This Command object holds a reference to the `LeftInputAdapterNode` and the propagated object. This stops any left-input propagations at insertion time, so that we know that a right-input propagation will never need to attempt a join with the left-inputs (removing the need for left-input memory). All nodes have their memory turned off, including the left-input Tuple memory

but excluding the right-input object memory, which means that the only node remembering an insertion propagation is the right-input object memory. Once all the assertions are finished and all right-input memories populated, we can then iterate the list of `LeftInputAdatperNode` Command objects calling each in turn. They will propagate down the network attempting to join with the right-input objects, but they won't be remembered in the left input as we know there will be no further object assertions and thus propagations into the right-input memory.

There is no longer an Agenda, with a priority queue to schedule the Tuples; instead, there is simply an array for the number of rules. The sequence number of the `RuleTerminalNode` indicates the element within the array where to place the Activation. Once all Command objects have finished we can iterate our array, checking each element in turn, and firing the Activations if they exist. To improve performance, we remember the first and the last populated cell in the array. The network is constructed, with each `RuleTerminalNode` being given a sequence number based on a salience number and its order of being added to the network.

Typically the right-input node memories are Hash Maps, for fast object retraction; here, as we know there will be no object retractions, we can use a list when the values of the object are not indexed. For larger numbers of objects indexed Hash Maps provide a performance increase; if we know an object type has only a few instances, indexing is probably not advantageous, and a list can be used.

Sequential mode can only be used with a Stateless Session and is off by default. To turn it on, either call `RuleBaseConfiguration.setSequential(true)`, or set the rulebase configuration property `drools.sequential` to true. Sequential mode can fall back to a dynamic agenda by calling `setSequentialAgenda` with `SequentialAgenda.DYNAMIC`. You may also set the "drools.sequential.agenda" property to "sequential" or "dynamic".

4.3.8. Commands and the CommandExecutor

Drools has the concept of stateful or stateless sessions. We've already covered stateful sessions, which use the standard working memory that can be worked with iteratively over time. Stateless is a one-off execution of a working memory with a provided data set. It may return some results, with the session being disposed at the end, prohibiting further iterative interactions. You can think of stateless as treating a rule engine like a function call with optional return results.

In Drools 4 we supported these two paradigms but the way the user interacted with them was different. StatelessSession used an execute(...) method which would insert a collection of objects as facts. StatefulSession didn't have this method, and insert used the more traditional `insert(...)` method. The other issue was that the StatelessSession did not return any results, so that users themselves had to map globals to get results, and it wasn't possible to do anything besides inserting objects; users could not start processes or execute queries.

Drools 5.0 addresses all of these issues and more. The foundation for this is the `CommandExecutor` interface, which both the stateful and stateless interfaces extend, creating consistency and `ExecutionResults`:

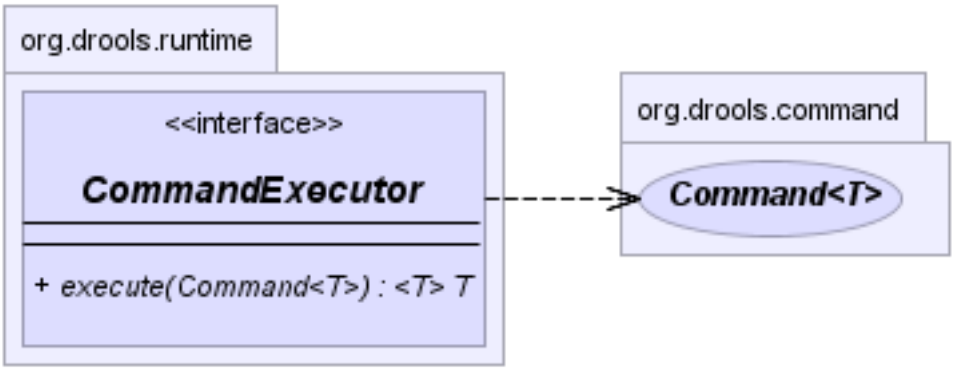


Figure 4.27. CommandExecutor

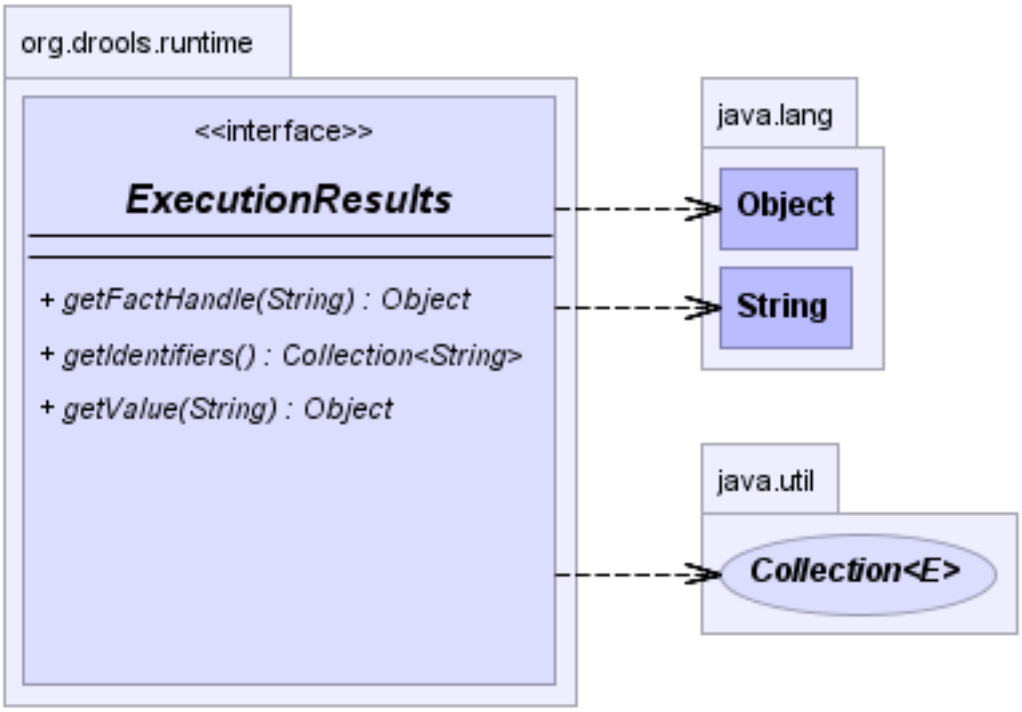


Figure 4.28. ExecutionResults

The `CommandFactory` allows for commands to be executed on those sessions, the only difference being that the Stateless Knowledge Session executes `fireAllRules()` at the end before disposing the session. The currently supported commands are:

- FireAllRules
- GetGlobal
- SetGlobal

- InsertObject
- InsertElements
- Query
- StartProcess
- BatchExecution

`InsertObject` will insert a single object, with an optional "out" identifier. `InsertElements` will iterate an Iterable, inserting each of the elements. What this means is that a Stateless Knowledge Session is no longer limited to just inserting objects, it can now start processes or execute queries, and do this in any order.

Example 4.38. Insert Command

```
StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();
ExecutionResults bresults =
  ksession.execute( CommandFactory.newInsert( new Cheese( "stilton" ), "stilton_id" ) );
Stilton stilton = bresults.getValue( "stilton_id" );
```

The execute method always returns an `ExecutionResults` instance, which allows access to any command results if they specify an out identifier such as the "stilton_id" above.

Example 4.39. InsertElements Command

```
StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();
Command cmd = CommandFactory.newInsertElements( Arrays.asList( Object[] {
                  new Cheese( "stilton" ),
                  new Cheese( "brie" ),
                  new Cheese( "cheddar" ),
              });
ExecutionResults bresults = ksession.execute( cmd );
```

The execute method only allows for a single command. That's where `BatchExecution` comes in, which represents a composite command, created from a list of commands. Now, execute will iterate over the list and execute each command in turn. This means you can insert some objects, start a process, call fireAllRules and execute a query, all in a single `execute(...)` call, which is quite powerful.

As mentioned previosly, the Stateless Knowledge Session will execute `fireAllRules()` automatically at the end. However the keen-eyed reader probably has already noticed the `FireAllRules` command and wondered how that works with a StatelessKnowledgeSession. The `FireAllRules` command is allowed, and using it will disable the automatic execution at the end; think of using it as a sort of manual override function.

Commands support out identifiers. Any command that has an out identifier set on it will add its results to the returned ExecutionResults instance. Let's look at a simple example to see how this works.

Example 4.40. BatchExecution Command

```
StatelessKnowledgeSession ksession = kbase.newStatelessKnowledgeSession();

List cmds = new ArrayList();
cmds.add( CommandFactory.newInsertObject( new Cheese( "stilton", 1), "stilton") );
cmds.add( CommandFactory.newStartProcess( "process cheeses" ) );
cmds.add( CommandFactory.newQuery( "cheeses" ) );
ExecutionResults bresults = ksession.execute( CommandFactory.newBatchExecution( cmds ) );
Cheese stilton = ( Cheese ) bresults.getValue( "stilton" );
QueryResults qresults = ( QueryResults ) bresults.getValue( "cheeses" );
```

In the above example multiple commands are executed, two of which populate the `ExecutionResults`. The query command defaults to use the same identifier as the query name, but it can also be mapped to a different identifier.

A custom XStream marshaller can be used with the Drools Pipeline to achieve XML scripting, which is perfect for services. Here are two simple XML samples, one for the BatchExecution and one for the `ExecutionResults`.

Example 4.41. Simple BatchExecution XML

```
<batch-execution>
   <insert out-identifier='outStilton'>
      <org.drools.Cheese>
         <type>stilton</type>
         <price>25</price>
         <oldPrice>0</oldPrice>
      </org.drools.Cheese>
   </insert>
</batch-execution>
```

Example 4.42. Simple ExecutionResults XML

```
<execution-results>
   <result identifier='outStilton'>
      <org.drools.Cheese>
         <type>stilton</type>
         <oldPrice>25</oldPrice>
         <price>30</price>
```

```
      </org.drools.Cheese>
   </result>
</execution-results>
```

Spring and Camel, covered in the integrations book, facilitate declarative services.

Example 4.43. BatchExecution Marshalled to XML

```
<batch-execution>
  <insert out-identifier="stilton">
    <org.drools.Cheese>
      <type>stilton</type>
      <price>1</price>
      <oldPrice>0</oldPrice>
    </org.drools.Cheese>
  </insert>
  <query out-identifier='cheeses2' name='cheesesWithParams'>
    <string>stilton</string>
    <string>cheddar</string>
  </query>
</batch-execution>
```

The `CommandExecutor` returns an `ExecutionResults`, and this is handled by the pipeline code snippet as well. A similar output for the <batch-execution> XML sample above would be:

Example 4.44. ExecutionResults Marshalled to XML

```
<execution-results>
  <result identifier="stilton">
    <org.drools.Cheese>
      <type>stilton</type>
      <price>2</price>
    </org.drools.Cheese>
  </result>
  <result identifier='cheeses2'>
    <query-results>
      <identifiers>
        <identifier>cheese</identifier>
      </identifiers>
      <row>
        <org.drools.Cheese>
          <type>cheddar</type>
          <price>2</price>
          <oldPrice>0</oldPrice>
        </org.drools.Cheese>
```

```
      </row>
      <row>
        <org.drools.Cheese>
          <type>cheddar</type>
          <price>1</price>
          <oldPrice>0</oldPrice>
        </org.drools.Cheese>
      </row>
    </query-results>
  </result>
</execution-results>
```

The `BatchExecutionHelper` provides a configured XStream instance to support the marshalling of Batch Executions, where the resulting XML can be used as a message format, as shown above. Configured converters only exist for the commands supported via the Command Factory. The user may add other converters for their user objects. This is very useful for scripting stateless or stateful knowledge sessions, especially when services are involved.

There is currently no XML schema to support schema validation. The basic format is outlined here, and the drools-pipeline module has an illustrative unit test in the `XStreamBatchExecutionTest` unit test. The root element is <batch-execution> and it can contain zero or more commands elements.

Example 4.45. Root XML element

```
<batch-execution>
...
</batch-execution>
```

This contains a list of elements that represent commands, the supported commands is limited to those Commands provided by the Command Factory. The most basic of these is the <insert> element, which inserts objects. The contents of the insert element is the user object, as dictated by XStream.

Example 4.46. Insert

```
<batch-execution>
   <insert>
      ...<!-- any user object -->
   </insert>
</batch-execution>
```

The insert element features an "out-identifier" attribute, demanding that the inserted object will also be returned as part of the result payload.

Example 4.47. Insert with Out Identifier Command

```
<batch-execution>
   <insert out-identifier='userVar'>
      ...
   </insert>
</batch-execution>
```

It's also possible to insert a collection of objects using the <insert-elements> element. This command does not support an out-identifier. The `org.domain.UserClass` is just an illustrative user object that XStream would serialize.

Example 4.48. Insert Elements command

```
<batch-execution>
   <insert-elements>
      <org.domain.UserClass>
         ...
      </org.domain.UserClass>
      <org.domain.UserClass>
         ...
      </org.domain.UserClass>
      <org.domain.UserClass>
         ...
      </org.domain.UserClass>
   </insert-elements>
</batch-execution>
```

Next, there is the `<set-global>` element, which sets a global for the session.

Example 4.49. Insert Elements command

```
<batch-execution>
   <set-global identifier='userVar'>
      <org.domain.UserClass>
         ...
      </org.domain.UserClass>
   </set-global>
</batch-execution>
```

`<set-global>` also supports two other optional attributes, `out` and `out-identifier`. A true value for the boolean `out` will add the global to the `<batch-execution-results>` payload, using the

name from the `identifier` attribute. `out-identifier` works like `out` but additionally allows you to override the identifier used in the `<batch-execution-results>` payload.

Example 4.50. Set Global Command

```
<batch-execution>
   <set-global identifier='userVar1' out='true'>
      <org.domain.UserClass>
         ...
      </org.domain.UserClass>
   </set-global>
   <set-global identifier='userVar2' out-identifier='alternativeUserVar2'>
      <org.domain.UserClass>
         ...
      </org.domain.UserClass>
   </set-global>
</batch-execution>
```

There is also a `<get-global>` element, without contents, with just an `out-identifier` attribute. (There is no need for an `out` attribute because retrieving the value is the sole purpose of a `<get-global>` element.

Example 4.51. Get Global Command

```
<batch-execution>
   <get-global identifier='userVar1' />
   <get-global identifier='userVar2' out-identifier='alternativeUserVar2'/>
</batch-execution>
```

While the `out` attribute is useful in returning specific instances as a result payload, we often wish to run actual queries. Both parameter and parameterless queries are supported. The `name` attribute is the name of the query to be called, and the `out-identifier` is the identifier to be used for the query results in the `<execution-results>` payload.

Example 4.52. Query Command

```
<batch-execution>
   <query out-identifier='cheeses' name='cheeses'/>
   <query out-identifier='cheeses2' name='cheesesWithParams'>
      <string>stilton</string>
      <string>cheddar</string>
   </query>
</batch-execution>
```

The `<start-process>` command accepts optional parameters. Other process related methods will be added later, like interacting with work items.

Example 4.53. Start Process Command

```
<batch-execution>
   <startProcess processId='org.drools.actions'>
      <parameter identifier='person'>
         <org.drools.TestVariable>
            <name>John Doe</name>
         </org.drools.TestVariable>
      </parameter>
   </startProcess>
</batch-execution
```

Example 4.54. Signal Event Command

```
<signal-event process-instance-id='1' event-type='MyEvent'>
   <string>MyValue</string>
</signal-event>
```

Example 4.55. Complete Work Item Command

```
<complete-work-item id='" + workItem.getId() + "' >
   <result identifier='Result'>
      <string>SomeOtherString</string>
   </result>
</complete-work-item>
```

Example 4.56. Abort Work Item Command

```
<abort-work-item id='21' />
```

Support for more commands will be added over time.

4.3.9. Marshalling

The `MarshallerFactory` is used to marshal and unmarshal Stateful Knowledge Sessions.

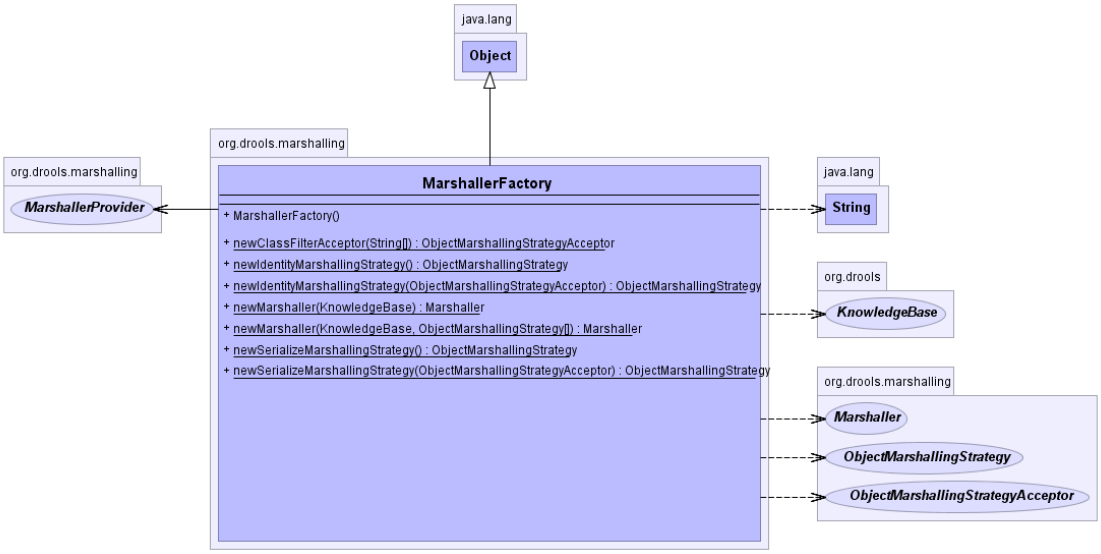


Figure 4.29. MarshallerFactory

At the simplest the `MarshallerFactory` can be used as follows:

Example 4.57. Simple Marshaller Example

```
// ksession is the StatefulKnowledgeSession
// kbase is the KnowledgeBase
ByteArrayOutputStream baos = new ByteArrayOutputStream();
Marshaller marshaller = MarshallerFactory.newMarshaller( kbase );
marshaller.marshall( baos, ksession );
baos.close();
```

However, with marshalling you need more flexibility when dealing with referenced user data. To achieve this we have the `ObjectMarshallingStrategy` interface. Two implementations are provided, but users can implement their own. The two supplied strategies are `IdentityMarshallingStrategy` and `SerializeMarshallingStrategy`. `SerializeMarshallingStrategy` is the default, as used in the example above, and it just calls the `Serializable` or `Externalizable` methods on a user instance. `IdentityMarshallingStrategy` instead creates an integer id for each user object and stores them in a Map, while the id is written to the stream. When unmarshalling it accesses the `IdentityMarshallingStrategy` map to retrieve the instance. This means that if you use the `IdentityMarshallingStrategy`, it is stateful for the life of the Marshaller instance and will create ids and keep references to all objects that it attempts to marshal. Below is he code to use an Identity Marshalling Strategy.

Example 4.58. IdentityMarshallingStrategy

```
ByteArrayOutputStream baos = new ByteArrayOutputStream();
```

```
ObjectMarshallingStrategy oms = MarshallerFactory.newIdentityMarshallingStrategy()
Marshaller marshaller =
  MarshallerFactory.newMarshaller( kbase, new ObjectMarshallingStrategy[]{ oms } );
marshaller.marshall( baos, ksession );
baos.close();
```

For added flexability we can't assume that a single strategy is suitable. Therefore we have added the `ObjectMarshallingStrategyAcceptor` interface that each Object Marshalling Strategy contains. The Marshaller has a chain of strategies, and when it attempts to read or write a user object it iterates the strategies asking if they accept responsability for marshalling the user object. One of the provided implementations is `ClassFilterAcceptor`. This allows strings and wild cards to be used to match class names. The default is "*.*", so in the above example the Identity Marshalling Strategy is used which has a default "*.*" acceptor.

Assuming that we want to serialize all classes except for one given package, where we will use identity lookup, we could do the following:

Example 4.59. IdentityMarshallingStrategy with Acceptor

```
ByteArrayOutputStream baos = new ByteArrayOutputStream();
ObjectMarshallingStrategyAcceptor identityAcceptor =
  MarshallerFactory.newClassFilterAcceptor( new String[] { "org.domain.pkg1.*" } );
ObjectMarshallingStrategy identityStrategy =
  MarshallerFactory.newIdentityMarshallingStrategy( identityAcceptor );
ObjectMarshallingStrategy sms = MarshallerFactory.newSerializeMarshallingStrategy();
Marshaller marshaller =
  MarshallerFactory.newMarshaller( kbase,
                                   new ObjectMarshallingStrategy[]{ identityStrategy, sms } );
marshaller.marshall( baos, ksession );
baos.close();
```

Note that the acceptance checking order is in the natural order of the supplied array.

4.3.10. Persistence and Transactions

Longterm out of the box persistence with Java Persistence API (JPA) is possible with Drools. You will need to have some implementation of the Java Transaction API (JTA) installed. For development purposes we recommend the Bitronix Transaction Manager, as it's simple to set up and works embedded, but for production use JBoss Transactions is recommended.

Example 4.60. Simple example using transactions

```
Environment env = KnowledgeBaseFactory.newEnvironment();
env.set( EnvironmentName.ENTITY_MANAGER_FACTORY,
         Persistence.createEntityManagerFactory( "emf-name" ) );
```

```
env.set( EnvironmentName.TRANSACTION_MANAGER,
         TransactionManagerServices.getTransactionManager() );

// KnowledgeSessionConfiguration may be null, and a default will be used
StatefulKnowledgeSession ksession =
  JPAKnowledgeService.newStatefulKnowledgeSession( kbase, null, env );
int sessionId = ksession.getId();

UserTransaction ut =
  (UserTransaction) new InitialContext().lookup( "java:comp/UserTransaction" );
ut.begin();
ksession.insert( data1 );
ksession.insert( data2 );
ksession.startProcess( "process1" );
ut.commit();
```

To use a JPA, the Environment must be set with both the `EntityManagerFactory` and the `TransactionManager`. If rollback occurs the ksession state is also rolled back, so you can continue to use it after a rollback. To load a previously persisted Stateful Knowledge Session you'll need the id, as shown below:

Example 4.61. Loading a StatefulKnowledgeSession

```
StatefulKnowledgeSession ksession =
  JPAKnowledgeService.loadStatefulKnowledgeSession( sessionId, kbase, null, env );
```

To enable persistence several classes must be added to your persistence.xml, as in the example below:

Example 4.62. Configuring JPA

```
<persistence-unit name="org.drools.persistence.jpa" transaction-type="JTA">
   <provider>org.hibernate.ejb.HibernatePersistence</provider>
   <jta-data-source>jdbc/BitronixJTADataSource</jta-data-source>
   <class>org.drools.persistence.session.SessionInfo</class>
   <class>org.drools.persistence.processinstance.ProcessInstanceInfo</class>
       <class>org.drools.persistence.processinstance.ProcessInstanceEventInfo</
class>
   <class>org.drools.persistence.processinstance.WorkItemInfo</class>
   <properties>

  <property name="hibernate.dialect" value="org.hibernate.dialect.H2Dialect"/>

        <property name="hibernate.max_fetch_depth" value="3"/>
        <property name="hibernate.hbm2ddl.auto" value="update" />
```

```
        <property name="hibernate.show_sql" value="true" />
        <property name="hibernate.transaction.manager_lookup_class"
              value="org.hibernate.transaction.BTMTransactionManagerLookup" />
   </properties>
</persistence-unit>
```

The jdbc JTA data source would have to be configured first. Bitronix provides a number of ways of doing this, and its documentation should be contsulted for details. For a quick start, here is the programmatic approach:

Example 4.63. Configuring JTA DataSource

```
PoolingDataSource ds = new PoolingDataSource();
ds.setUniqueName( "jdbc/BitronixJTADataSource" );
ds.setClassName( "org.h2.jdbcx.JdbcDataSource" );
ds.setMaxPoolSize( 3 );
ds.setAllowLocalTransactions( true );
ds.getDriverProperties().put( "user", "sa" );
ds.getDriverProperties().put( "password", "sasa" );
ds.getDriverProperties().put( "URL", "jdbc:h2:mem:mydb" );
ds.init();
```

Bitronix also provides a simple embedded JNDI service, ideal for testing. To use it add a jndi.properties file to your META-INF and add the following line to it:

Example 4.64. JNDI properties

```
java.naming.factory.initial=bitronix.tm.jndi.BitronixInitialContextFactory
```

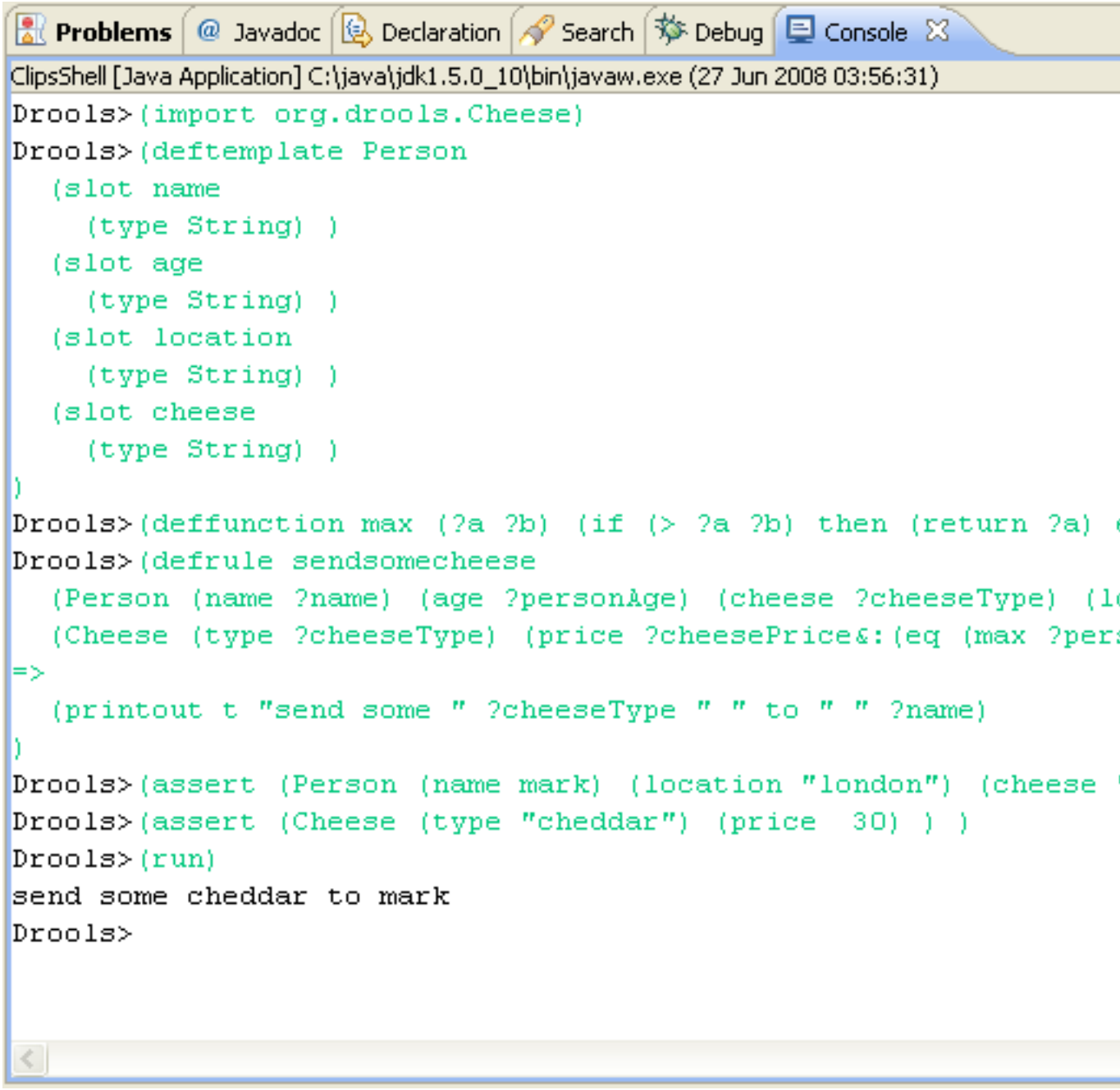
4.3.11. Drools Clips

Drools Clips is an alpha level research project to provide a Clips like front end ot Drools. As of Drools 5.2 this module as stopped working, we will try and fix for 5.3.

Deftemplates are working, the knowledge base handles multiple name spaces and you can attach the knoweldge base to the session for interative building, to provide a more "shell" like environment suitable for Clips.

- deftemplate
- defrule
- deffunction

- and/or/not/exists/test conditional elements
- Literal, Variable, Return Value and Predicate field constarints



This project is very early stages and in need of love. If you want to help, open up eclipse import api, core, compiler and clips and you should be good to go. The unit tests should be self explanatory.

Chapter 5. The Rule Language

5.1. Overview

Drools has a "native" rule language. This format is very light in terms of punctuation, and supports natural and domain specific languages via "expanders" that allow the language to morph to your problem domain. This chapter is mostly concerted with this native rule format. The diagrams used to present the syntax are known as "railroad" diagrams, and they are basically flow charts for the language terms. The technically very keen may also refer to `DRL.g` which is the Antlr3 grammar for the rule language. If you use the Rule Workbench, a lot of the rule structure is done for you with content assistance, for example, type "ru" and press ctrl+space, and it will build the rule structure for you.

5.1.1. A rule file

A rule file is typically a file with a .drl extension. In a DRL file you can have multiple rules, queries and functions, as well as some resource declarations like imports, globals and attributes that are assigned and used by your rules and queries. However, you are also able to spread your rules across multiple rule files (in that case, the extension .rule is suggested, but not required) - spreading rules across files can help with managing large numbers of rules. A DRL file is simply a text file.

The overall structure of a rule file is:

Example 5.1. Rules file

```
package package-name

imports

globals

functions

queries

rules
```

The order in which the elements are declared is not important, except for the package name that, if declared, must be the first element in the rules file. All elements are optional, so you will use only those you need. We will discuss each of them in the following sections.

5.1.2. What makes a rule

For the inpatients, just as an early view, a rule has the following rough structure:

```
rule "name"
    attributes
    when
        LHS
    then
        RHS
end
```

It's really that simple. Mostly punctuation is not needed, even the double quotes for "name" are optional, as are newlines. Attributes are simple (always optional) hints to how the rule should behave. LHS is the conditional parts of the rule, which follows a certain syntax which is covered below. RHS is basically a block that allows dialect specific semantic code to be executed.

It is important to note that white space is not important, *except* in the case of domain specific languages, where lines are processed one by one and spaces may be significant to the domain language.

5.2. Keywords

Drools 5 introduces the concept of *hard* and *soft* keywords.

Hard keywords are reserved, you cannot use any hard keyword when naming your domain objects, properties, methods, functions and other elements that are used in the rule text.

Here is the list of hard keywords that must be avoided as identifiers when writing rules:

- `true`
- `false`
- `null`

Soft keywords are just recognized in their context, enabling you to use these words in any other place if you wish, although, it is still recommended to avoid them, to avoid confusions, if possible. Here is a list of the soft keywords:

- `lock-on-active`
- `date-effective`
- `date-expires`
- `no-loop`
- `auto-focus`

- `activation-group`
- `agenda-group`
- `ruleflow-group`
- `entry-point`
- `duration`
- `package`
- `import`
- `dialect`
- `salience`
- `enabled`
- `attributes`
- `rule`
- `extend`
- when
- then
- `template`
- `query`
- `declare`
- `function`
- `global`
- `eval`
- `not`
- `in`
- `or`
- `and`
- `exists`
- `forall`

- accumulate
- collect
- from
- `action`
- `reverse`
- `result`
- `end`
- over
- `init`

Of course, you can have these (hard and soft) words as part of a method name in camel case, like notSomething() or accumulateSomething() - there are no issues with that scenario.

Although the 3 hard keywords above are unlikely to be used in your existing domain models, if you absolutely need to use them as identifiers instead of keywords, the DRL language provides the ability to escape hard keywords on rule text. To escape a word, simply enclose it in grave accents, like this:

```
Holiday( `true` == "yes" ) // please note that Drools will resolve that reference
 to the method Holiday.isTrue()
```

5.3. Comments

Comments are sections of text that are ignored by the rule engine. They are stripped out when they are encountered, except inside semantic code blocks, like the RHS of a rule.

5.3.1. Single line comment

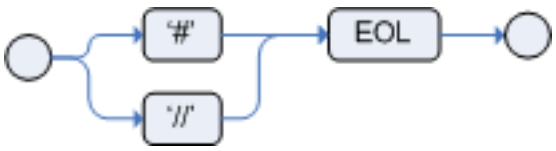


Figure 5.1. Single line comment

To create single line comments, you can use '//'. The parser will ignore anything in the line after the comment symbol. Example:

```
rule "Testing Comments"
```

```
when
    // this is a single line comment
    eval( true ) // this is a comment in the same line of a pattern
then
    // this is a comment inside a semantic code block
end
```

Warning

Drools also suppors for backward compatibility the use of '#' for single line comments, but this is deprecated and will be removed in future releases.

5.3.2. Multi-line comment

Figure 5.2. Multi-line comment

Multi-line comments are used to comment blocks of text, both in and outside semantic code blocks. Example:

```
rule "Test Multi-line Comments"
when
    /* this is a multi-line comment
       in the left hand side of a rule */
    eval( true )
then
    /* and this is a multi-line comment
       in the right hand side of a rule */
end
```

5.4. Error Messages

Drools 5 introduces standardized error messages. This standardization aims to help users to find and resolve problems in a easier and faster way. In this section you will learn how to identify and interpret those error messages, and you will also receive some tips on how to solve the problems associated with them.

5.4.1. Message format

The standardization includes the error message format and to better explain this format, let's use the following example:

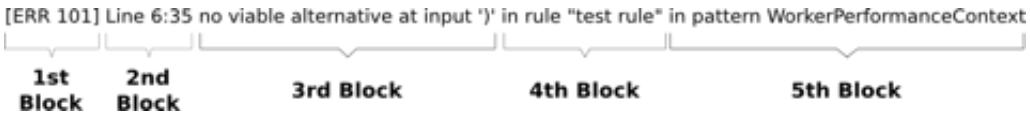


Figure 5.3. Error Message Format

1st Block: This area identifies the error code.

2nd Block: Line and column information.

3rd Block: Some text describing the problem.

4th Block: This is the first context. Usually indicates the rule, function, template or query where the error occurred. This block is not mandatory.

5th Block: Identifies the pattern where the error occurred. This block is not mandatory.

5.4.2. Error Messages Description

5.4.2.1. 101: No viable alternative

Indicates the most common errors, where the parser came to a decision point but couldn't identify an alternative. Here are some examples:

Example 5.2.

```
1: rule one
2:   when
3:     exists Foo()
4:     exits Bar()
5:   then
6: end
```

The above example generates this message:

- [ERR 101] Line 4:4 no viable alternative at input 'exits' in rule one

At first glance this seems to be valid syntax, but it is not (exits != exists). Let's take a look at next example:

Example 5.3.

```
1: package org.drools;
2: rule
3:   when
4:     Object()
5:   then
```

```
6:     System.out.println("A RHS");
7: end
```

Now the above code generates this message:

- [ERR 101] Line 3:2 no viable alternative at input 'WHEN'

This message means that the parser encountered the token **WHEN**, actually a hard keyword, but it's in the wrong place since the the rule name is missing.

The error "no viable alternative" also occurs when you make a simple lexical mistake. Here is a sample of a lexical problem:

Example 5.4.

```
1: rule simple_rule
2:   when
3:     Student( name == "Andy )
4:   then
5: end
```

The above code misses to close the quotes and because of this the parser generates this error message:

- [ERR 101] Line 0:-1 no viable alternative at input '<eof>' in rule simple_rule in pattern Student

Note

Usually the Line and Column information are accurate, but in some cases (like unclosed quotes), the parser generates a 0:-1 position. In this case you should check whether you didn't forget to close quotes, apostrophes or parentheses.

5.4.2.2. 102: Mismatched input

This error indicates that the parser was looking for a particular symbol that it didn’t #nd at the current input position. Here are some samples:

Example 5.5.

```
1: rule simple_rule
2:   when
3:     foo3 : Bar(
```

The above example generates this message:

- [ERR 102] Line 0:-1 mismatched input '<eof>' expecting ')' in rule simple_rule in pattern Bar

To fix this problem, it is necessary to complete the rule statement.

Note

Usually when you get a 0:-1 position, it means that parser reached the end of source.

The following code generates more than one error message:

Example 5.6.

```
1: package org.drools;
2:
3: rule "Avoid NPE on wrong syntax"
4:   when
5:      not( Cheese( ( type == "stilton", price == 10 ) || ( type == "brie",
 price == 15 ) ) from $cheeseList )
6:   then
7:     System.out.println("OK");
8: end
```

These are the errors associated with this source:

- [ERR 102] Line 5:36 mismatched input ',' expecting ')' in rule "Avoid NPE on wrong syntax" in pattern Cheese
- [ERR 101] Line 5:57 no viable alternative at input 'type' in rule "Avoid NPE on wrong syntax"
- [ERR 102] Line 5:106 mismatched input ')' expecting 'then' in rule "Avoid NPE on wrong syntax"

Note that the second problem is related to the first. To fix it, just replace the commas (',') by AND operator ('&&').

Note

In some situations you can get more than one error message. Try to fix one by one, starting at the first one. Some error messages are generated merely as consequences of other errors.

5.4.2.3. 103: Failed predicate

A validating semantic predicate evaluated to false. Usually these semantic predicates are used to identify soft keywords. This sample shows exactly this situation:

Example 5.7.

```
 1: package nesting;
 2: dialect "mvel"
 3:
 4: import org.drools.Person
 5: import org.drools.Address
 6:
 7: fdsfdsfds
 8:
 9: rule "test something"
10:   when
11:     p: Person( name=="Michael" )
12:   then
13:     p.name = "other";
14:     System.out.println(p.name);
15: end
```

With this sample, we get this error message:

- [ERR 103] Line 7:0 rule 'rule_key' failed predicate: {(validateIdentifierKey(DroolsSoftKeywords.RULE))}? in rule

The **fdsfdsfds** text is invalid and the parser couldn't identify it as the soft keyword `rule`.

Note

This error is very similar to 102: Mismatched input, but usually involves soft keywords.

5.4.2.4. 104: Trailing semi-colon not allowed

This error is associated with the `eval` clause, where its expression may not be terminated with a semicolon. Check this example:

Example 5.8.

```
1: rule simple_rule
2:   when
```

```
3:     eval(abc();)
4:   then
5: end
```

Due to the trailing semicolon within eval, we get this error message:

- [ERR 104] Line 3:4 trailing semi-colon not allowed in rule simple_rule

This problem is simple to fix: just remove the semi-colon.

5.4.2.5. 105: Early Exit

The recognizer came to a subrule in the grammar that must match an alternative at least once, but the subrule did not match anything. Simply put: the parser has entered a branch from where there is no way out. This example illustrates it:

Example 5.9.

```
1: template test_error
2:   aa s  11;
3: end
```

This is the message associated to the above sample:

- [ERR 105] Line 2:2 required (...)+ loop did not match anything at input 'aa' in template test_error

To fix this problem it is necessary to remove the numeric value as it is neither a valid data type which might begin a new template slot nor a possible start for any other rule file construct.

5.4.3. Other Messages

Any other message means that something bad has happened, so please contact the development team.

5.5. Package

A package is a collection of rules and other related constructs, such as imports and globals. The package members are typically related to each other - perhaps HR rules, for instance. A package represents a namespace, which ideally is kept unique for a given grouping of rules. The package name itself is the namespace, and is not related to files or folders in any way.

It is possible to assemble rules from multiple rule sources, and have one top level package configuration that all the rules are kept under (when the rules are assembled). Although, it is not possible to merge into the same package resources declared under different names. A single

Rulebase may, however, contain multiple packages built on it. A common structure is to have all the rules for a package in the same file as the package declaration (so that is it entirely self-contained).

The following railroad diagram shows all the components that may make up a package. Note that a package *must* have a namespace and be declared using standard Java conventions for package names; i.e., no spaces, unlike rule names which allow spaces. In terms of the order of elements, they can appear in any order in the rule file, with the exception of the `package` statement, which must be at the top of the file. In all cases, the semicolons are optional.

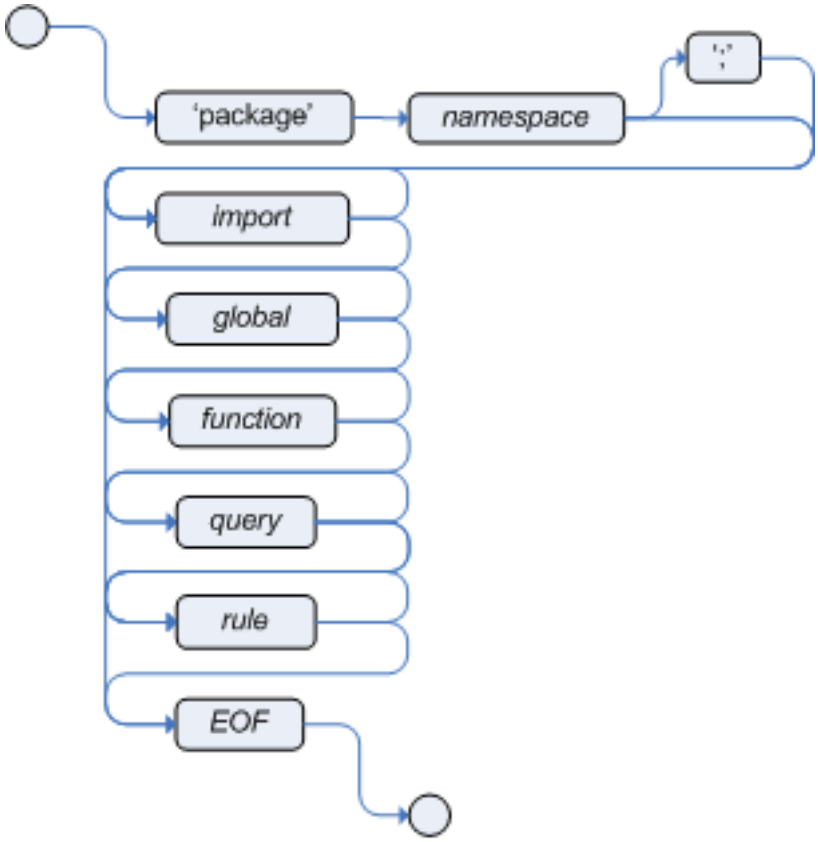


Figure 5.4. package

Notice that any rule atttribute (as described the section Rule Attributes) may also be written at package level, superseding the attribute's default value. The modified default may still be replaced by an attribute setting within a rule.

5.5.1. import

Figure 5.5. import

Import statements work like import statements in Java. You need to specify the fully qualified paths and type names for any objects you want to use in the rules. Drools automatically imports classes from the Java package of the same name, and also from the package `java.lang`.

5.5.2. global

Figure 5.6. global

With `global` you define global variables. They are used to make application objects available to the rules. Typically, they are used to provide data or services that the rules use, especially application services used in rule consequences, and to return data from the rules, like logs or values added in rule consequences, or for the rules to interact with the application, doing callbacks. Globals are not inserted into the Working Memory, and therefore a global should never be used to establish conditions in rules except when it has a constant immutable value. The engine cannot be notified about value changes of globals and does not track their changes. Incorrect use of globals in constraints may yield surprising results - surprising in a bad way.

If multiple packages declare globals with the same identifier they must be of the same type and all of them will reference the same global value.

In order to use globals you must:

1. Declare your global variable in your rules file and use it in rules. Example:

```
global java.util.List myGlobalList;

rule "Using a global"
when
    eval( true )
then
    myGlobalList.add( "Hello World" );
end
```

2. Set the global value on your working memory. It is a best practice to set all global values before asserting any fact to the working memory. Example:

```
List list = new ArrayList();
WorkingMemory wm = rulebase.newStatefulSession();
wm.setGlobal( "myGlobalList", list );
```

Note that these are just named instances of objects that you pass in from your application to the working memory. This means you can pass in any object you want: you could pass in a service locator, or perhaps a service itself. With the new `from` element it is now common to pass a Hibernate session as a global, to allow `from` to pull data from a named Hibernate query.

One example may be an instance of a Email service. In your integration code that is calling the rule engine, you obtain your emailService object, and then set it in the working memory. In the DRL, you declare that you have a global of type EmailService, and give it the name "email". Then in your rule consequences, you can use things like email.sendSMS(number, message).

Globals are not designed to share data between rules and they should never be used for that purpose. Rules always reason and react to the working memory state, so if you want to pass data from rule to rule, assert the data as facts into the working memory.

It is strongly discouraged to set or change a global value from inside your rules. We recommend to you always set the value from your application using the working memory interface.

5.6. Function

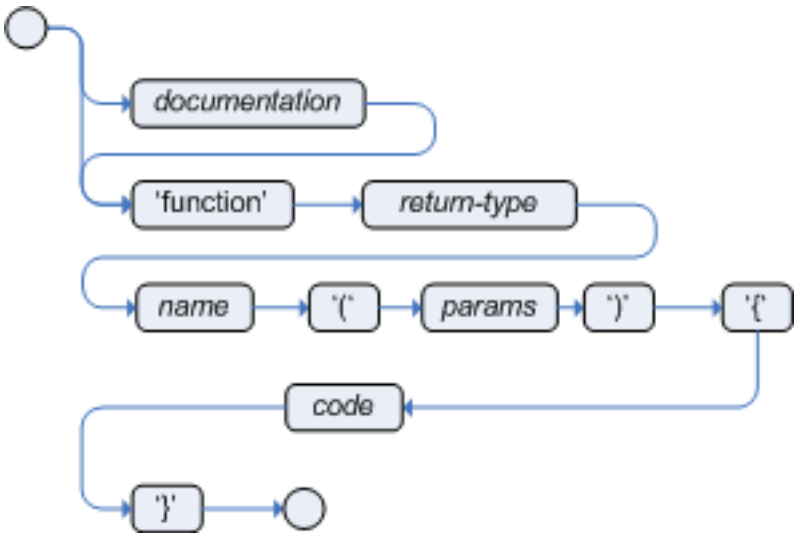


Figure 5.7. function

Functions are a way to put semantic code in your rule source file, as opposed to in normal Java classes. They can't do anything more than what you can do with helper classes. (In fact, the compiler generates the helper class for you behind the scenes.) The main advantage of using functions in a rule is that you can keep the logic all in one place, and you can change the functions as needed (which can be a good or a bad thing). Functions are most useful for invoking actions on the consequence (`then`) part of a rule, especially if that particular action is used over and over again, perhaps with only differing parameters for each rule.

A typical function declaration looks like:

```
function String hello(String name) {
```

```
    return "Hello "+name+"!";
}
```

Note that the `function` keyword is used, even though its not really part of Java. Parameters to the function are defined as for a method, and you don't have to have parameters if they are not needed. The return type is defined just like in a regular method.

Alternatively, you could use a static method in a helper class, e.g., `Foo.hello()`. Drools supports the use of function imports, so all you would need to do is:

```
import function my.package.Foo.hello
```

Irrespective of the way the function is defined or imported, you use a function by calling it by its name, in the consequence or inside a semantic code block. Example:

```
rule "using a static function"
when
    eval( true )
then
    System.out.println( hello( "Bob" ) );
end
```

5.7. Type Declaration

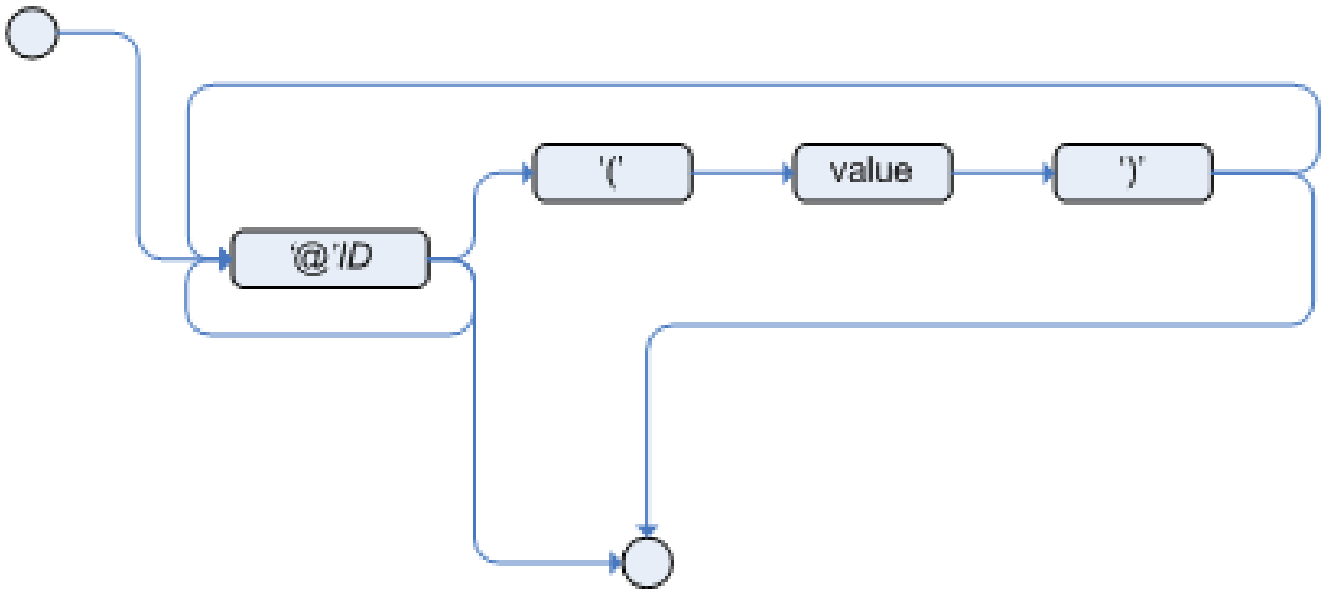


Figure 5.8. meta_data

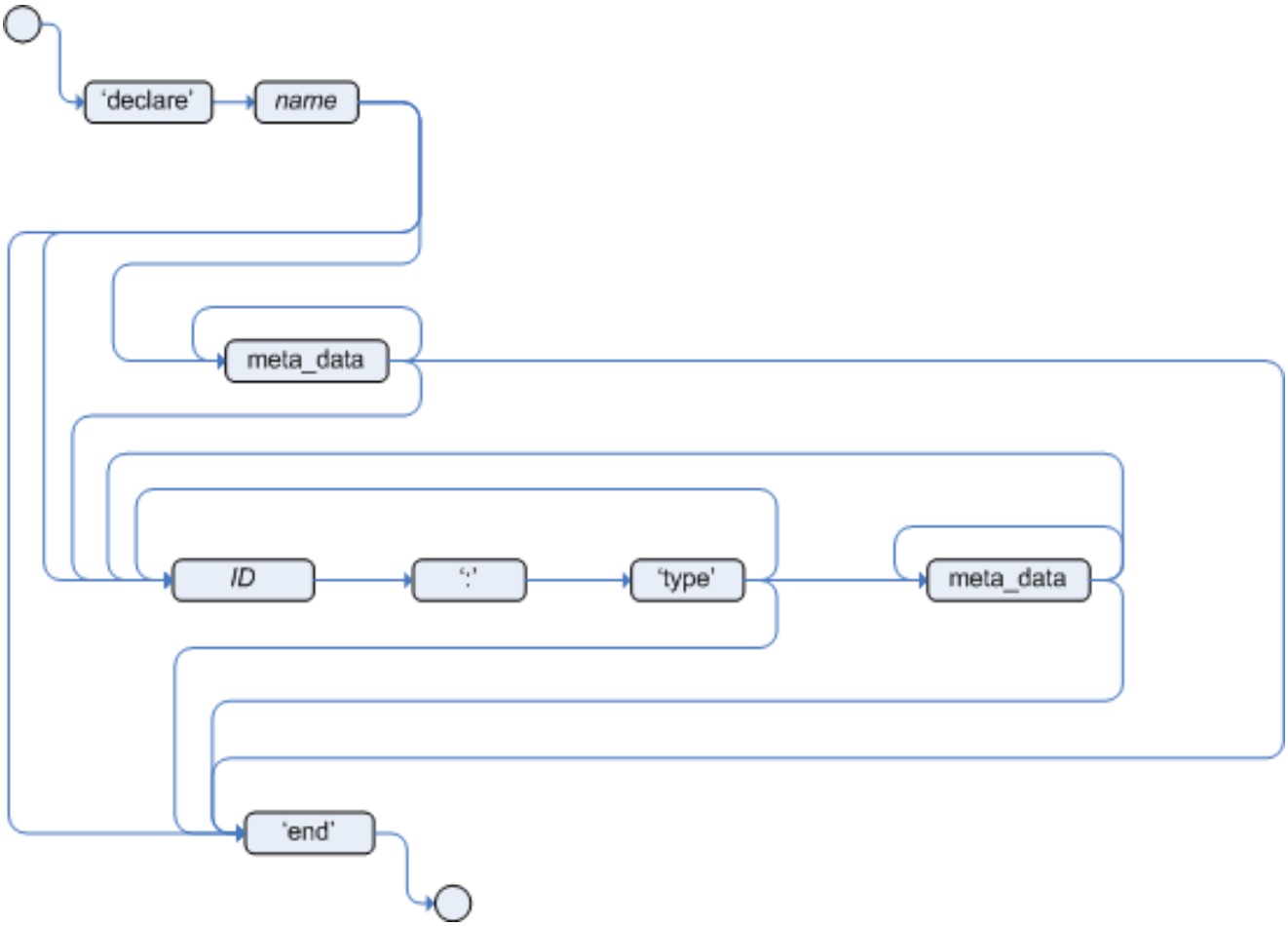


Figure 5.9. type_declaration

Type declarations have two main goals in the rules engine: to allow the declaration of new types, and to allow the declaration of metadata for types.

- **Declaring new types:** Drools works out of the box with plain Java objects as facts. Sometimes, however, users may want to define the model directly to the rules engine, without worrying about creating models in a lower level language like Java. At other times, there is a domain model already built, but eventually the user wants or needs to complement this model with additional entities that are used mainly during the reasoning process.
- **Declaring metadata:** facts may have meta information associated to them. Examples of meta information include any kind of data that is not represented by the fact attributes and is consistent among all instances of that fact type. This meta information may be queried at runtime by the engine and used in the reasoning process.

5.7.1. Declaring New Types

To declare a new type, all you need to do is use the keyword `declare`, followed by the list of fields, and the keyword `end`.

Example 5.10. Declaring a new fact type: Address

```
declare Address
   number : int
   streetName : String
   city : String
end
```

The previous example declares a new fact type called `Address`. This fact type will have three attributes: `number`, `streetName` and `city`. Each attribute has a type that can be any valid Java type, including any other class created by the user or even other fact types previously declared.

For instance, we may want to declare another fact type `Person`:

Example 5.11. declaring a new fact type: Person

```
declare Person
    name : String
    dateOfBirth : java.util.Date
    address : Address
end
```

As we can see on the previous example, `dateOfBirth` is of type `java.util.Date`, from the Java API, while `address` is of the previously defined fact type Address.

You may avoid having to write the fully qualified name of a class every time you write it by using the `import` clause, as previously discussed.

Example 5.12. Avoiding the need to use fully qualified class names by using import

```
import java.util.Date

declare Person
    name : String
    dateOfBirth : Date
    address : Address
end
```

When you declare a new fact type, Drools will, at compile time, generate bytecode that implements a Java class representing the fact type. The generated Java class will be a one-to-one Java Bean mapping of the type definition. So, for the previous example, the generated Java class would be:

Example 5.13. generated Java class for the previous Person fact type declaration

```
public class Person implements Serializable {
    private String name;
    private java.util.Date dateOfBirth;
    private Address address;

    // empty constructor
    public Person() {...}

    // constructor with all fields
    public Person( String name, Date dateOfBirth, Address address ) {...}

    // if keys are defined, constructor with keys
    public Person( ...keys... ) {...}

    // getters and setters
    // equals/hashCode
    // toString
}
```

Since the generated class is a simple Java class, it can be used transparently in the rules, like any other fact.

Example 5.14. Using the declared types in rules

```
rule "Using a declared Type"
when
    $p : Person( name == "Bob" )
then
    // Insert Mark, who is Bob's mate.
    Person mark = new Person();
    mark.setName("Mark");
    insert( mark );
end
```

5.7.2. Declaring Metadata

Metadata may be assigned to several different constructions in Drools: fact types, fact attributes and rules. Drools uses the at sign ('@') to introduce metadata, and it always uses the form:

```
@metadata_key( metadata_value )
```

The parenthesized *metadata_value* is optional.

For instance, if you want to declare a metadata attribute like `author`, whose value is *Bob*, you could simply write:

Example 5.15. Declaring a metadata attribute

```
@author( Bob )
```

Drools allows the declaration of any arbitrary metadata attribute, but some will have special meaning to the engine, while others are simply available for querying at runtime. Drools allows the declaration of metadata both for fact types and for fact attributes. Any metadata that is declared before the attributes of a fact type are assigned to the fact type, while metadata declared after an attribute are assigned to that particular attribute.

Example 5.16. Declaring metadata attributes for fact types and attributes

```
import java.util.Date

declare Person
    @author( Bob )
    @dateOfCreation( 01-Feb-2009 )

    name : String @key @maxLength( 30 )
    dateOfBirth : Date
    address : Address
end
```

In the previous example, there are two metadata items declared for the fact type (`@author` and `@dateOfCreation`) and two more defined for the name attribute (`@key` and `@maxLength`). Please note that the `@key` metadata has no required value, and so the parentheses and the value were omitted.:

@position can be used to declare the position of a field, overriding the default declared order. This is used for positional constraints in patterns.

```
declare Cheese
    name : String @position(1)
    shop : String @position(2)
    price : int @position(0)
end
```

5.7.2.1. Predefined class level annotations

Some annotations have predefined semantics that are interpreted by the engine. The following is a list of some of these predefined annotations and their meaning.

5.7.2.1.1. @role(<fact | event>)

See Drools Fusion documentation for details.

5.7.2.1.2. @typesafe(<boolean>)

By default all type declarations are compiled with type safety enabled; @typesafe(false) provides a means to override this behaviour by permitting a fall-back, to type unsafe evaluation where all constraints are generated as MVEL constraints and executed dynamically. This can be important when dealing with collections that do not have any generics or mixed type collections.

5.7.2.1.3. @timestamp(<attribute name>)

See Drools Fusion documentation for details.

5.7.2.1.4. @duration(<attribute name>)

See Drools Fusion documentation for details.

5.7.2.1.5. @expires(<time interval>)

See Drools Fusion documentation for details.

5.7.2.1.6. @propertyChangeSupport

Facts that implement support for property changes as defined in the Javabean(tm) spec, now can be annotated so that the engine register itself to listen for changes on fact properties. The boolean parameter that was used in the insert() method in the Drools 4 API is deprecated and does not exist in the drools-api module.

Example 5.17. @propertyChangeSupport

```
declare Person
  @propertyChangeSupport
end
```

5.7.2.2. Predefined attribute level annotations

As noted before, Drools also supports annotations in type attributes. Here is a list of predefined attribute annotations.

5.7.2.2.1. @key

Declaring an attribute as a key attribute has 2 major effects on generated types:

1. The attribute will be used as a key identifier for the type, and as so, the generated class will implement the equals() and hashCode() methods taking the attribute into account when comparing instances of this type.

2. Drools will generate a constructor using all the key attributes as parameters.

For instance:

Example 5.18. example of @key declarations for a type

```
declare Person
    firstName : String @key
    lastName : String @key
    age : int
end
```

For the previous example, Drools will generate equals() and hashCode() methods that will check the firstName and lastName attributes to determine if two instances of Person are equal to each other, but will not check the age attribute. It will also generate a constructutor taking firstName and lastName as parameters, allowing one to create instances with a code like this:

Example 5.19. creating an instance using the key constructor

```
Person person = new Person( "John", "Doe" );
```

5.7.2.2.2. @position

Patterns support positional arguments on type declarations.

Positional arguments are ones where you don't need to specify the field name, as the position maps to a known named field. i.e. Person(name == "mark") can be rewritten as Person("mark";). The semicolon ';' is important so that the engine knows that everything before it is a positional argument. Otherwise we might assume it was a boolean expression, which is how it could be interpretted after the semicolon. You can mix positional and named arguments on a pattern by using the semicolon ';' to separate them. Any variables used in a positional that have not yet been bound will be bound to the field that maps to that position.

```
declare Cheese
    name : String
    shop : String
```

```
    price : int
end
```

The default order is the declared order, but this can be overiden using @position

```
declare Cheese
    name : String @position(1)
    shop : String @position(2)
    price : int @position(0)
end
```

The @Position annotation, in the org.drools.definition.type package, can be used to annotate original pojos on the classpath. Currently only fields on classes can be annotated. Inheritence of classes is supported, but not interfaces of methods yet.

Example patterns, with two constraints and a binding. Remember semicolon ';' is used to differentiate the positional section from the named argument section. Variables and literals and expressions using just literals are supported in posional arguments, but not variables.

```
Cheese( "stilton", "Cheese Shop", p; )
Cheese( "stilton", "Cheese Shop"; p : price )
Cheese( "stilton"; shop == "Cheese Shop", p : price )
Cheese( name == "stilton"; shop == "Cheese Shop", p : price )
```

5.7.3. Declaring Metadata for Existing Types

Drools allows the declaration of metadata attributes for existing types in the same way as when declaring metadata attributes for new fact types. The only difference is that there are no fields in that declaration.

For instance, if there is a class org.drools.examples.Person, and one wants to declare metadata for it, it's possible to write the following code:

Example 5.20. Declaring metadata for an existing type

```
import org.drools.examples.Person

declare Person
    @author( Bob )
    @dateOfCreation( 01-Feb-2009 )
end
```

Instead of using the import, it is also possible to reference the class by its fully qualified name, but since the class will also be referenced in the rules, it is usually shorter to add the import and use the short class name everywhere.

Example 5.21. Declaring metadata using the fully qualified class name

```
declare org.drools.examples.Person
    @author( Bob )
    @dateOfCreation( 01-Feb-2009 )
end
```

5.7.4. Parameterized constructors for declared types

Generate constructors with parameters for declared types.

Example: for a declared type like the following:

```
declare Person
    firstName : String @key
    lastName : String @key
    age : int
end
```

The compiler will implicitly generate 3 constructors: one without parameters, one with the @key fields, and one with all fields.

```
Person() // parameterless constructor
Person( String firstName, String lastName )
Person( String firstName, String lastName, int age )
```

5.7.5. Non Typesafe Classes

@typesafe(<boolean>) has been added to type declarations. By default all type declarations are compiled with type safety enabled; @typesafe(false) provides a means to override this behaviour by permitting a fall-back, to type unsafe evaluation where all constraints are generated as MVEL constraints and executed dynamically. This can be important when dealing with collections that do not have any generics or mixed type collections.

5.7.6. Accessing Declared Types from the Application Code

Declared types are usually used inside rules files, while Java models are used when sharing the model between rules and applications. Although, sometimes, the application may need to access

and handle facts from the declared types, especially when the application is wrapping the rules engine and providing higher level, domain specific user interfaces for rules management.

In such cases, the generated classes can be handled as usual with the Java Reflection API, but, as we know, that usually requires a lot of work for small results. Therefore, Drools provides a simplified API for the most common fact handling the application may want to do.

The first important thing to realize is that a declared fact will belong to the package where it was declared. So, for instance, in the example below, `Person` will belong to the `org.drools.examples` package, and so the fully qualified name of the generated class will be `org.drools.examples.Person`.

Example 5.22. Declaring a type in the org.drools.examples package

```
package org.drools.examples

import java.util.Date

declare Person
    name : String
    dateOfBirth : Date
    address : Address
end
```

Declared types, as discussed previously, are generated at knowledge base compilation time, i.e., the application will only have access to them at application run time. Therefore, these classes are not available for direct reference from the application.

Drools then provides an interface through which users can handle declared types from the application code: `org.drools.definition.type.FactType`. Through this interface, the user can instantiate, read and write fields in the declared fact types.

Example 5.23. Handling declared fact types through the API

```
// get a reference to a knowledge base with a declared type:
KnowledgeBase kbase = ...

// get the declared FactType
FactType personType = kbase.getFactType( "org.drools.examples",
                                         "Person" );

// handle the type as necessary:
// create instances:
Object bob = personType.newInstance();

// set attributes values
```

```
personType.set( bob,
                "name",
                "Bob" );
personType.set( bob,
                "age",
                42 );

// insert fact into a session
StatefulKnowledgeSession ksession = ...
ksession.insert( bob );
ksession.fireAllRules();

// read attributes
String name = personType.get( bob, "name" );
int age = personType.get( bob, "age" );
```

The API also includes other helpful methods, like setting all the attributes at once, reading values from a Map, or reading all attributes at once, into a Map.

Although the API is similar to Java reflection (yet much simpler to use), it does not use reflection underneath, relying on much more performant accessors implemented with generated bytecode.

5.7.7. Type Declaration 'extends'

Type declarations now support 'extends' keyword for inheritance

In order to extend a type declared in Java by a DRL declared subtype, repeat the supertype in a declare statement without any fields.

```
import org.people.Person

declare Person
end

declare Student extends Person
    school : String
end

declare LongTermStudent extends Student
    years : int
    course : String
end
```

5.8. Rule

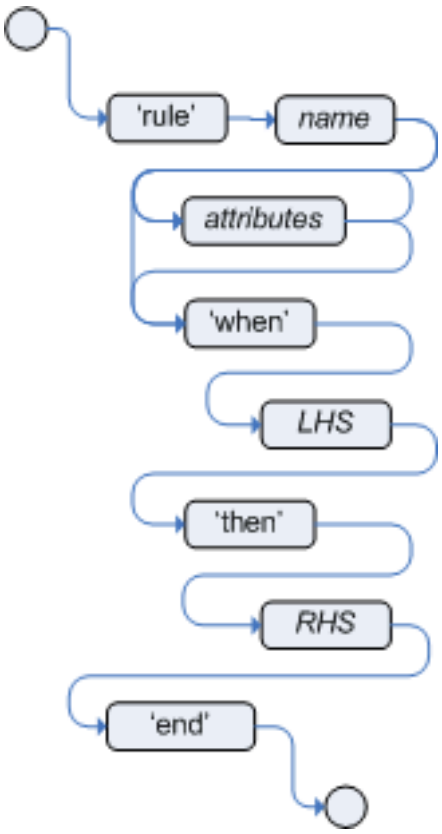


Figure 5.10. rule

A rule specifies that *when* a particular set of conditions occur, specified in the Left Hand Side (LHS), *then* do what queryis specified as a list of actions in the Right Hand Side (RHS). A common question from users is "Why use when instead of if?" "When" was chosen over "if" because "if" is normally part of a procedural execution flow, where, at a specific point in time, a condition is to be checked. In contrast, "when" indicates that the condition evaluation is not tied to a specific evaluation sequence or point in time, but that it happens continually, at any time during the life time of the engine; whenever the condition is met, the actions are executed.

A rule must have a name, unique within its rule package. If you define a rule twice in the same DRL it produces an error while loading. If you add a DRL that includes a rule name already in the package, it replaces the previous rule. If a rule name is to have spaces, then it will need to be enclosed in double quotes (it is best to always use double quotes).

Attributes - described below - are optional. They are best written one per line.

The LHS of the rule follows the `when` keyword (ideally on a new line), similarly the RHS follows the `then` keyword (again, ideally on a newline). The rule is terminated by the keyword `end`. Rules cannot be nested.

Example 5.24. Rule Syntax Overview

```
rule "<name>"
    <attribute>*
when
    <conditional element>*
then
    <action>*
end
```

Example 5.25. A simple rule

```
rule "Approve if not rejected"
  salience -100
  agenda-group "approval"
    when
        not Rejection()
        p : Policy(approved == false, policyState:status)
        exists Driver(age > 25)
        Process(status == policyState)
    then
        log("APPROVED: due to no objections.");
        p.setApproved(true);
end
```

5.8.1. Rule Attributes

Rule attributes provide a declarative way to influence the behavior of the rule. Some are quite simple, while others are part of complex subsystems such as ruleflow. To get the most from Drools you should make sure you have a proper understanding of each attribute.

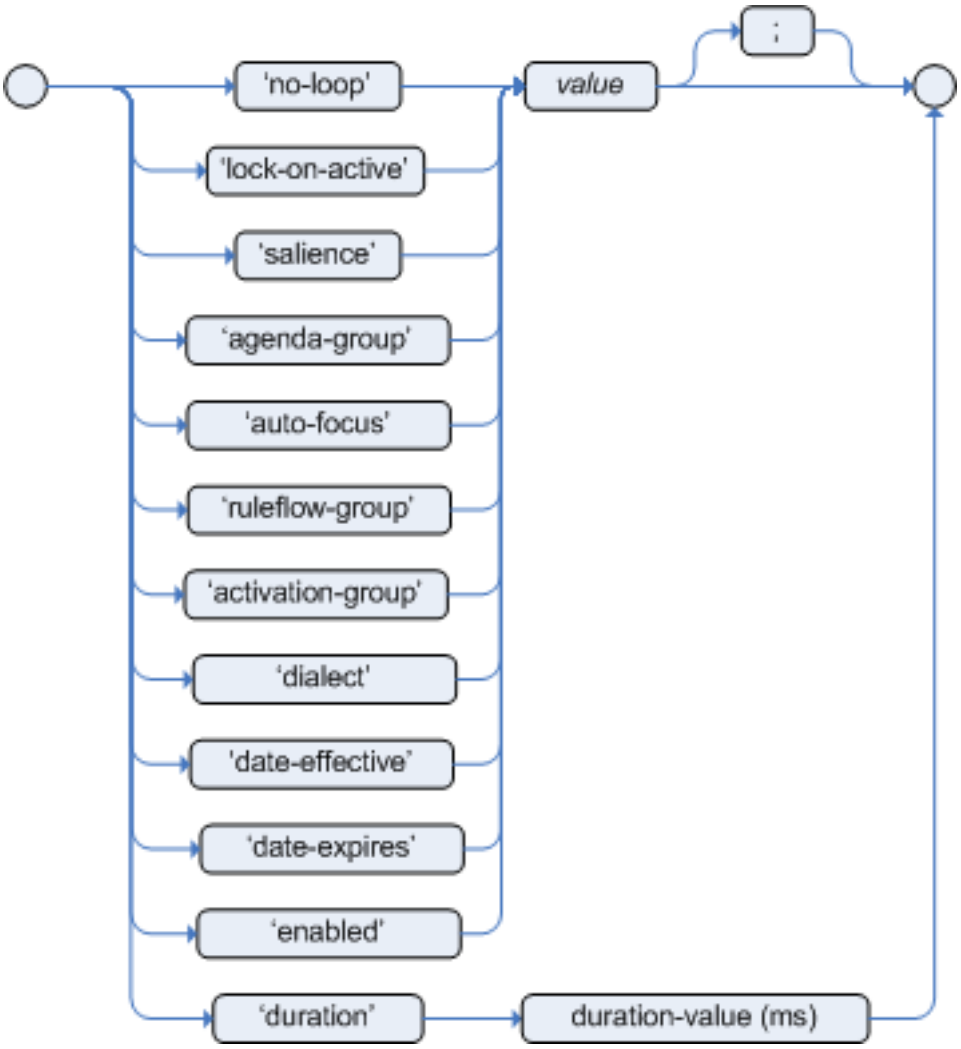


Figure 5.11. rule attributes

`no-loop`
default value: `false`

type: Boolean

When a rule's consequence modifies a fact it may cause the rule to activate again, causing an infinite loop. Setting no-loop to true will skip the creation of another Activation for the rule with the current set of facts.

`ruleflow-group`
default value: N/A

type: String

Ruleflow is a Drools feature that lets you exercise control over the firing of rules. Rules that are assembled by the same ruleflow-group identifier fire only when their group is active.

`lock-on-active`
default value: `false`

type: Boolean

Whenever a ruleflow-group becomes active or an agenda-group receives the focus, any rule within that group that has lock-on-active set to true will not be activated any more; irrespective of the origin of the update, the activation of a matching rule is discarded. This is a stronger version of no-loop, because the change could now be caused not only by the rule itself. It's ideal for calculation rules where you have a number of rules that modify a fact and you don't want any rule re-matching and firing again. Only when the ruleflow-group is no longer active or the agenda-group loses the focus those rules with lock-on-active set to true become eligible again for their activations to be placed onto the agenda.

`salience`
default value: `0`

type: integer

Each rule has an integer salience attribute which defaults to zero and can be negative or positive. Salience is a form of priority where rules with higher salience values are given higher priority when ordered in the Activation queue.

Drools also supports dynamic salience where you can use an expression involving bound variables.

Example 5.26. Dynamic Salience

```
rule "Fire in rank order 1,2,.."
        salience( -$rank )
    when
        Element( $rank : rank,... )
    then
        ...
end
```

`agenda-group`
default value: MAIN

type: String

Agenda groups allow the user to partition the Agenda providing more execution control. Only rules in the agenda group that has acquired the focus are allowed to fire.

`auto-focus`
default value: `false`

type: Boolean

When a rule is activated where the `auto-focus` value is true and the rule's agenda group does not have focus yet, then it is given focus, allowing the rule to potentially fire.

`activation-group`
default value: N/A

type: String

Rules that belong to the same activation-group, identified by this attribute's string value, will only fire exclusively. In other words, the first rule in an activation-group to fire will cancel the other rules' activations, i.e., stop them from firing.

Note: This used to be called Xor group, but technically it's not quite an Xor. You may still hear people mention Xor group; just swap that term in your mind with activation-group.

`dialect`
default value: as specified by the package

type: String

possible values: "java" or "mvel"

The dialect species the language to be used for any code expressions in the LHS or the RHS code block. Currently two dialects are available, Java and MVEL. While the dialect can be specified at the package level, this attribute allows the package definition to be overridden for a rule.

`date-effective`
default value: N/A

type: String, containing a date and time definition

A rule can only activate if the current date and time is after date-effective attribute.

`date-expires`
default value: N/A

type: String, containing a date and time definition

A rule cannot activate if the current date and time is after the date-expires attribute.

`duration`
default value: no default value

type: long

The duration dictates that the rule will fire after a specified duration, if it is still true.

Example 5.27. Some attribute examples

```
rule "my rule"
  salience 42
  agenda-group "number 1"
    when ...
```

5.8.2. Timers and Calendars

Rules now suport both interval and cron based timers, which replace the now deprecated duration attribute.

Example 5.28. Sample timer attribute uses

```
timer ( int: <initial delay> <repeat interval>? )
timer ( int: 30s )
timer ( int: 30s 5m )

timer ( cron: <cron expression> )
timer ( cron:* 0/15 * * * ? )
```

Interval (indicated by "int:") timers follow the semantics of java.util.Timer objects, with an initial delay and an optional repeat interval. Cron (indicated by "cron:") timers follow standard Unix cron expressions:

Example 5.29. A Cron Example

```
rule "Send SMS every 15 minutes"
    timer (cron:* 0/15 * * * ?)
when
    $a : Alarm( on == true )
then
   channels[ "sms" ].insert( new Sms( $a.mobileNumber, "The alarm is still on" );
end
```

Calendars are used to control when rules can fire. The Calendar API is modelled on *Quartz* [http://www.quartz-scheduler.org/]:

Example 5.30. Adapting a Quartz Calendar

```
Calendar weekDayCal = QuartzHelper.quartzCalendarAdapter(org.quartz.Calendar quartzCal)
```

Calendars are registered with the StatefulKnowledgeSession:

Example 5.31. Registering a Calendar

```
ksession.getCalendars().set( "weekday", weekDayCal );
```

They can be used in conjunction with normal rules and rules including timers. The rule attribute "calendars" may contain one or more comma-separated calendar names written as string literals.

Example 5.32. Using Calendars and Timers together

```
rule "weekdays are high priority"
   calendars "weekday"
   timer (int:0 1h)
when
    Alarm()
then
    send( "priority high - we have an alarm# );
end

rule "weekend are low priority"
   calendars "weekend"
   timer (int:0 4h)
when
    Alarm()
then
    send( "priority low - we have an alarm# );
end
```

5.8.3. Left Hand Side (when) syntax

5.8.3.1. What is the Left Hand Side?

The Left Hand Side (LHS) is a common name for the conditional part of the rule. It consists of zero or more Conditional Elements. If the LHS is empty, it will be considered as a condition element that is always true and it will be activated once, when a new WorkingMemory session is created.

Figure 5.12. Left Hand Side

Example 5.33. Rule without a Conditional Element

```
rule "no CEs"
when
    // empty
then
    ... // actions (executed once)
end

# The above rule is internally rewritten as:

rule "eval(true)"
when
    eval( true )
then
    ... // actions (executed once)
end
```

Conditional elements work on one or more *patterns* (which are described below). The most common conditional element is `"and"`. Therefore it is implicit when you have multiple patterns in the LHS of a rule that are not connected in any way:

Example 5.34. Implicit and

```
rule "2 unconnected patterns"
when
    Pattern1()
    Pattern2()
then
    ... // actions
end

# The above rule is internally rewritten as:

rule "2 and connected patterns"
when
    Pattern1()
    and Pattern2()
then
    ... // actions
end
```

Note

An "`and`" cannot have a leading declaration binding (unlike for example `or`). This is obvious, since a declaration can only reference a single fact at a time, and when the "`and`" is satisfied it matches both facts - so which fact would the declaration bind to?

```
// Compile error
$person : (Person( name == "Romeo" ) and Person( name == "Juliet"))
```

5.8.3.2. Pattern (conditional element)

5.8.3.2.1. What is a pattern?

A pattern element is the most important Conditional Element. It can potentially match on each fact that is inserted in the working memory.

A pattern contains of zero or more constraints and has an optional pattern binding. The railroad diagram below shows the syntax for this.

Figure 5.13. Pattern

In its simplest form, with no constraints, a pattern matches against a fact of the given type. In the following case the type is `Cheese`, which means that the pattern will match against all `Person` objects in the Working Memory:

```
Person()
```

The type need not be the actual class of some fact object. Patterns may refer to superclasses or even interfaces, thereby potentially matching facts from many different classes.

```
Object() // matches all objects in the working memory
```

Inside of the pattern parenthesis is where all the action happens: it defines the constraints for that pattern. For example, with a age related constraint:

```
Person( age == 100 )
```

Note

For backwards compatibility reasons it's allowed to suffix patterns with the `;` character. But it is not recommended to do that.

5.8.3.2.2. Pattern binding

For referring to the matched object, use a pattern binding variable such as `$p`.

Example 5.35. Pattern with a binding variable

```
rule ...
when
    $p : Person()
then
    System.out.println( "Person " + $p );
end
```

The prefixed dollar symbol (`$`) is just a convention; it can be useful in complex rules where it helps to easily differentiate between variables and fields, but it is not mandatory.

5.8.3.3. Constraint (part of a pattern)

5.8.3.3.1. What is a constraint?

A constraint is an expression that returns `true` or `false`. This example has a constraint that states *5 is smaller than 6*:

```
Person( 5 < 6 )  // just an example, as constraints like this would be useless
 in a real pattern
```

In essence, it's a Java expression with some enhancements (such as property access) and a few differences (such as `equals()` semantics for `==`). Let's take a deeper look.

5.8.3.3.2. Property access on Java Beans (POJO's)

Any bean property can be used directly. A bean property is exposed using a standard Java bean getter: a method `getMyProperty()` (or `isMyProperty()` for a primitive boolean) which takes no arguments and return something. For example: the age property is written as `age` in DRL instead of the getter `getAge()`:

```
Person( age == 50 )

// this is the same as:
Person( getAge() == 50 )
```

Drools uses the standard JDK `Introspector` class to do this mapping, so it follows the standard Java bean specification.

Note

We recommend using property access (`age`) over using getters explicitly (`getAge()`) because of performance enhancements through field indexing.

Warning

Property accessors must not change the state of the object in a way that may effect the rules. Remember that the rule engine effectively caches the results of its matching in between invocations to make it faster.

```
public int getAge() {
    age++; // Do NOT do this
    return age;
}
```

```
public int getAge() {
    Date now = DateUtil.now(); // Do NOT do this
    return DateUtil.differenceInYears(now, birthday);
}
```

To solve this latter case, insert a fact that wraps the current date into working memory and update that fact between `fireAllRules` as needed.

Note

The following fallback applies: if the getter of a property cannot be found, the compiler will resort to using the property name as a method name and without arguments:

```
Person( age == 50 )

// If Person.getAge() does not exists, this falls back to:
Person( age() == 50 )
```

Nested property access is also supported:

```
Person( address.houseNumber == 50 )

// this is the same as:
Person( getAddress().getHouseNumber() == 50 )
```

Nested properties are also indexed.

Warning

In a stateful session, care should be taken when using nested accessors as the Working Memory is not aware of any of the nested values, and does not know when they change. Either consider them immutable while any of their parent references are inserted into the Working Memory. Or, instead, if you wish to modify a nested value you should mark all of the outer facts as updated. In the above example, when the `houseNumber` changes, any `Person` with that `Address` must be marked as updated.

5.8.3.3.3. Java expression

You can use any Java expression that returns a `boolean` as a constraint inside the parentheses of a pattern. Java expressions can be mixed with other expression enhancements, such as property access:

```
Person( age == 50 )
```

It is possible to change the evaluation priority by using parentheses, as in any logic or mathematical expression:

```
Person( age > 100 && ( age % 10 == 0 ) )
```

It is possible to reuse Java methods:

```
Person( Math.round( weight / ( height * height ) ) < 25.0 )
```

Warning

As for property accessors, methods must not change the state of the object in a way that may affect the rules. Any method executed on a fact in the LHS should be a *read only* method.

```
Person( incrementAndGetAge() == 10 ) // Do NOT do this
```

Warning

The state of a fact should not change between rule invocations (unless those facts are marked as updated to the working memory on every change):

```
Person( System.currentTimeMillis() % 1000 == 0 ) // Do NOT do this
```

Normal Java operator precedence applies, see the operator precedence list below.

Important

All operators have normal Java semantics except for == and `!=`.

The == operator has null-safe `equals()` semantics:

```
// Similar to: java.util.Objects.equals(person.getFirstName(),
 "John")
// so (because "John" is not null) similar to:
// "John".equals(person.getFirstName())
Person( firstName == "John" )
```

The `!=` operator has null-safe `!equals()` semantics:

```
// Similar to: !java.util.Objects.equals(person.getFirstName(),
 "John")
```

```
Person( firstName != "John" )
```

Type coercion is always attempted if the field and the value are of different types; exceptions will be thrown if a bad coercion is attempted. For instance, if "ten" is provided as a string in a numeric evaluator, an exception is thrown, whereas "10" would coerce to a numeric 10. Coercion is always in favor of the field type and not the value type:

```
Person( age == "10" ) // "10" is coerced to 10
```

5.8.3.3.4. Comma separated AND

The comma character (',') is used to separate constraint groups. It has implicit *AND* connective semantics.

```
// Person is at least 50 and weighs at least 80 kg
Person( age > 50, weight > 80 )
```

```
// Person is at least 50, weighs at least 80 kg and is taller than 2 meter.
Person( age > 50, weight > 80, height > 2 )
```

Note

Although the `&&` and `,` operators have the same semantics, they are resolved with different priorities: The `&&` operator precedes the `||` operator. Both the `&&` and `||` operator precede the `,` operator. See the operator precedence list below.

The comma operator should be preferred at the top level constraint, as it makes constraints easier to read and the engine will often be able to optimize them better.

The comma (`,`) operator cannot be embedded in a composite constraint expression, such as parentheses:

```
Person( ( age > 50, weight > 80 ) || height > 2 ) // Do NOT do this: compile error

// Use this instead
Person( ( age > 50 && weight > 80 ) || height > 2 )
```

5.8.3.3.5. Binding variables

A property can be bound to a variable:

```
// 2 persons of the same age
Person( $firstAge : age ) // binding
Person( age == $firstAge ) // constraint expression
```

The prefixed dollar symbol ($) is just a convention; it can be useful in complex rules where it helps to easily differentiate between variables and fields.

Note

For backwards compatibility reasons, It's allowed (but not recommended) to mix a constraint binding and constraint expressions as such:

```
// Not recommended
Person( $age : age * 2 < 100 )
```

```
// Recommended (seperates bindings and constraint expressions)
Person( age * 2 < 100, $age : age )
```

Bound variable restrictions using the operator == provide for very fast execution as it use hash indexing to improve performance.

5.8.3.3.6. Unification

Drools does not allow bindings to the same declaration. However this is an important aspect to derivation query unification. While positional arguments are always processed with unification a special unification symbol, ':=', was introduced for named arguments named arguments. The following "unifies" the age argument across two people.

```
Person( $age := age )
Person( $age := age)
```

In essence unification will declare a binding for the first occurance, and constrain to the same value of the bound field for sequence occurances.

5.8.3.3.7. Special literal support

Besides normal Java literals (including Java 5 enums), this literal is also supported:

5.8.3.3.7.1. Date literal

The date format `dd-mmm-yyyy` is supported by default. You can customize this by providing an alternative date format mask as the System property named `drools.dateformat`. If more control is required, use a restriction.

Example 5.36. Date Literal Restriction

```
Cheese( bestBefore < "27-Oct-2009" )
```

5.8.3.3.8. List and Map access

It's possible to directly access a `List` value by index:

```
// Same as childList(0).getAge() == 18
Person( childList[0].age == 18 )
```

It's also possible to directly access a `Map` value by key:

```
// Same as credentialMap.get("jsmith").isValid()
Person( credentialMap["jsmith"].valid )
```

5.8.3.3.9. Abbreviated combined relation condition

This allows you to place more than one restriction on a field using the restriction connectives `&&` or `||`. Grouping via parentheses is permitted, resulting in a recursive syntax pattern.

Figure 5.14. Abbreviated combined relation condition

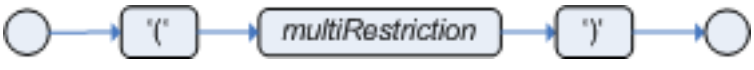


Figure 5.15. Abbreviated combined relation condition with parentheses

```
// Simple abbreviated combined relation condition using a single &&
```

```
Person( age > 30 && < 40 )
```

```
// Complex abbreviated combined relation using groupings
Person( age ( (> 30 && < 40) ||
              (> 20 && < 25) ) )
```

```
// Mixing abbreviated combined relation with constraint connectives
Person( age > 30 && < 40 || location == "london" )
```

5.8.3.3.10. Special DRL operators

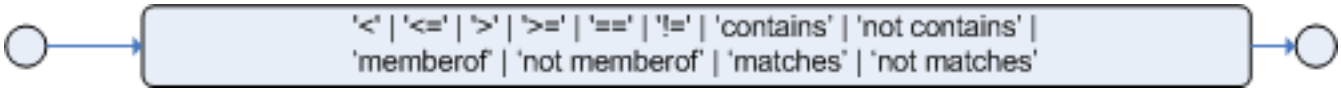


Figure 5.16. Operators

Coercion to the correct value for the evaluator and the field will be attempted.

5.8.3.3.10.1. The operators `<` `<=` `>` `>=`

These operators can be used on properties with natural ordering. For example, for Date fields, `<` means *before*, for `String` fields, it means alphabetically lower.

```
Person( firstName < $otherFirstName )
```

```
Person( birthDate < $otherBirthDate )
```

Only applies on `Comperable` properties.

5.8.3.3.10.2. The operator `matches`

Matches a field against any valid Java Regular Expression. Typically that regexp is a string literal, but variables that resolve to a valid regexp are also allowed.

Example 5.37. Regular Expression Constraint

```
Cheese( type matches "(Buffalo)?\\S*Mozarella" )
```

Note

Like in Java, regular expressions written as string literals *need to escape* '\'.

Only applies on `String` properties.

5.8.3.3.10.3. The operator `not matches`

The operator returns true if the String does not match the regular expression. The same rules apply as for the `matches` operator. Example:

Example 5.38. Regular Expression Constraint

```
Cheese( type not matches "(Buffulo)?\\S*Mozarella" )
```

Only applies on `String` properties.

5.8.3.3.10.4. The operator `contains`

The operator `contains` is used to check whether a field that is a Collection or array contains the specified value.

Example 5.39. Contains with Collections

```
CheeseCounter( cheeses contains "stilton" ) // contains with a String literal
CheeseCounter( cheeses contains $var ) // contains with a variable
```

Only applies on `Collection` properties.

5.8.3.3.10.5. The operator `not contains`

The operator `not contains` is used to check whether a field that is a Collection or array does *not* contain the specified value.

Example 5.40. Literal Constraint with Collections

```
CheeseCounter( cheeses not contains "cheddar" ) // not contains with a String
 literal
CheeseCounter( cheeses not contains $var ) // not contains with a variable
```

Only applies on `Collection` properties.

Note

For backward compatibility, the `excludes` operator is supported as a synonym for `not contains`.

5.8.3.3.10.6. The operator `memberOf`

The operator `memberOf` is used to check whether a field is a member of a collection or array; that collection must be a variable.

Example 5.41. Literal Constraint with Collections

```
CheeseCounter( cheese memberOf $matureCheeses )
```

5.8.3.3.10.7. The operator `not memberOf`

The operator `not memberOf` is used to check whether a field is not a member of a collection or array; that collection must be a variable.

Example 5.42. Literal Constraint with Collections

```
CheeseCounter( cheese not memberOf $matureCheeses )
```

5.8.3.3.10.8. The operator `soundslike`

This operator is similar to `matches`, but it checks whether a word has almost the same sound (using English pronunciation) as the given value. This is based on the Soundex algorithm (see `http://en.wikipedia.org/wiki/Soundex`).

Example 5.43. Test with soundslike

```
// match cheese "fubar" or "foobar"
Cheese( name soundslike 'foobar' )
```

5.8.3.3.10.9. The operator `str`

This operator `str` is used to check whether a field that is a `String` starts with or ends with a certain value. It can also be used to check the length of the String.

```
Message( routingValue str[startsWith] "R1" )
```

```
Message( routingValue str[endsWith] "R2" )
```

```
Message( routingValue str[length] 17 )
```

5.8.3.3.10.10. The operators `in` and `not in` (compound value restriction)

The compound value restriction is used where there is more than one possible value to match. Currently only the `in` and `not in` evaluators support this. The second operand of this operator must be a comma-separated list of values, enclosed in parentheses. Values may be given as variables, literals, return values or qualified identifiers. Both evaluators are actually *syntactic sugar*, internally rewritten as a list of multiple restrictions using the operators `!=` and `==`.

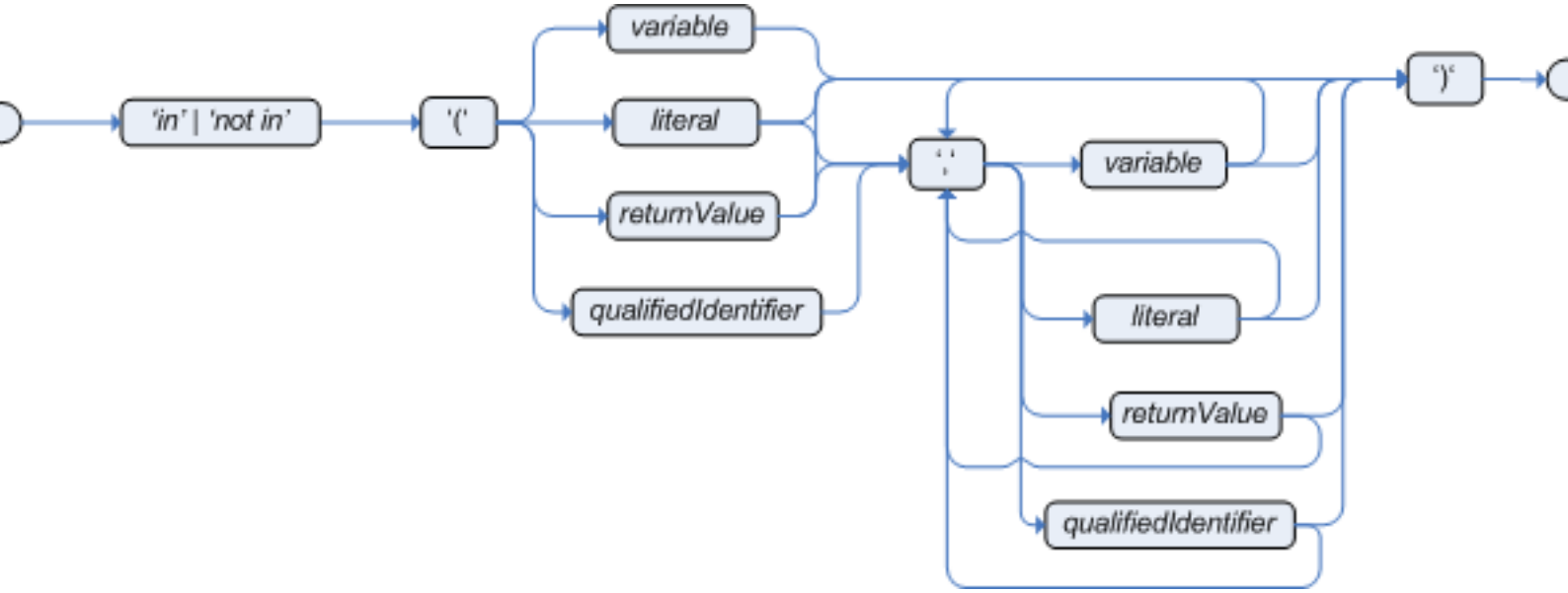


Figure 5.17. compoundValueRestriction

Example 5.44. Compound Restriction using "in"

```
Person( $cheese : favouriteCheese )
Cheese( type in ( "stilton", "cheddar", $cheese ) )
```

5.8.3.3.11. Inline eval operator (deprecated)

Figure 5.18. Inline Eval Expression

An inline eval constraint can use any valid dialect expression as long as it results to a primitive boolean. The expression must be constant over time. Any previously bound variable, from the current or previous pattern, can be used; autovivification is also used to auto-create field binding variables. When an identifier is found that is not a current variable, the builder looks to see if the identifier is a field on the current object type, if it is, the field binding is auto-created as a variable of the same name. This is called autovivification of field variables inside of inline eval's.

This example will find all male-female pairs where the male is 2 years older than the female; the variable `age` is auto-created in the second pattern by the autovivification process.

Example 5.45. Return Value operator

```
Person( girlAge : age, sex = "F" )
Person( eval( age == girlAge + 2 ), sex = 'M' ) // eval() is actually obselete
 in this example
```

Note

Inline eval's are effectively obsolete as their inner syntax is now directly supported. It's recommended not to use them. Simply write the expression without wrapping eval() around it.

5.8.3.3.12. Operator precedence

The operators are evaluated in this precedence:

Table 5.1. Operator precedence

Operator type	Operators	Notes
(nested) property access	`.`	Not normal Java semantics
List/Map access	`[ ]`	Not normal Java semantics
constraint binding	`:`	Not normal Java semantics
multiplicative	`* / %`	
additive	`+ -`	
shift	`<< >> >>>`	
relational	`< > <= >= instanceof`	
equality	`== !=`	Does not use normal Java (*not*) *same* semantics: uses (*not*) *equals* semantics instead.
non-short circuiting AND	`&`	

Operator type	Operators	Notes
non-short circuiting exclusive OR	^	
non-short circuiting inclusive OR	|	
logical AND	&&	
logical OR	||	
ternary	? :	
Comma separated AND	,	Not normal Java semantics

5.8.3.4. Positional Arguments

Patterns now support positional arguments on type declarations.

Positional arguments are ones where you don't need to specify the field name, as the position maps to a known named field. i.e. Person(name == "mark") can be rewritten as Person("mark";). The semicolon ';' is important so that the engine knows that everything before it is a positional argument. Otherwise we might assume it was a boolean expression, which is how it could be interpretted after the semicolon. You can mix positional and named arguments on a pattern by using the semicolon ';' to separate them. Any variables used in a positional that have not yet been bound will be bound to the field that maps to that position.

```
declare Cheese
    name : String
    shop : String
    price : int
end
```

Example patterns, with two constraints and a binding. Remember semicolon ';' is used to differentiate the positional section from the named argument section. Variables and literals and expressions using just literals are supported in posional arguments, but not variables. Positional arguments are always resolved using unification.

```
Cheese( "stilton", "Cheese Shop", p; )
Cheese( "stilton", "Cheese Shop"; p : price )
Cheese( "stilton"; shop == "Cheese Shop", p : price )
Cheese( name == "stilton"; shop == "Cheese Shop", p : price )
```

Positional arguments that are given a previously declared binding will consrain against that using unification; these are referred to as input arguments. If the binding does not yet exist, it will create the declaration binding it to the field represented by the position argument; these are referred to as output arguments.

5.8.3.5. Basic conditional elements

5.8.3.5.1. Conditional Element `and`

The Conditional Element `"and"` is used to group other Conditional Elements into a logical conjunction. Drools supports both prefix `and` and infix `and`.

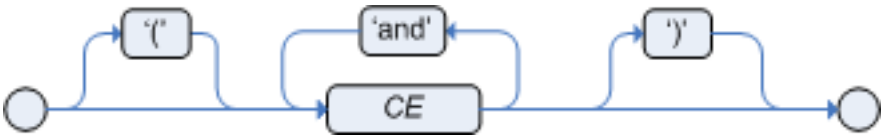


Figure 5.19. infixAnd

Traditional infix `and` is supported:

```
//infixAnd
Cheese( cheeseType : type ) and Person( favouriteCheese == cheeseType )
```

Explicit grouping with parentheses is also supported:

```
//infixAnd with grouping
( Cheese( cheeseType : type ) and
  ( Person( favouriteCheese == cheeseType ) or
    Person( favouriteCheese == cheeseType ) )
```

Note

The symbol `&&` (as an alternative to `and`) is deprecated. But it is still supported in the syntax for backwards compatibility.

Figure 5.20. prefixAnd

Prefix `and` is also supported:

```
(and Cheese( cheeseType : type )
     Person( favouriteCheese == cheeseType ) )
```

The root element of the LHS is an implicit prefix `and` and doesn't need to be specified:

Example 5.46. implicit root prefixAnd

```
when
    Cheese( cheeseType : type )
    Person( favouriteCheese == cheeseType )
then
    ...
```

5.8.3.5.2. Conditional Element `or`

The Conditional Element `or` is used to group other Conditional Elements into a logical disjunction. Drools supports both prefix `or` and infix `or`.

Figure 5.21. infixOr

Traditional infix `or` is supported:

```
//infixOr
Cheese( cheeseType : type ) or Person( favouriteCheese == cheeseType )
```

Explicit grouping with parentheses is also supported:

```
//infixOr with grouping
( Cheese( cheeseType : type ) or
  ( Person( favouriteCheese == cheeseType ) and
    Person( favouriteCheese == cheeseType ) )
```

Note

The symbol `||` (as an alternative to `or`) is deprecated. But it is still supported in the syntax for backwards compatibility.

Figure 5.22. prefixOr

Prefix `or` is also supported:

```
(or Person( sex == "f", age > 60 )
    Person( sex == "m", age > 65 )
```

Note

The behavior of the Conditional Element `or` is different from the connective `||` for constraints and restrictions in field constraints. The engine actually has no understanding of the Conditional Element `or`. Instead, via a number of different logic transformations, a rule with `or` is rewritten as a number of subrules. This process ultimately results in a rule that has a single `or` as the root node and one subrule for each of its CEs. Each subrule can activate and fire like any normal rule; there is no special behavior or interaction between these subrules. - This can be most confusing to new rule authors.

The Conditional Element `or` also allows for optional pattern binding. This means that each resulting subrule will bind its pattern to the pattern binding. Each pattern must be bound separately, using eponymous variables:

```
pensioner : ( Person( sex == "f", age > 60 ) or Person( sex == "m", age > 65 ) )
```

```
(or pensioner : Person( sex == "f", age > 60 )
    pensioner : Person( sex == "m", age > 65 ) )
```

Since the conditional element `or` results in multiple subrule generation, one for each possible logically outcome, the example above would result in the internal generation of two rules. These two rules work independently within the Working Memory, which means both can match, activate and fire - there is no shortcutting.

The best way to think of the conditional element `or` is as a shortcut for generating two or more similar rules. When you think of it that way, it's clear that for a single rule there could be multiple activations if two or more terms of the disjunction are true.

5.8.3.5.3. Conditional Element `not`

Figure 5.23. not

The CE `not` is first order logic's non-existential quantifier and checks for the non-existence of something in the Working Memory. Think of "not" as meaning "there must be none of...".

The keyword `not` may be followed by parentheses around the CEs that it applies to. In the simplest case of a single pattern (like below) you may optionally omit the parentheses.

Example 5.47. No Busses

```
not Bus()
```

Example 5.48. No red Busses

```
// Brackets are optional:
not Bus(color == "red")
// Brackets are optional:
not ( Bus(color == "red", number == 42) )
// "not" with nested infix and - two patterns,
// brackets are requires:
not ( Bus(color == "red") and
      Bus(color == "blue") )
```

5.8.3.5.4. Conditional Element `exists`

Figure 5.24. exists

The CE `exists` is first order logic's existential quantifier and checks for the existence of something in the Working Memory. Think of "exists" as meaning "there is at least one..". It is different from just having the pattern on its own, which is more like saying "for each one of...". If you use `exists` with a pattern, the rule will only activate at most once, regardless of how much data there is in working memory that matches the condition inside of the `exists` pattern. Since only the existence matters, no bindings will be established.

The keyword `exists` must be followed by parentheses around the CEs that it applies to. In the simplest case of a single pattern (like below) you may omit the parentheses.

Example 5.49. At least one Bus

```
exists Bus()
```

Example 5.50. At least one red Bus

```
exists Bus(color == "red")
// brackets are optional:
exists ( Bus(color == "red", number == 42) )
// "exists" with nested infix and,
// brackets are required:
exists ( Bus(color == "red") and
         Bus(color == "blue") )
```

5.8.3.6. Advanced conditional elements

5.8.3.6.1. Conditional Element `forall`

Figure 5.25. forall

The Conditional Element `forall` completes the First Order Logic support in Drools. The Conditional Element `forall` evaluates to true when all facts that match the first pattern match all the remaining patterns. Example:

```
rule "All English buses are red"
when
    forall( $bus : Bus( type == 'english')
                   Bus( this == $bus, color = 'red' ) )
then
    # all english buses are red
end
```

In the above rule, we "select" all Bus objects whose type is "english". Then, for each fact that matches this pattern we evaluate the following patterns and if they match, the forall CE will evaluate to true.

To state that all facts of a given type in the working memory must match a set of constraints, `forall` can be written with a single pattern for simplicity. Example:

Example 5.51. Single Pattern Forall

```
rule "All Buses are Red"
when
    forall( Bus( color == 'red' ) )
then
    # all asserted Bus facts are red
end
```

Another example shows multiple patterns inside the `forall`:

Example 5.52. Multi-Pattern Forall

```
rule "all employees have health and dental care programs"
when
    forall( $emp : Employee()
            HealthCare( employee == $emp )
            DentalCare( employee == $emp )
          )
then
    # all employees have health and dental care
end
```

Forall can be nested inside other CEs. For instance, `forall` can be used inside a `not` CE. Note that only single patterns have optional parentheses, so that with a nested `forall` parentheses must be used:

Example 5.53. Combining Forall with Not CE

```
rule "not all employees have health and dental care"
when
    not ( forall( $emp : Employee()
                  HealthCare( employee == $emp )
                  DentalCare( employee == $emp ) )
        )
then
    # not all employees have health and dental care
end
```

As a side note, `forall( p1 p2 p3...)` is equivalent to writing:

```
not(p1 and not(and p2 p3...))
```

Also, it is important to note that `forall` is a *scope delimiter*. Therefore, it can use any previously bound variable, but no variable bound inside it will be available for use outside of it.

5.8.3.6.2. Conditional Element `from`

Figure 5.26. from

The Conditional Element `from` enables users to specify an arbitrary source for data to be matched by LHS patterns. This allows the engine to reason over data not in the Working Memory. The data source could be a sub-field on a bound variable or the results of a method call. It is a powerful construction that allows out of the box integration with other application components and frameworks. One common example is the integration with data retrieved on-demand from databases using hibernate named queries.

The expression used to define the object source is any expression that follows regular MVEL syntax. Therefore, it allows you to easily use object property navigation, execute method calls and access maps and collections elements.

Here is a simple example of reasoning and binding on another pattern sub-field:

```
rule "validate zipcode"
when
    Person( $personAddress : address )
    Address( zipcode == "23920W") from $personAddress
then
    # zip code is ok
end
```

With all the flexibility from the new expressiveness in the Drools engine you can slice and dice this problem many ways. This is the same but shows how you can use a graph notation with the 'from':

```
rule "validate zipcode"
when
    $p : Person( )
    $a : Address( zipcode == "23920W") from $p.address
then
    # zip code is ok
end
```

Previous examples were evaluations using a single pattern. The CE `from` also support object sources that return a collection of objects. In that case, `from` will iterate over all objects in the collection and try to match each of them individually. For instance, if we want a rule that applies 10% discount to each item in an order, we could do:

```
rule "apply 10% discount to all items over US$ 100,00 in an order"
when
    $order : Order()
    $item  : OrderItem( value > 100 ) from $order.items
then
    # apply discount to $item
end
```

The above example will cause the rule to fire once for each item whose value is greater than 100 for each given order.

You must take caution, however, when using `from`, especially in conjunction with the `lock-on-active` rule attribute as it may produce unexpected results. Consider the example provided earlier, but now slightly modified as follows:

```
rule "Assign people in North Carolina (NC) to sales region 1"
ruleflow-group "test"
lock-on-active true
when
    $p : Person( )
    $a : Address( state == "NC") from $p.address
then
    modify ($p) {} #Assign person to sales region 1 in a modify block
end

rule "Apply a discount to people in the city of Raleigh"
ruleflow-group "test"
lock-on-active true
when
    $p : Person( )
    $a : Address( city == "Raleigh") from $p.address
then
    modify ($p) {} #Apply discount to person in a modify block
end
```

In the above example, persons in Raleigh, NC should be assigned to sales region 1 and receive a discount; i.e., you would expect both rules to activate and fire. Instead you will find that only the second rule fires.

If you were to turn on the audit log, you would also see that when the second rule fires, it deactivates the first rule. Since the rule attribute `lock-on-active` prevents a rule from creating new activations when a set of facts change, the first rule fails to reactivate. Though the set of facts have not changed, the use of `from` returns a new fact for all intents and purposes each time it is evaluated.

First, it's important to review why you would use the above pattern. You may have many rules across different rule-flow groups. When rules modify working memory and other rules downstream of your RuleFlow (in different rule-flow groups) need to be reevaluated, the use of `modify` is critical. You don't, however, want other rules in the same rule-flow group to place activations on one another recursively. In this case, the `no-loop` attribute is ineffective, as it would only prevent a rule from activating itself recursively. Hence, you resort to `lock-on-active`.

There are several ways to address this issue:

- Avoid the use of `from` when you can assert all facts into working memory or use nested object references in your constraint expressions (shown below).
- Place the variable assigned used in the modify block as the last sentence in your condition (LHS).
- Avoid the use of `lock-on-active` when you can explicitly manage how rules within the same rule-flow group place activations on one another (explained below).

The preferred solution is to minimize use of `from` when you can assert all your facts into working memory directly. In the example above, both the Person and Address instance can be asserted into working memory. In this case, because the graph is fairly simple, an even easier solution is to modify your rules as follows:

```
rule "Assign people in North Carolina (NC) to sales region 1"
ruleflow-group "test"
lock-on-active true
when
    $p : Person(address.state == "NC" )
then
    modify ($p) {} #Assign person to sales region 1 in a modify block
end

rule "Apply a discount to people in the city of Raleigh"
ruleflow-group "test"
lock-on-active true
when
    $p : Person(address.city == "Raleigh" )
then
    modify ($p) {} #Apply discount to person in a modify block
end
```

Now, you will find that both rules fire as expected. However, it is not always possible to access nested facts as above. Consider an example where a Person holds one or more Addresses and you wish to use an existential quantifier to match people with at least one address that meets certain conditions. In this case, you would have to resort to the use of `from` to reason over the collection.

There are several ways to use `from` to achieve this and not all of them exhibit an issue with the use of `lock-on-active`. For example, the following use of `from` causes both rules to fire as expected:

```
rule "Assign people in North Carolina (NC) to sales region 1"
ruleflow-group "test"
lock-on-active true
when
    $p : Person($addresses : addresses)
    exists (Address(state == "NC") from $addresses)
then
    modify ($p) {} #Assign person to sales region 1 in a modify block
end

rule "Apply a discount to people in the city of Raleigh"
ruleflow-group "test"
lock-on-active true
when
    $p : Person($addresses : addresses)
    exists (Address(city == "Raleigh") from $addresses)
then
    modify ($p) {} #Apply discount to person in a modify block
end
```

However, the following slightly different approach does exhibit the problem:

```
rule "Assign people in North Carolina (NC) to sales region 1"
ruleflow-group "test"
lock-on-active true
when
    $assessment : Assessment()
    $p : Person()
    $addresses : List() from $p.addresses
    exists (Address( state == "NC") from $addresses)
then
    modify ($assessment) {} #Modify assessment in a modify block
end

rule "Apply a discount to people in the city of Raleigh"
ruleflow-group "test"
lock-on-active true
```

```
when
    $assessment : Assessment()
    $p : Person()
    $addresses : List() from $p.addresses
    exists (Address( city == "Raleigh") from $addresses)
then
    modify ($assessment) {} #Modify assessment in a modify block
end
```

In the above example, the $addresses variable is returned from the use of `from`. The example also introduces a new object, assessment, to highlight one possible solution in this case. If the $assessment variable assigned in the condition (LHS) is moved to the last condition in each rule, both rules fire as expected.

Though the above examples demonstrate how to combine the use of `from` with `lock-on-active` where no loss of rule activations occurs, they carry the drawback of placing a dependency on the order of conditions on the LHS. In addition, the solutions present greater complexity for the rule author in terms of keeping track of which conditions may create issues.

A better alternative is to assert more facts into working memory. In this case, a person's addresses may be asserted into working memory and the use of `from` would not be necessary.

There are cases, however, where asserting all data into working memory is not practical and we need to find other solutions. Another option is to reevaluate the need for `lock-on-active`. An alternative to `lock-on-active` is to directly manage how rules within the same rule-flow group activate one another by including conditions in each rule that prevent rules from activating each other recursively when working memory is modified. For example, in the case above where a discount is applied to citizens of Raleigh, a condition may be added to the rule that checks whether the discount has already been applied. If so, the rule does not activate.

5.8.3.6.3. Conditional Element `collect`

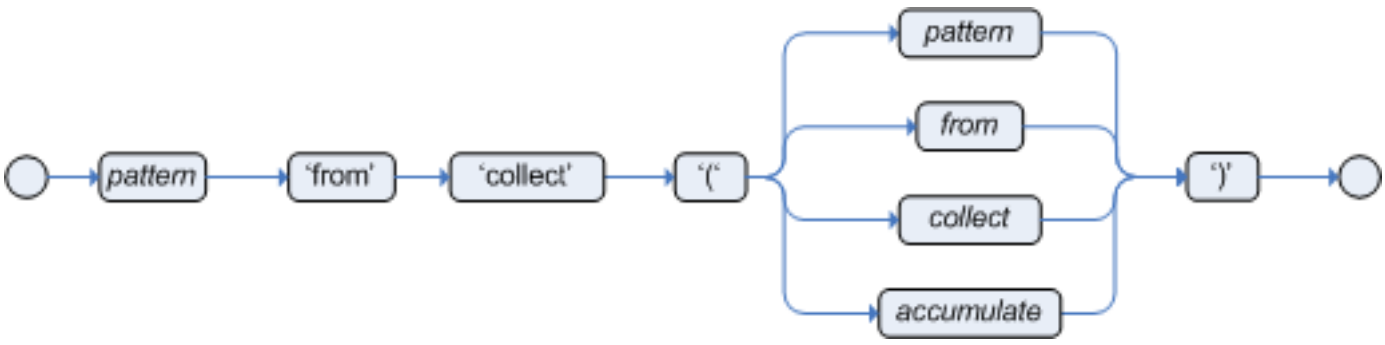


Figure 5.27. collect

The Conditional Element `collect` allows rules to reason over a collection of objects obtained from the given source or from the working memory. In First Oder Logic terms this is the cardinality quantifier. A simple example:

```
import java.util.ArrayList

rule "Raise priority if system has more than 3 pending alarms"
when
    $system : System()
    $alarms : ArrayList( size >= 3 )
              from collect( Alarm( system == $system, status == 'pending' ) )
then
    # Raise priority, because system $system has
    # 3 or more alarms pending. The pending alarms
    # are $alarms.
end
```

In the above example, the rule will look for all pending alarms in the working memory for each given system and group them in ArrayLists. If 3 or more alarms are found for a given system, the rule will fire.

The result pattern of `collect` can be any concrete class that implements the `java.util.Collection` interface and provides a default no-arg public constructor. This means that you can use Java collections like ArrayList, LinkedList, HashSet, etc., or your own class, as long as it implements the `java.util.Collection` interface and provide a default no-arg public constructor.

Both source and result patterns can be constrained as any other pattern.

Variables bound before the `collect` CE are in the scope of both source and result patterns and therefore you can use them to constrain both your source and result patterns. But note that `collect` is a scope delimiter for bindings, so that any binding made inside of it is not available for use outside of it.

Collect accepts nested `from` CEs. The following example is a valid use of "collect":

```
import java.util.LinkedList;

rule "Send a message to all mothers"
when
    $town : Town( name == 'Paris' )
    $mothers : LinkedList()
               from collect( Person( gender == 'F', children > 0 )
                             from $town.getPeople()
                           )
then
    # send a message to all mothers
end
```

5.8.3.6.4. Conditional Element `accumulate`

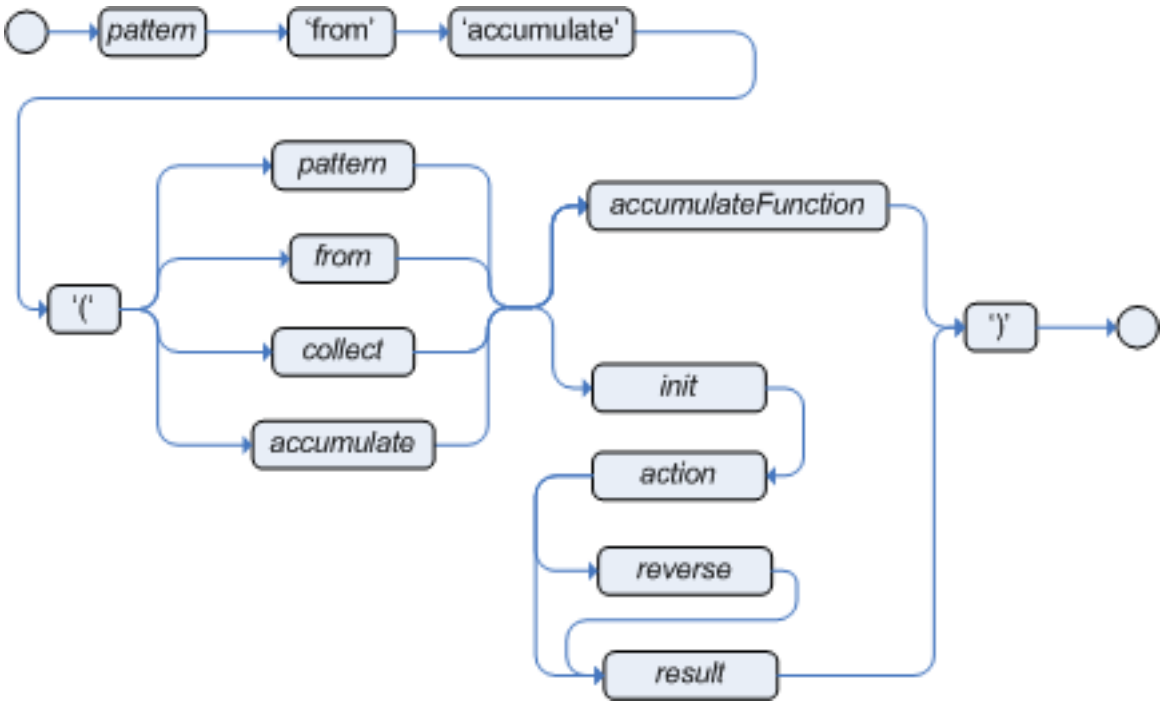


Figure 5.28. accumulate

The Conditional Element `accumulate` is a more flexible and powerful form of `collect`, in the sense that it can be used to do what `collect` does and also achieve results that the CE `collect` is not capable of doing. Basically, what it does is that it allows a rule to iterate over a collection of objects, executing custom actions for each of the elements, and at the end it returns a result object.

Accumulate supports both the use of pre-defined accumulate functions, or the use of inline custom code. Inline custom code should be avoided though, as it is extremely hard to maintain, and frequently leads to code duplication. Accumulate functions are easier to test and reuse.

5.8.3.6.4.1. Accumulate Functions

The accumulate CE is a very powerful CE, but it gets real declarative and easy to use when using predefined functions that are known as Accumulate Functions. They work exactly like accumulate, but instead of explicitly writing custom code in every accumulate CE, the user can use predefined code for common operations.

For instance, a rule to apply a 10% discount on orders over $100 could be written in the following way, using Accumulate Functions:

```
rule "Apply 10% discount to orders over US$ 100,00"
when
    $order : Order()
    $total : Number( doubleValue > 100 )
```

```
            from accumulate( OrderItem( order == $order, $value : value ),
                             sum( $value ) )
then
    # apply discount to $order
end
```

In the above example, sum is an Accumulate Function and will sum the $value of all OrderItems and return the result.

Drools ships with the following built-in accumulate functions:

- average
- min
- max
- count
- sum
- collectList
- collectSet

These common functions accept any expression as input. For instance, if someone wants to calculate the average profit on all items of an order, a rule could be written using the average function:

```
rule "Average profit"
when
    $order : Order()
    $profit : Number()
                from accumulate( OrderItem( order == $order, $cost : cost,
 $price : price )
                                 average( 1 - $cost / $price ) )
then
    # average profit for $order is $profit
end
```

Accumulate Functions are all pluggable. That means that if needed, custom, domain specific functions can easily be added to the engine and rules can start to use them without any restrictions. To implement a new Accumulate Functions all one needs to do is to create a Java class that implements the `org.drools.runtime.rule.TypedAccumulateFunction` interface and add a line to the configuration file or set a system property to let the engine know about the new function. As an example of an Accumulate Function implementation, the following is the implementation of the `average` function:

```
/**
 * An implementation of an accumulator capable of calculating average values
 */
public class AverageAccumulateFunction implements AccumulateFunction {

    public void readExternal(ObjectInput in) throws IOException, ClassNotFoundException {

    }

    public void writeExternal(ObjectOutput out) throws IOException {

    }

    public static class AverageData implements Externalizable {
        public int    count = 0;
        public double total = 0;

        public AverageData() {}

        public void readExternal(ObjectInput in) throws IOException, ClassNotFoundException {
            count   = in.readInt();
            total   = in.readDouble();
        }

        public void writeExternal(ObjectOutput out) throws IOException {
            out.writeInt(count);
            out.writeDouble(total);
        }

    }

    /* (non-Javadoc)
     * @see org.drools.base.accumulators.AccumulateFunction#createContext()
     */
    public Serializable createContext() {
        return new AverageData();
    }

    /* (non-Javadoc)
                                                                 *            @see
 org.drools.base.accumulators.AccumulateFunction#init(java.lang.Object)
     */
    public void init(Serializable context) throws Exception {
        AverageData data = (AverageData) context;
        data.count = 0;
        data.total = 0;
    }
```

```
    /* (non-Javadoc)
                                                                    *            @see

 java.lang.Object)
     */
    public void accumulate(Serializable context,
                           Object value) {
        AverageData data = (AverageData) context;
        data.count++;
        data.total += ((Number) value).doubleValue();
    }

    /* (non-Javadoc)
                                                                    *            @see

 java.lang.Object)
     */
    public void reverse(Serializable context,
                        Object value) throws Exception {
        AverageData data = (AverageData) context;
        data.count--;
        data.total -= ((Number) value).doubleValue();
    }

    /* (non-Javadoc)
                                                                    *            @see
 org.drools.base.accumulators.AccumulateFunction#getResult(java.lang.Object)
     */
    public Object getResult(Serializable context) throws Exception {
        AverageData data = (AverageData) context;
        return new Double( data.count == 0 ? 0 : data.total / data.count );
    }

    /* (non-Javadoc)
     * @see org.drools.base.accumulators.AccumulateFunction#supportsReverse()
     */
    public boolean supportsReverse() {
        return true;
    }

    /**
     * {@inheritDoc}
     */
    public Class< ? > getResultType() {
        return Number.class;
    }

}
```

The code for the function is very simple, as we could expect, as all the "dirty" integration work is done by the engine. Finally, to plug the function into the engine, we added it to the configuration file:

```
drools.accumulate.function.average =
   org.drools.base.accumulators.AverageAccumulateFunction
```

Here, "drools.accumulate.function." is a prefix that must always be used, "average" is how the function will be used in the rule file, and "org.drools.base.accumulators.AverageAccumulateFunction" is the fully qualified name of the class that implements the function behavior.

5.8.3.6.4.2. Alternate Syntax: single function with return type

The accumulate syntax evolved over time with the goal of becoming more compact and expressive. Nevertheless, Drools still supports previous sintaxes for backward compatibility purposes.

In case the rule is using a single accumulate function on a given accumulate, the author may add a pattern for the result object and use the "from" keyword to link it to the accumulate result. Example: a rule to apply a 10% discount on orders over $100 could be written in the following way:

```
rule "Apply 10% discount to orders over US$ 100,00"
when
    $order : Order()
    $total : Number( doubleValue > 100 )
             from accumulate( OrderItem( order == $order, $value : value ),
                              sum( $value ) )
then
    # apply discount to $order
end
```

In the above example, the accumulate element is using only one function (sum), and so, the rules author opted to explicitly write a pattern for the result type of the accumulate function (Number) and write the constraints inside it. There are no problems in using this syntax over the compact syntax presented before, except that is is a bit more verbose.

5.8.3.6.4.3. Accumulate with inline custom code

Warning

The use of accumulate with inline custom code is not a good practice for several reasons, including dificulties on maintaining and testing rules that use them, as well as the inability of reusing that code. Implementing your own accumulate functions

is very simple and straightforward, they are easy to unit test and to use. This form of accumulate is supported for backward compatibility only.

The general syntax of the `accumulate` CE with inline custom code is:

```
<result pattern> from accumulate( <source pattern>,
                                  init( <init code> ),
                                  action( <action code> ),
                                  reverse( <reverse code> ),
                                  result( <result expression> ) )
```

The meaning of each of the elements is the following:

- *<source pattern>*: the source pattern is a regular pattern that the engine will try to match against each of the source objects.
- *<init code>*: this is a semantic block of code in the selected dialect that will be executed once for each tuple, before iterating over the source objects.
- *<action code>*: this is a semantic block of code in the selected dialect that will be executed for each of the source objects.
- *<reverse code>*: this is an optional semantic block of code in the selected dialect that if present will be executed for each source object that no longer matches the source pattern. The objective of this code block is to undo any calculation done in the *<action code>* block, so that the engine can do decremental calculation when a source object is modified or retracted, hugely improving performance of these operations.
- *<result expression>*: this is a semantic expression in the selected dialect that is executed after all source objects are iterated.
- *<result pattern>*: this is a regular pattern that the engine tries to match against the object returned from the *<result expression>*. If it matches, the `accumulate` conditional element evaluates to *true* and the engine proceeds with the evaluation of the next CE in the rule. If it does not matches, the `accumulate` CE evaluates to *false* and the engine stops evaluating CEs for that rule.

It is easier to understand if we look at an example:

```
rule "Apply 10% discount to orders over US$ 100,00"
when
    $order : Order()
    $total : Number( doubleValue > 100 )
             from accumulate( OrderItem( order == $order, $value : value ),
                              init( double total = 0; ),
                              action( total += $value; ),
```

```
                                reverse( total -= $value; ),
                                result( total ) )
then
    # apply discount to $order
end
```

In the above example, for each `Order` in the Working Memory, the engine will execute the *init code* initializing the total variable to zero. Then it will iterate over all `OrderItem` objects for that order, executing the *action* for each one (in the example, it will sum the value of all items into the total variable). After iterating over all `OrderItem` objects, it will return the value corresponding to the *result expression* (in the above example, the value of variable `total`). Finally, the engine will try to match the result with the `Number` pattern, and if the double value is greater than 100, the rule will fire.

The example used Java as the semantic dialect, and as such, note that the usage of the semicolon as statement delimiter is mandatory in the init, action and reverse code blocks. The result is an expression and, as such, it does not admit ';'. If the user uses any other dialect, he must comply to that dialect's specific syntax.

As mentioned before, the *reverse code* is optional, but it is strongly recommended that the user writes it in order to benefit from the *improved performance on update and retract*.

The `accumulate` CE can be used to execute any action on source objects. The following example instantiates and populates a custom object:

```
rule "Accumulate using custom objects"
when
    $person   : Person( $likes : likes )
    $cheesery : Cheesery( totalAmount > 100 )
                from accumulate( $cheese : Cheese( type == $likes ),
                                 init( Cheesery cheesery = new Cheesery(); ),
                                 action( cheesery.addCheese( $cheese ); ),
                                 reverse( cheesery.removeCheese( $cheese ); ),
                                 result( cheesery ) );
then
    // do something
end
```

5.8.3.6.4.4. Multi-function Accumulates

The accumulate CE now supports multiple functions. For instance, if one needs to find the minimum, maximum and average value for the same set of data, instead of having to repeat the accumulate statement 3 times, a single accumulate can be used.

```
rule "Max, min and average"
```

```
    when
        accumulate( Cheese( $price : price ),
                    $max : max( $price ),
                    $min : min( $price ),
                    $avg : average( $price ) )
    then
        // do something
end
```

5.8.3.7. Conditional Element `eval`

Figure 5.29. eval

The conditional element `eval` is essentially a catch-all which allows any semantic code (that returns a primitive boolean) to be executed. This code can refer to variables that were bound in the LHS of the rule, and functions in the rule package. Overuse of eval reduces the declarativeness of your rules and can result in a poorly performing engine. While `eval` can be used anywhere in the patterns, the best practice is to add it as the last conditional element in the LHS of a rule.

Evals cannot be indexed and thus are not as efficient as Field Constraints. However this makes them ideal for being used when functions return values that change over time, which is not allowed within Field Constraints.

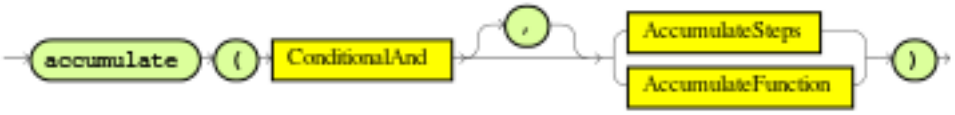
For folks who are familiar with Drools 2.x lineage, the old Drools parameter and condition tags are equivalent to binding a variable to an appropriate type, and then using it in an eval node.

```
p1 : Parameter()
p2 : Parameter()
eval( p1.getList().containsKey( p2.getItem() ) )
```

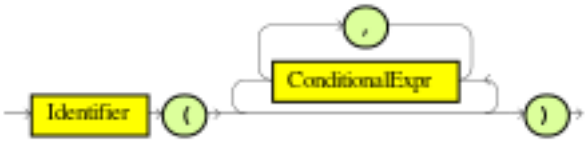
```
p1 : Parameter()
p2 : Parameter()
// call function isValid in the LHS
eval( isValid( p1, p2 ) )
```

5.8.3.8. Railroad diagrams

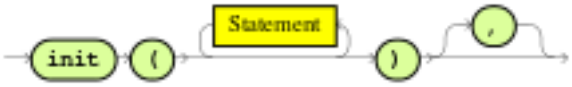
AccumulateClause



AccumulateFunction

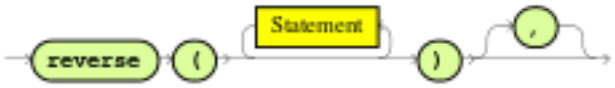


AccumulateInit



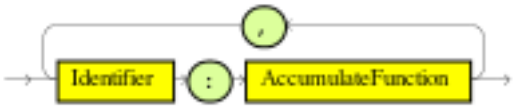
AccumulateResult

AccumulateReverse

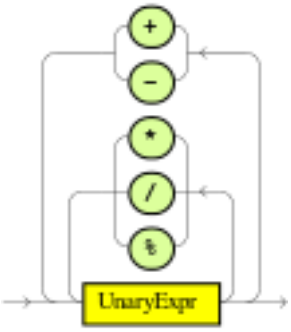


AccumulateSteps

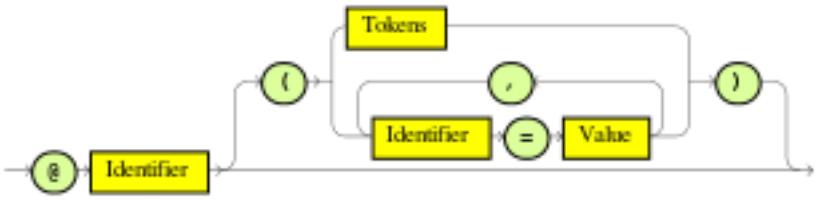
Accumulations



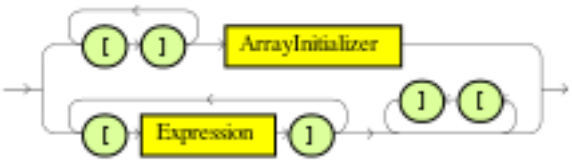
AdditiveExpr



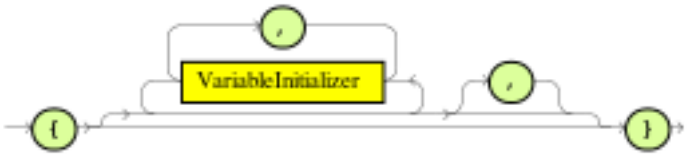
Annotation



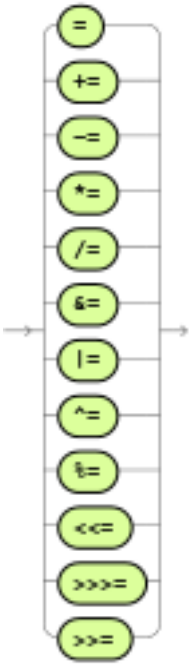
ArrayCreatorRest



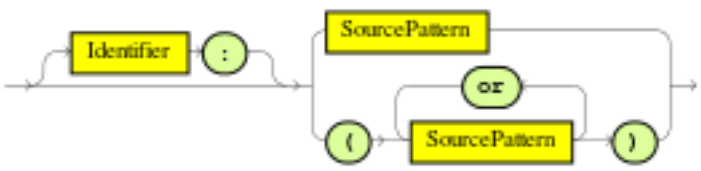
ArrayInitializer



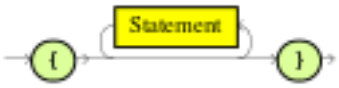
AssignmentOperator



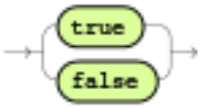
BindingPattern



Block

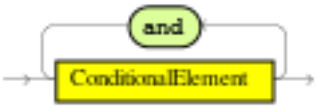


BooleanLiteral



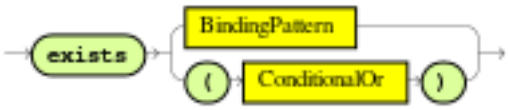
CompilationUnit

ConditionalAnd



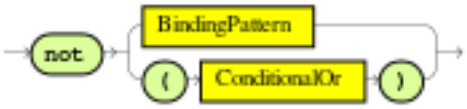
ConditionalElementAccumulate

ConditionalElementExists

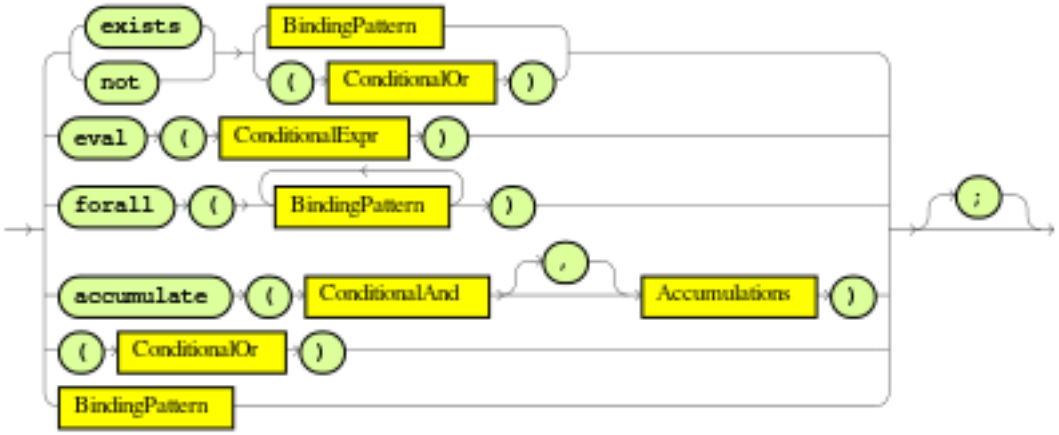


ConditionalElementForall

ConditionalElementNot

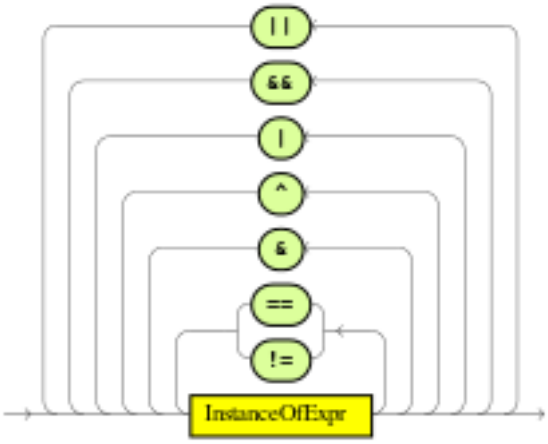


ConditionalElement

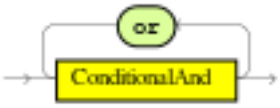


ConditionalExpr

ConditionalOrExpr

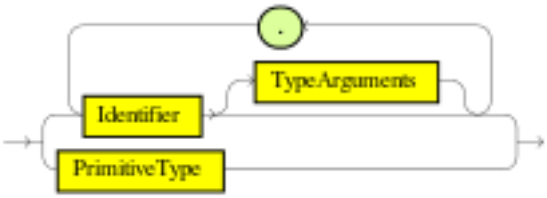


ConditionalOr

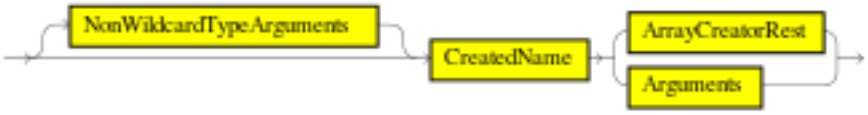


Constraints

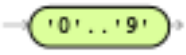
CreatedName



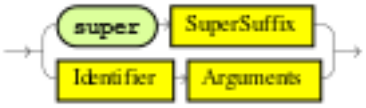
Creator



Digit

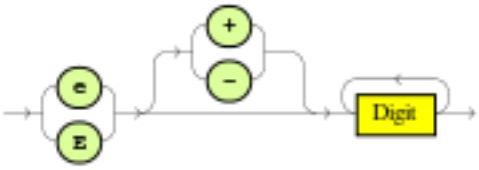


ExplicitGenericInvocationSuffix

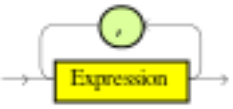


ExplicitGenericInvocation

Exponent



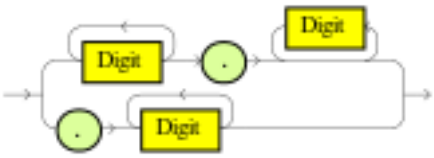
ExpressionList



Expression

Field

Fraction



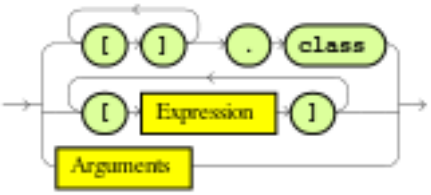
FromAccumulateClause

FromClause

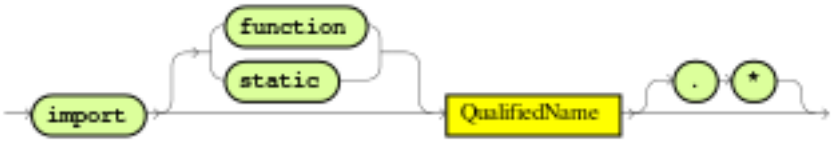
FunctionDefinition

GlobalDefinition

IdentifierSuffix

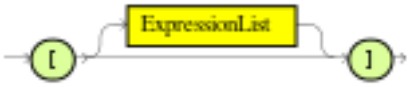


ImportDefinition

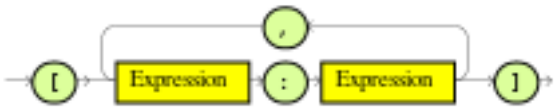


InExpr

InlineListExpr

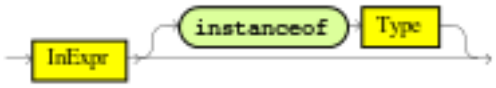


InlineMapExpr

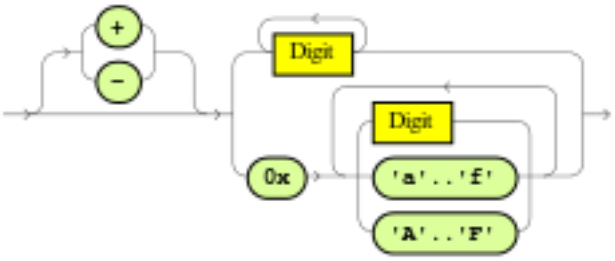


InnerCreator

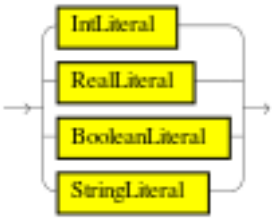
InstanceOfExpr



IntLiteral



Literal



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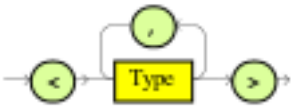
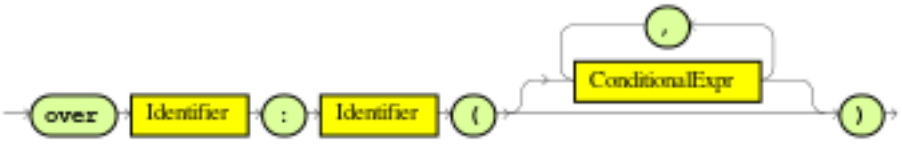


OrRestriction

OverClause



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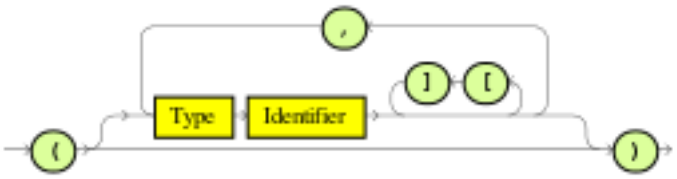
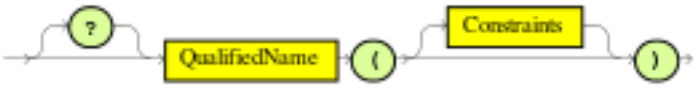
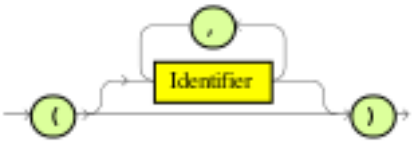


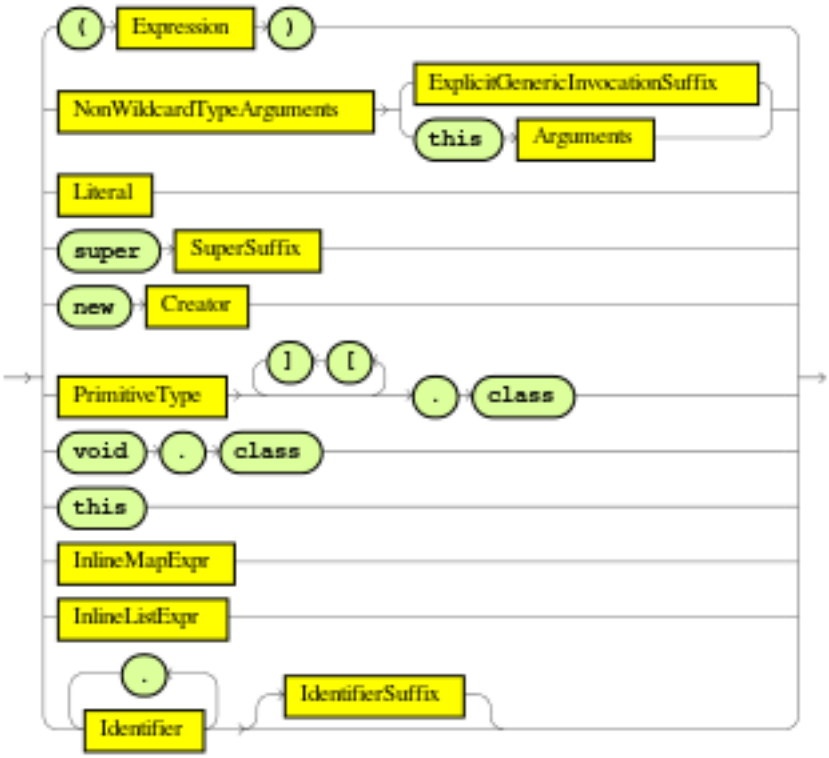
Pattern



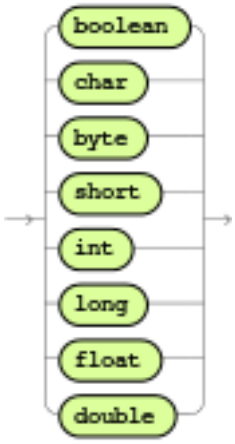
Placeholders



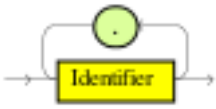
Primary



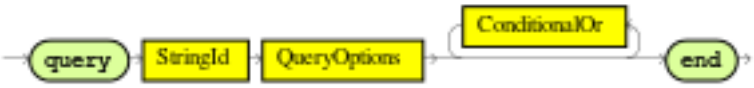
PrimitiveType



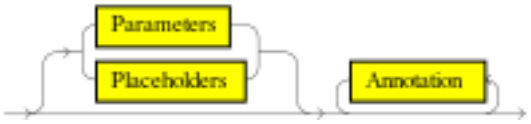
QualifiedName



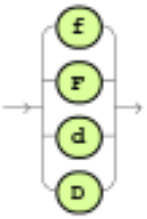
QueryDefinition



QueryOptions

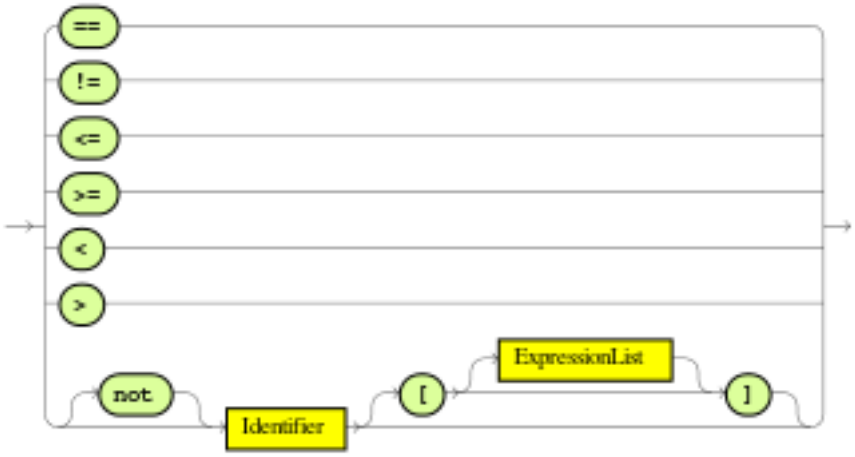


RealTypeSuffix

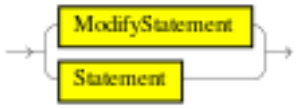


RelationalExpr

RelationalOperator

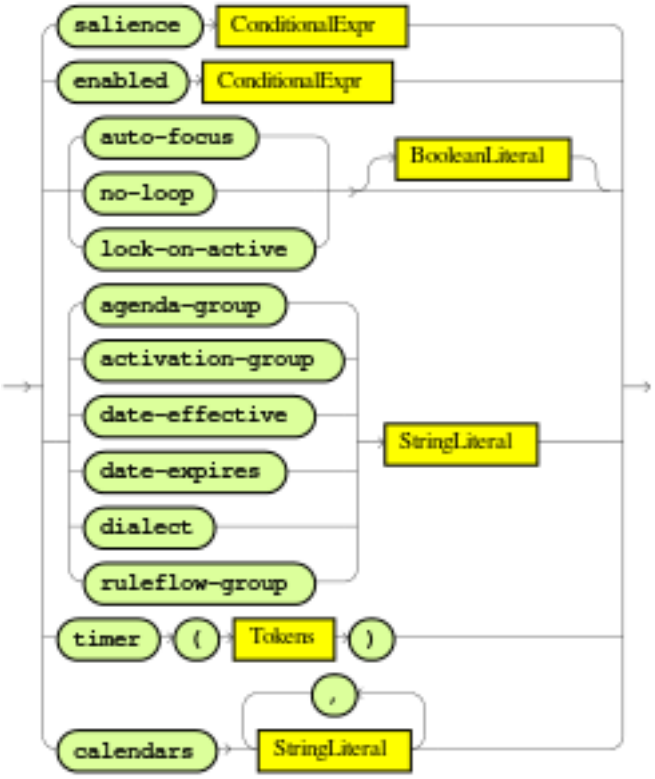


RhsStatement



RuleAttributes

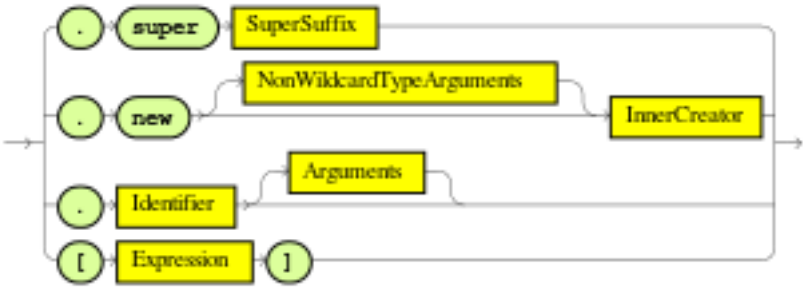
RuleAttribute



RuleDefinition

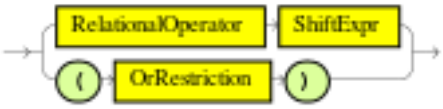
RuleOptions

Selector

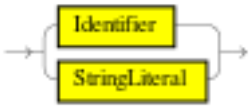


ShiftExpr

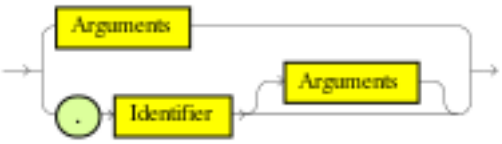
SingleRestriction



StringId

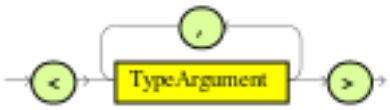


SuperSuffix



ThenPart

TypeArguments



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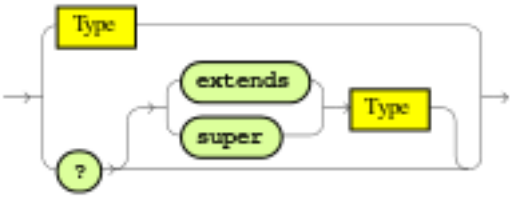
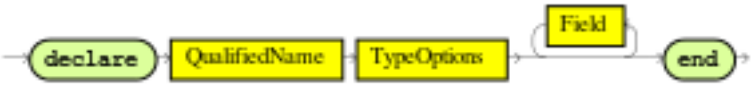
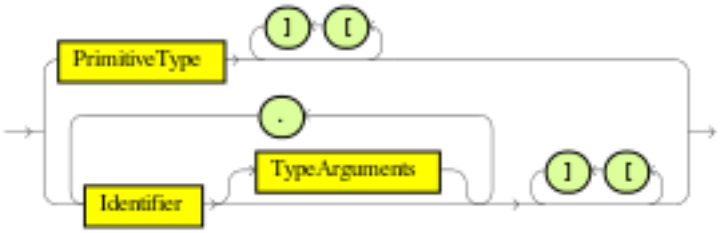


TypeDefinition

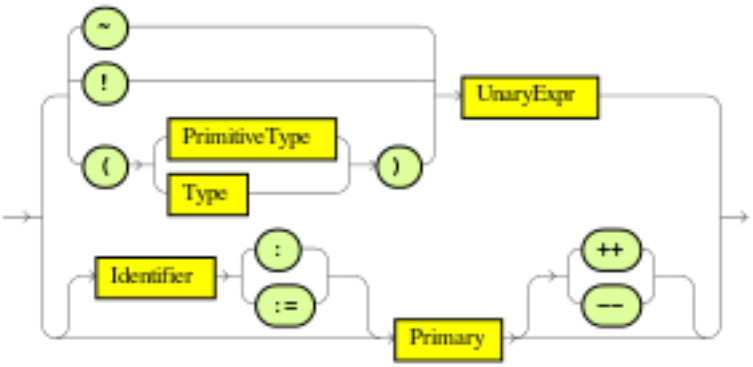


TypeOptions

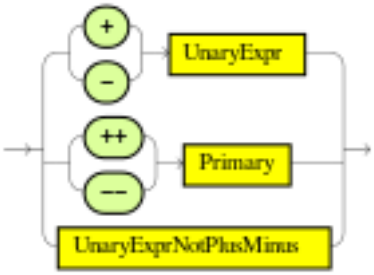
Type



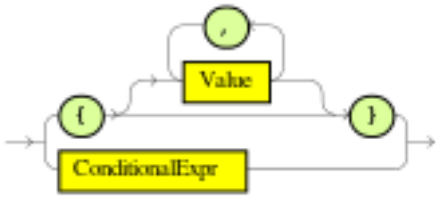
UnaryExprNotPlusMinus



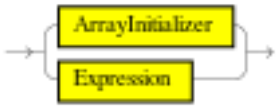
UnaryExpr



Value



VariableInitializer



WhenPart

5.8.4. The Right Hand Side (then)

5.8.4.1. Usage

The Right Hand Side (RHS) is a common name for the consequence or action part of the rule; this part should contain a list of actions to be executed. It is bad practice to use imperative or conditional code in the RHS of a rule; as a rule should be atomic in nature - "when this, then do this", not "when this, maybe do this". The RHS part of a rule should also be kept small, thus keeping it declarative and readable. If you find you need imperative and/or conditional code in the RHS, then maybe you should be breaking that rule down into multiple rules. The main purpose of the RHS is to insert, retractor modify working memory data. To assist with that there are a few convenience methods you can use to modify working memory; without having to first reference a working memory instance.

`update(`*object, handle*`);` will tell the engine that an object has changed (one that has been bound to something on the LHS) and rules may need to be reconsidered.

`update(`*object*`);` can also be used; here the Knowledge Helper will look up the facthandle for you, via an identity check, for the passed object. (Note that if you provide Property Change Listeners to your Java beans that you are inserting into the engine, you can avoid the need to call `update()` when the object changes.). After a fact's field values have changed you must call update before

changing another fact, or you will cause problems with the indexing within the rule engine. The modify keyword avoids this problem.

`insert(new` *Something*`());` will place a new object of your creation into the Working Memory.

`insertLogical(new` *Something*`());` is similar to insert, but the object will be automatically retracted when there are no more facts to support the truth of the currently firing rule.

`retract(`*handle*`);` removes an object from Working Memory.

These convenience methods are basically macros that provide short cuts to the `KnowledgeHelper` instance that lets you access your Working Memory from rules files. The predefined variable `drools` of type `KnowledgeHelper` lets you call several other useful methods. (Refer to the `KnowledgeHelper` interface documentation for more advanced operations).

- The call `drools.halt()` terminates rule execution immediately. This is required for returning control to the point whence the current session was put to work with `fireUntilHalt()`.
- Methods `insert(Object o)`, `update(Object o)` and `retract(Object o)` can be called on `drools` as well, but due to their frequent use they can be called without the object reference.
- `drools.getWorkingMemory()` returns the `WorkingMemory` object.
- `drools.setFocus( String s)` sets the focus to the specified agenda group.
- `drools.getRule().getName()`, called from a rule's RHS, returns the name of the rule.
- `drools.getTuple()` returns the Tuple that matches the currently executing rule, and `drools.getActivation()` delivers the corresponding Activation. (These calls are useful for logging and debugging purposes.)

The full Knowledge Runtime API is exposed through another predefined variable, `kcontext`, of type `KnowledgeContext`. Its method `getKnowledgeRuntime()` delivers an object of type `KnowledgeRuntime`, which, in turn, provides access to a wealth of methods, many of which are quite useful for coding RHS logic.

- The call `kcontext.getKnowledgeRuntime().halt()` terminates rule execution immediately.
- The accessor `getAgenda()` returns a reference to this session's `Agenda`, which in turn provides access to the various rule groups: activation groups, agenda groups, and rule flow groups. A fairly common paradigm is the activation of some agenda group, which could be done with the lengthy call:

```
// give focus to the agenda group CleanUp
kcontext.getKnowledgeRuntime().getAgenda().getAgendaGroup( "CleanUp" ).setFocus();
```

(You can achieve the same using `drools.setFocus( "CleanUp" )`.)

- To run a query, you call `getQueryResults(String query)`, whereupon you may process the results, as explained in section "*Query*".
- A set of methods dealing with event management lets you, among other things, add and remove event listeners for the Working Memory and the Agenda.
- Method`getKnowledgeBase()` returns the `KnowledgeBase` object, the backbone of all the Knowledge in your system, and the originator of the current session.
- You can manage globals with `setGlobal(...)`, `getGlobal(...)` and `getGlobals()`.
- Method `getEnvironment()` returns the runtime's `Environment` which works much like what you know as your operating system's environment.

5.8.4.2. The `modify` Statement

This language extension provides a structured approach to fact updates. It combines the update operation with a number of setter calls to change the object's fields. This is the syntax schema for the `modify` statement:

```
modify ( <fact-expression> ) {
    <expression> [ , <expression> ]*
}
```

The parenthesized *<fact-expression>* must yield a fact object reference. The expression list in the block should consist of setter calls for the given object, to be written without the usual object reference, which is automatically prepended by the compiler.

The example illustrates a simple fact modification.

Example 5.54. A modify statement

```
rule "modify stilton"
when
    $stilton : Cheese(type == "stilton")
then
    modify( $stilton ){
        setPrice( 20 ),
        setAge( "overripe" )
    }
end
```

5.8.5. A Note on Auto-boxing and Primitive Types

Drools attempts to preserve numbers in their primitive or object wrapper form, so a variable bound to an int primitive when used in a code block or expression will no longer need manual unboxing;

unlike Drools 3.0 where all primitives were autoboxed, requiring manual unboxing. A variable bound to an object wrapper will remain as an object; the existing JDK 1.5 and JDK 5 rules to handle auto-boxing and unboxing apply in this case. When evaluating field constraints, the system attempts to coerce one of the values into a comparable format; so a primitive is comparable to an object wrapper.

5.9. Query

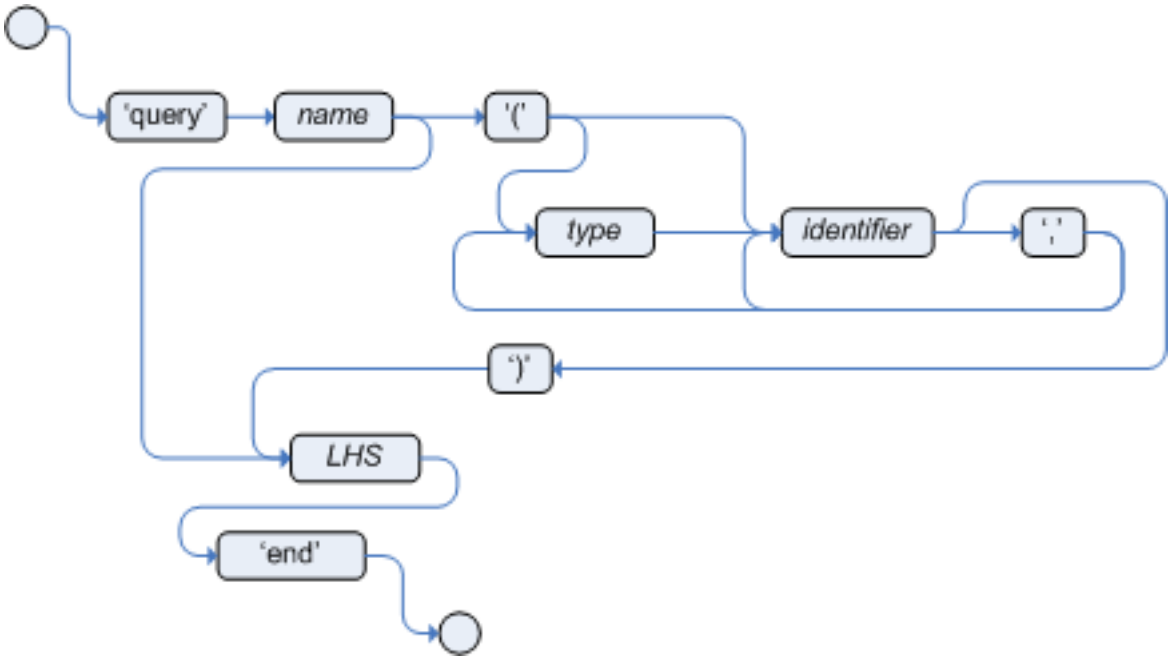


Figure 5.30. query

A query is a simple way to search the working memory for facts that match the stated conditions. Therefore, it contains only the structure of the LHS of a rule, so that you specify neither "when" nor "then". A query has an optional set of parameters, each of which can be optionally typed. If the type is not given, the type Object is assumed. The engine will attempt to coerce the values as needed. Query names are global to the KnowledgeBase; so do not add queries of the same name to different packages for the same RuleBase.

To return the results use `ksession.getQueryResults("name")`, where "name" is the query's name. This returns a list of query results, which allow you to retrieve the objects that matched the query.

The first example presents a simple query for all the people over the age of 30. The second one, using parameters, combines the age limit with a location.

Example 5.55. Query People over the age of 30

```
query "people over the age of 30"
    person : Person( age > 30 )
```

```
end
```

Example 5.56. Query People over the age of x, and who live in y

```
query "people over the age of x"  (int x, String y)
    person : Person( age > x, location == y )
end
```

We iterate over the returned QueryResults using a standard "for" loop. Each element is a QueryResultsRow which we can use to access each of the columns in the tuple. These columns can be accessed by bound declaration name or index position.

Example 5.57. Query People over the age of 30

```
QueryResults results = ksession.getQueryResults( "people over the age of 30" );
System.out.println( "we have " + results.size() + " people over the age  of 30" );

System.out.println( "These people are are over 30:" );

for ( QueryResultsRow row : results ) {
    Person person = ( Person ) row.get( "person" );
    System.out.println( person.getName() + "\n" );
}
```

Support for positional syntax has been added for more compact code. By default the the declared type order in the type declaration matches the argument position. But it possible to override these using the @position annotation.

```
declare Cheese
    name : String @position(1)
    shop : String @position(2)
    price : int @position(0)
end
```

The @Position annotation, in the org.drools.definition.type package, can be used to annotate original pojos on the classpath. Currently only fields on classes can be annotated. Inheritence of classes is supported, but not interfaces of methods yet.

Queries can now call other queries, this combined with optional query arguments provides deriviation query style backward chaining. Positional and mixed positional/named type is supported. Literal expressions can passed as query arguments, but at this stage you cannot mix expressions with variables. Here s an example of a query that calls another query. Note that 'z'

here will always be an 'out' variable. The '?' symbol means the query is pull only, once the results are returned you will not received further results as the underlying data changes.

```
declare Location
    thing : String
    location : String
end

query isContainedIn( String x, String y )
    Location(x, y;)
    or
    ( Location(z, y;) and ?isContainedIn(x, z;) )
end
```

As previously mentioned you can use live "open" queries to reactively receive changes over time from the query results, as the underlying data it queries against changes. Notice the "look" rule calls the query without using '?'.

```
query isContainedIn( String x, String y )
    Location(x, y;)
    or
    ( Location(z, y;) and isContainedIn(x, z;) )
end

rule look when
    Person( $l : likes )
    isContainedIn( $l, 'office'; )
then
   insertLogical( $l 'is in the office' );
end
```

Drools supports unification for derivation queries, in short this means that arguments are optional. It is possible to call queries from java leaving arguments unspecified using the static field org.drools.runtime.rule.Variable.v - note you must use 'v' and not an alternative instanceof Variable. These are referred to as 'out' arguments. Note that the query itself does not declare at compile time whether an argument is in or an out, this can be defined purely at runtime on each use. The following example will return all objects contained in the office.

```
results = ksession.getQueryResults( "isContainedIn", new Object[] {  Variable.v,
 "office" } );
l = new ArrayList<List<String>>();
for ( QueryResultsRow r : results ) {
      l.add(  Arrays.asList(  new  String[]  {  (String)  r.get(  "x"  ),  (String)
 r.get( "y" ) } ) );
```

```
}
```

The algorithm uses stacks to handle recursion, so the method stack will not blow up.

The following is not yet suported:

- List and Map unification
- Variables for the fields of facts
- Expression unification - pred(X, X + 1, X * Y / 7)

5.10. Domain Specific Languages

Domain Specific Languages (or DSLs) are a way of creating a rule language that is dedicated to your problem domain. A set of DSL definitions consists of transformations from DSL "sentences" to DRL constructs, which lets you use of all the underlying rule language and engine features. Given a DSL, you write rules in DSL rule (or DSLR) files, which will be translated into DRL files.

DSL and DSLR files are plain text files, and you can use any text editor to create and modify them. But there are also DSL and DSLR editors, both in the IDE as well as in the web based BRMS, and you can use those as well, although they may not provide you with the full DSL functionality.

5.10.1. When to Use a DSL

DSLs can serve as a layer of separation between rule authoring (and rule authors) and the technical intricacies resulting from the modelling of domain object and the rule engine's native language and methods. If your rules need to be read and validated by domain experts (such as business analysts, for instance) who are not programmers, you should consider using a DSL; it hides implementation details and focuses on the rule logic proper. DSL sentences can also act as "templates" for conditional elements and consequence actions that are used repeatedly in your rules, possibly with minor variations. You may define DSL sentences as being mapped to these repeated phrases, with parameters providing a means for accomodating those variations.

DSLs have no impact on the rule engine at runtime, they are just a compile time feature, requiring a special parser and transformer.

5.10.2. DSL Basics

The Drools DSL mechanism allows you to customise conditional expressions and consequence actions. A global substitution mechanism ("keyword") is also available.

Example 5.58. Example DSL mapping

```
[when]Something is {colour}=Something(colour=="{colour}")
```

In the preceding example, `[when]` indicates the scope of the expression, i.e., whether it is valid for the LHS or the RHS of a rule. The part after the bracketed keyword is the expression that you use in the rule; typically a natural language expression, but it doesn't have to be. The part to the right of the equal sign ("=") is the mapping of the expression into the rule language. The form of this string depends on its destination, RHS or LHS. If it is for the LHS, then it ought to be a term according to the regular LHS syntax; if it is for the RHS then it might be a Java statement.

Whenever the DSL parser matches a line from the rule file written in the DSL with an expression in the DSL definition, it performs three steps of string manipulation. First, it extracts the string values appearing where the expression contains variable names in braces (here: `{colour}`). Then, the values obtained from these captures are then interpolated wherever that name, again enclosed in braces, occurs on the right hand side of the mapping. Finally, the interpolated string replaces whatever was matched by the entire expression in the line of the DSL rule file.

Note that the expressions (i.e., the strings on the left hand side of the equal sign) are used as regular expressions in a pattern matching operation against a line of the DSL rule file, matching all or part of a line. This means you can use (for instance) a '?' to indicate that the preceding character is optional. One good reason to use this is to overcome variations in natural language phrases of your DSL. But, given that these expressions are regular expression patterns, this also means that all "magic" characters of Java's pattern syntax have to be escaped with a preceding backslash ('\').

It is important to note that the compiler transforms DSL rule files line by line. In the above example, all the text after "Something is " to the end of the line is captured as the replacement value for "{colour}", and this is used for interpolating the target string. This may not be exactly what you want. For instance, when you intend to merge different DSL expressions to generate a composite DRL pattern, you need to transform a DSLR line in several independent operations. The best way to achieve this is to ensure that the captures are surrounded by characteristic text - words or even single characters. As a result, the matching operation done by the parser plucks out a substring from somewhere within the line. In the example below, quotes are used as distinctive characters. Note that the characters that surround the capture are not included during interpolation, just the contents between them.

As a rule of thumb, use quotes for textual data that a rule editor may want to enter. You can also enclose the capture with words to ensure that the text is correctly matched. Both is illustrated by the following example. Note that a single line such as `Something is "green" and another solid thing` is now correctly expanded.

Example 5.59. Example with quotes

```
[when]something is "{colour}"=Something(colour=="{colour}")
[when]another {state} thing=OtherThing(state=="{state}"
```

It is a good idea to avoid punctuation (other than quotes or apostrophes) in your DSL expressions as much as possible. The main reason is that punctuation is easy to forget for rule authors

using your DSL. Another reason is that parentheses, the period and the question mark are magic characters, requiring escaping in the DSL definition.

In a DSL mapping, the braces "{" and "}" should only be used to enclose a variable definition or reference, resulting in a capture. If they should occur literally, either in the expression or within the replacement text on the right hand side, they must be escaped with a preceding backslash ("\"):

```
[then]do something= if (foo) \{ doSomething(); \}
```

Note

If braces "{" and "}" should appear in the replacement string of a DSL definition, escape them with a backslash ('\').

Example 5.60. Examples of DSL mapping entries

```
# This is a comment to be ignored.
[when]There is a person with name of "{name}"=Person(name=="{name}")
[when]Person is at least {age} years old and lives in "{location}"=
      Person(age >= {age}, location=="{location}")
[then]Log "{message}"=System.out.println("{message}");
[when]And = and
```

Given the above DSL examples, the following examples show the expansion of various DSLR snippets:

Example 5.61. Examples of DSL expansions

```
There is a person with name of "Kitty"
   ==> Person(name="Kitty")
Person is at least 42 years old and lives in "Atlanta"
   ==> Person(age >= 42, location="Atlanta")
Log "boo"
   ==> System.out.println("boo");
There is a person with name of "Bob" and Person is at least 30 years old and
 lives in "Utah"
   ==> Person(name="Bob") and Person(age >= 30, location="Utah")
```

Note

Don't forget that if you are capturing plain text from a DSL rule line and want to use it as a string literal in the expansion, you must provide the quotes on the right hand side of the mapping.

You can chain DSL expressions together on one line, as long as it is clear to the parser where one ends and the next one begins and where the text representing a parameter ends. (Otherwise you risk getting all the text until the end of the line as a parameter value.) The DSL expressions are tried, one after the other, according to their order in the DSL definition file. After any match, all remaining DSL expressions are investigated, too.

The resulting DRL text may consist of more than one line. Line ends are in the replacement text are written as `\n`.

5.10.3. Adding Constraints to Facts

A common requirement when writing rule conditions is to be able to add an arbitrary combination of constraints to a pattern. Given that a fact type may have many fields, having to provide an individual DSL statement for each combination would be plain folly.

The DSL facility allows you to add constraints to a pattern by a simple convention: if your DSL expression starts with a hyphen (minus character, "-") it is assumed to be a field constraint and, consequently, is is added to the last pattern line preceding it.

For an example, lets take look at class `Cheese`, with the following fields: type, price, age and country. We can express some LHS condition in normal DRL like the following

```
Cheese(age < 5, price == 20, type=="stilton", country=="ch")
```

The DSL definitions given below result in three DSL phrases which may be used to create any combination of constraint involving these fields.

```
[when]There is a Cheese with=Cheese()
[when]- age is less than {age}=age<{age}
[when]- type is '{type}'=type=='{type}'
[when]- country equal to '{country}'=country=='{country}'
```

You can then write rules with conditions like the following:

```
There is a Cheese with
        - age is less than 42
```

```
        - type is 'stilton'
```

The parser will pick up a line beginning with "-" and add it as a constraint to the preceding pattern, inserting a comma when it is required. For the preceding example, the resulting DRL is:

```
Cheese(age<42, type=='stilton')
```

Combining all all numeric fields with all relational operators (according to the DSL expression "age is less than..." in the preceding example) produces an unwieldy amount of DSL entries. But you can define DSL phrases for the various operators and even a generic expression that handles any field constraint, as shown below. (Notice that the expression definition contains a regular expression in addition to the variable name.)

```
[when][]is less than or equal to=<=
[when][]is less than=<
[when][]is greater than or equal to=>=
[when][]is greater than=>
[when][]is equal to===
[when][]equals===
[when][]There is a Cheese with=Cheese()
```

[when][]- {field:\w*} {operator} {value:\d*}={field} {operator} {value}

Given these DSL definitions, you can write rules with conditions such as:

```
There is a Cheese with
   - age is less than 42
   - rating is greater than 50
   - type equals 'stilton'
```

In this specific case, a phrase such as "is less than" is replaced by <, and then the line matches the last DSL entry. This removes the hyphen, but the final result is still added as a constraint to the preceding pattern. After processing all of the lines, the resulting DRL text is:

```
Cheese(age<42, rating > 50, type=='stilton')
```

Note

The order of the entries in the DSL is important if separate DSL expressions are intended to match the same line, one after the other.

5.10.4. Developing a DSL

A good way to get started is to write representative samples of the rules your application requires, and to test them as you develop. This will provide you with a stable framework of conditional elements and their constraints. Rules, both in DRL and in DSLR, refer to entities according to the data model representing the application data that should be subject to the reasoning process defined in rules. Notice that writing rules is generally easier if most of the data model's types are facts.

Given an initial set of rules, it should be possible to identify recurring or similar code snippets and to mark variable parts as parameters. This provides reliable leads as to what might be a handy DSL entry. Also, make sure you have a full grasp of the jargon the domain experts are using, and base your DSL phrases on this vocabulary.

You may postpone implementation decisions concerning conditions and actions during this first design phase by leaving certain conditional elements and actions in their DRL form by prefixing a line with a greater sign (">"). (This is also handy for inserting debugging statements.)

During the next development phase, you should find that the DSL configuration stabilizes pretty quickly. New rules can be written by reusing the existing DSL definitions, or by adding a parameter to an existing condition or consequence entry.

Try to keep the number of DSL entries small. Using parameters lets you apply the same DSL sentence for similar rule patterns or constraints. But do not exaggerate: authors using the DSL should still be able to identify DSL phrases by some fixed text.

5.10.5. DSL and DSLR Reference

A DSL file is a text file in a line-oriented format. Its entries are used for transforming a DSLR file into a file according to DRL syntax.

- A line starting with "#" or "//" (with or without preceding white space) is treated as a comment. A comment line starting with "#/" is scanned for words requesting a debug option, see below.
- Any line starting with an opening bracket ("[") is assumed to be the first line of a DSL entry definition.
- Any other line is appended to the preceding DSL entry definition, with the line end replaced by a space.

A DSL entry consists of the following four parts:

- A scope definition, written as one of the keywords "when" or "condition", "then" or "consequence", "*" and "keyword", enclosed in brackets ("[" and "]"). This indicates whether the DSL entry is valid for the condition or the consequence of a rule, or both. A scope indication of "keyword" means that the entry has global significance, i.e., it is recognized anywhere in a DSLR file.
- A type definition, written as a Java class name, enclosed in brackets. This part is optional unless the the next part begins with an opening bracket. An empty pair of brackets is valid, too.
- A DSL expression consists of a (Java) regular expression, with any number of embedded *variable definitions,* terminated by an equal sign ("="). A variable definition is enclosed in braces ("{" and "}"). It consists of a variable name and two optional attachements, separated by colons (":"). If there is one attachment, it is a regular expression for matching text that is to be assigned to the variable; if there are two attachments, the first one is a hint for the GUI editor and the second one the regular expression.

  Note that all characters that are "magic" in regular expressions must be escaped with a preceding backslash ("\") if they should occur literally within the expression.
- The remaining part of the line after the delimiting equal sign is the replacement text for any DSLR text matching the regular expression. It may contain variable references, i.e., a variable name enclosed in braces. Optionally, the variable name may be followed by an exclamation mark ("!") and a transformation function, see below.

  Note that braces ("{" and "}") must be escaped with a preceding backslash ("\") if they should occur literally within the replacement string.

Debugging of DSL expansion can be turned on, selectively, by using a comment line starting with "#/" which may contain one or more words from the table presented below. The resulting output is written to standard output.

Table 5.2. Debug options for DSL expansion

Word	Description
result	Prints the resulting DRL text, with line numbers.
steps	Prints each expansion step of condition and consequence lines.
keyword	Dumps the internal representation of all DSL entries with scope "keyword".
when	Dumps the internal representation of all DSL entries with scope "when" or "*".
then	Dumps the internal representation of all DSL entries with scope "then" or "*".

Word	Description
usage	Displays a usage statistic of all DSL entries.

Below are some sample DSL definitions, with comments describing the language features they illustrate.

```
# Comment: DSL examples

#/ debug: display result and usage

# keyword definition: replaces "regula" by "rule"
[keyword][]regula=rule

# conditional element: "T" or "t", "a" or "an", convert matched word
[when][][Tt]here is an? {entity:\w+}=
        ${entity!lc}: {entity!ucfirst} ()

# consequence statement: convert matched word, literal braces
[then][]update {entity:\w+}=modify( ${entity!lc} )\{ \}
```

The transformation of a DSLR file proceeds as follows:

1. The text is read into memory.
2. Each of the "keyword" entries is applied to the entire text. First, the regular expression from the keyword definition is modified by replacing white space sequences with a pattern matching any number of white space characters, and by replacing variable definitions with a capture made from the regular expression provided with the definition, or with the default (".*?"). Then, the DSLR text is searched exhaustively for occurrences of strings matching the modified regular expression. Substrings of a matching string corresponding to variable captures are extracted and replace variable references in the corresponding replacement text, and this text replaces the matching string in the DSLR text.
3. Sections of the DSLR text between "when" and "then", and "then" and "end", respectively, are located and processed in a uniform manner, line by line, as described below.

   For a line, each DSL entry pertaining to the line's section is taken in turn, in the order it appears in the DSL file. Its regular expression part is modified: white space is replaced by a pattern matching any number of white space characters; variable definitions with a regular expression are replaced by a capture with this regular expression, its default being ".*?". If the resulting regular expression matches all or part of the line, the matched part is replaced by the suitably modified replacement text.

   Modification of the replacement text is done by replacing variable references with the text corresponding to the regular expression capture. This text may be modified according to the string transformation function given in the variable reference; see below for details.

If there is a variable reference naming a variable that is not defined in the same entry, the expander substitutes a value bound to a variable of that name, provided it was defined in one of the preceding lines of the current rule.

4. If a DSLR line in a condition is written with a leading hyphen, the expanded result is inserted into the last line, which should contain a pattern CE, i.e., a type name followed by a pair of parentheses. if this pair is empty, the expanded line (which should contain a valid constraint) is simply inserted, otherwise a comma (",") is inserted beforehand.

   If a DSLR line in a consequence is written with a leading hyphen, the expanded result is inserted into the last line, which should contain a "modify" statement, ending in a pair of braces ("{" and "}"). If this pair is empty, the expanded line (which should contain a valid method call) is simply inserted, otherwise a comma (",") is inserted beforehand.

Note

It is currently *not* possible to use a line with a leading hyphen to insert text into other conditional element forms (e.g., "accumulate") or it may only work for the first insertion (e.g., "eval").

All string transformation functions are described in the following table.

Table 5.3. String transformation functions

Name	Description
uc	Converts all letters to upper case.
lc	Converts all letters to lower case.
ucfirst	Converts the first letter to upper case, and all other letters to lower case.
num	Extracts all digits and "-" from the string. If the last two digits in the original string are preceded by "." or ",", a decimal period is inserted in the corresponding position.
a?*b*/*c*	Compares the string with string *a*, and if they are equal, replaces it with *b*, otherwise with *c*. But *c* can be another triplet *a*, *b*, *c*, so that the entire structure is, in fact, a translation table.

The following DSL examples show how to use string transformation functions.

```
# definitions for conditions
[when][]There is an? {entity}=${entity!lc}: {entity!ucfirst}()
[when][]- with an? {attr} greater than {amount}={attr} <= {amount!num}
```

```
[when][]- with a {what} {attr}={attr} {what!positive?>0/negative?%lt;0/zero?==0/
ERROR}
```

A file containing a DSL definition is customarily given the extension `.dsl`. It is passed to the Knowledge Builder with `ResourceType.DSL`. For a file using DSL definition, the extension `.dslr` should be used. The Knowledge Builder expects `ResourceType.DSLR`. The IDE, however, relies on file extensions to correctly recognize and work with your rules file.

The DSL must be passed to the Knowledge Builder ahead of any rules file using the DSL.

```
KnowledgeBuilder kBuilder = new KnowledgeBuilder();
Resource dsl = ResourceFactory.newClassPathResource( dslPath, getClass() );
kBuilder.add( dsl, ResourceType.DSL );
Resource dslr = ResourceFactory.newClassPathResource( dslrPath, getClass() );
kBuilder.add( dslr, ResourceType.DSLR );
```

For parsing and expanding a DSLR file the DSL configuration is read and supplied to the parser. Thus, the parser can "recognize" the DSL expressions and transform them into native rule language expressions.

5.11. XML Rule Language

As an option, Drools also supports a "native" rule language as an alternative to DRL. This allows you to capture and manage your rules as XML data. Just like the non-XML DRL format, the XML format is parsed into the internal "AST" representation - as fast as possible (using a SAX parser). There is no external transformation step required. All the features are available with XML that are available to DRL.

5.11.1. When to use XML

There are several scenarios that XML is desirable. However, we recommend that it is not a default choice, as XML is not readily human readable (unless you like headaches) and can create visually bloated rules.

If you do want to edit XML by hand, use a good schema aware editor that provides nice hierarchical views of the XML, ideally visually (commercial tools like XMLSpy, Oxygen etc are good, but cost money, but then so do headache tablets).

Other scenarios where you may want to use the XML format are if you have a tool that generates rules from some input (programmatically generated rules), or perhaps interchange from another rule language, or from another tool that emits XML (using XSLT you can easily transform between XML formats). Note you can always generate normal DRL as well.

Alternatively you may be embedding Drools in a product that already uses XML for configuration, so you would like the rules to be in an XML format. You may be creating your own rule language

on XML - note that you can always use the AST objects directly to create your own rule language as well (the options are many, due to the open architecture).

5.11.2. The XML format

A full W3C standards (XMLSchema) compliant XSD is provided that describes the XML language, which will not be repeated here verbatim. A summary of the language follows.

Example 5.62. A rule in XML

```
<?xml version="1.0" encoding="UTF-8"?>

<package name="com.sample"
         xmlns="http://drools.org/drools-4.0"
         xmlns:xs="http://www.w3.org/2001/XMLSchema-instance"
         xs:schemaLocation="http://drools.org/drools-4.0 drools-4.0.xsd">

<import name="java.util.HashMap" />
<import name="org.drools.*" />

<global identifier="x" type="com.sample.X" />
<global identifier="yada" type="com.sample.Yada" />

<function return-type="void" name="myFunc">
    <parameter identifier="foo" type="Bar" />
    <parameter identifier="bada" type="Bing" />

    <body>
     System.out.println("hello world");
    </body>
</function>

<rule name="simple_rule">
<rule-attribute name="salience" value="10" />
<rule-attribute name="no-loop" value="true" />
<rule-attribute name="agenda-group" value="agenda-group" />
<rule-attribute name="activation-group" value="activation-group" />

<lhs>
    <pattern identifier="foo2" object-type="Bar" >
            <or-constraint-connective>
                <and-constraint-connective>
                    <field-constraint field-name="a">
                        <or-restriction-connective>
                            <and-restriction-connective>
                               <literal-restriction evaluator=">" value="60" />
                               <literal-restriction evaluator="<" value="70" />
                            </and-restriction-connective>
```

```
                        <and-restriction-connective>
                           <literal-restriction evaluator="<" value="50" />
                           <literal-restriction evaluator=">" value="55" />
                        </and-restriction-connective>
                    </or-restriction-connective>
                </field-constraint>

                <field-constraint field-name="a3">
                    <literal-restriction evaluator="==" value="black" />
                </field-constraint>
            </and-constraint-connective>

            <and-constraint-connective>
                <field-constraint field-name="a">
                    <literal-restriction evaluator="==" value="40" />
                </field-constraint>

                <field-constraint field-name="a3">
                    <literal-restriction evaluator="==" value="pink" />
                </field-constraint>
            </and-constraint-connective>

            <and-constraint-connective>
                <field-constraint field-name="a">
                    <literal-restriction evaluator="==" value="12"/>
                </field-constraint>

                <field-constraint field-name="a3">
                    <or-restriction-connective>
                       <literal-restriction evaluator="==" value="yellow"/>
                        <literal-restriction evaluator="==" value="blue" />
                    </or-restriction-connective>
                </field-constraint>
            </and-constraint-connective>
        </or-constraint-connective>
    </pattern>

    <not>
        <pattern object-type="Person">
            <field-constraint field-name="likes">
                <variable-restriction evaluator="==" identifier="type"/>
            </field-constraint>
        </pattern>

        <exists>
            <pattern object-type="Person">
                <field-constraint field-name="likes">
                   <variable-restriction evaluator="==" identifier="type"/>
                </field-constraint>
```

```
                </pattern>
            </exists>
        </not>

        <or-conditional-element>
            <pattern identifier="foo3" object-type="Bar" >
                <field-constraint field-name="a">
                    <or-restriction-connective>
                        <literal-restriction evaluator="==" value="3" />
                        <literal-restriction evaluator="==" value="4" />
                    </or-restriction-connective>
                </field-constraint>
                <field-constraint field-name="a3">
                    <literal-restriction evaluator="==" value="hello" />
                </field-constraint>
                <field-constraint field-name="a4">
                    <literal-restriction evaluator="==" value="null" />
                </field-constraint>
            </pattern>

            <pattern identifier="foo4" object-type="Bar" >
                <field-binding field-name="a" identifier="a4" />
                <field-constraint field-name="a">
                    <literal-restriction evaluator="!=" value="4" />
                    <literal-restriction evaluator="!=" value="5" />
                </field-constraint>
            </pattern>
        </or-conditional-element>

        <pattern identifier="foo5" object-type="Bar" >
            <field-constraint field-name="b">
                <or-restriction-connective>
                     <return-value-restriction evaluator="==" >a4 + 1</return-
value-restriction>
                    <variable-restriction evaluator=">" identifier="a4" />
                    <qualified-identifier-restriction evaluator="==">
                        org.drools.Bar.BAR_ENUM_VALUE
                    </qualified-identifier-restriction>
                </or-restriction-connective>
            </field-constraint>
        </pattern>

        <pattern identifier="foo6" object-type="Bar" >
            <field-binding field-name="a" identifier="a4" />
            <field-constraint field-name="b">
                <literal-restriction evaluator="==" value="6" />
            </field-constraint>
        </pattern>
  </lhs>
```

```
 <rhs>
    if ( a == b ) {
      assert( foo3 );
    } else {
      retract( foo4 );
    }
    System.out.println( a4 );
   </rhs>
</rule>

</package>
```

In the preceding XML text you will see the typical XML element, the package declaration, imports, globals, functions, and the rule itself. Most of the elements are self explanatory if you have some understanding of the Drools features.

The `import` elements import the types you wish to use in the rule.

The `global` elements define global objects that can be referred to in the rules.

The `function` contains a function declaration, for a function to be used in the rules. You have to specify a return type, a unique name and parameters, in the body goes a snippet of code.

The rule is discussed below.

Example 5.63. Detail of rule element

```
<rule name="simple_rule">
<rule-attribute name="salience" value="10" />
<rule-attribute name="no-loop" value="true" />
<rule-attribute name="agenda-group" value="agenda-group" />
<rule-attribute name="activation-group" value="activation-group" />

<lhs>
    <pattern identifier="cheese" object-type="Cheese">
        <from>
            <accumulate>
                <pattern object-type="Person"></pattern>
                <init>
                    int total = 0;
                </init>
                <action>
                    total += $cheese.getPrice();
                </action>
                <result>
                    new Integer( total ) );
                </result>
            </accumulate>
```

```
        </from>
    </pattern>

    <pattern identifier="max" object-type="Number">
        <from>
            <accumulate>
                <pattern identifier="cheese" object-type="Cheese"></pattern>
                <external-function evaluator="max" expression="$price"/>
            </accumulate>
        </from>
    </pattern>
</lhs>
<rhs>
    list1.add( $cheese );
</rhs>
</rule>
```

In the above detail of the rule we see that the rule has LHS and RHS (conditions and consequence) sections. The RHS is simple, it is just a block of semantic code that will be executed when the rule is activated. The LHS is slightly more complicated as it contains nested elements for conditional elements, constraints and restrictions.

A key element of the LHS is the Pattern element. This allows you to specify a type (class) and perhaps bind a variable to an instance of that class. Nested under the pattern object are constraints and restrictions that have to be met. The Predicate and Return Value constraints allow Java expressions to be embedded.

That leaves the conditional elements, not, exists, and, or etc. They work like their DRL counterparts. Elements that are nested under and an "and" element are logically "anded" together. Likewise with "or" (and you can nest things further). "Exists" and "Not" work around patterns, to check for the existence or nonexistence of a fact meeting the pattern's constraints.

The Eval element allows the execution of a valid snippet of Java code - as long as it evaluates to a boolean (do not end it with a semi-colon, as it is just a fragment) - this can include calling a function. The Eval is less efficient than the columns, as the rule engine has to evaluate it each time, but it is a "catch all" feature for when you can express what you need to do with Column constraints.

5.11.3. Legacy Drools 2.x XML rule format

The Drools 2.x legacy XML format is no longer supported by Drools XML parser

5.11.4. Automatic transforming between formats (XML and DRL)

Drools comes with some utility classes to transform between formats. This works by parsing the rules from the source format into the AST, and then "dumping" out to the appropriate target format. This allows you, for example, to write rules in DRL, and when needed, export to XML if necessary at some point in the future.

The classes to look at if you need to do this are:

```
XmlDumper - for exporting XML.
DrlDumper - for exporting DRL.
DrlParser - reading DRL.
XmlPackageReader - reading XML.
```

Using combinations of the above, you can convert between any format (including round trip). Note that DSLs will not be preserved (from DRLs that are using a DSL) - but they will be able to be converted.

Feel free to make use of XSLT to provide all sorts of possibilities for XML, XSLT and its ilk are what make XML powerful.

Chapter 6. Authoring

6.1. Decision Tables in Spreadsheets

Decision tables are a "precise yet compact" (ref. Wikipedia) way of representing conditional logic, and are well suited to *business* level rules.

Drools supports managing rules in a spreadsheet format. Supported formats are Excel (XLS), and CSV, which means that a variety of spreadsheet programs (such as Microsoft Excel, OpenOffice.org Calc amongst others) can be utilized. It is expected that web based decision table editors will be included in a near future release.

Decision tables are an old concept (in software terms) but have proven useful over the years. Very briefly speaking, in Drools decision tables are a way to generate rules driven from the data entered into a spreadsheet. All the usual features of a spreadsheet for data capture and manipulation can be taken advantage of.

6.1.1. When to Use Decision Tables

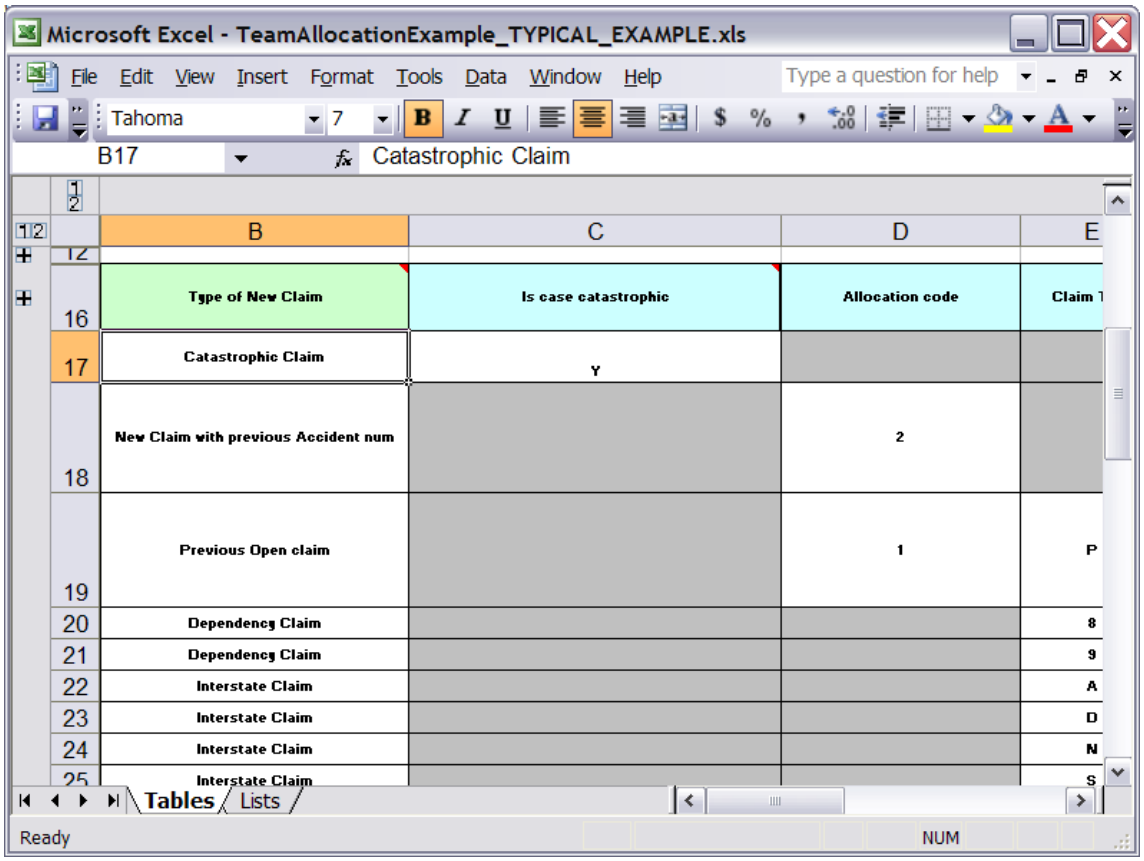
Consider decision tables as a course of action if rules exist that can be expressed as rule templates and data: each row of a decision table provides data that is combined with a template to generate a rule.

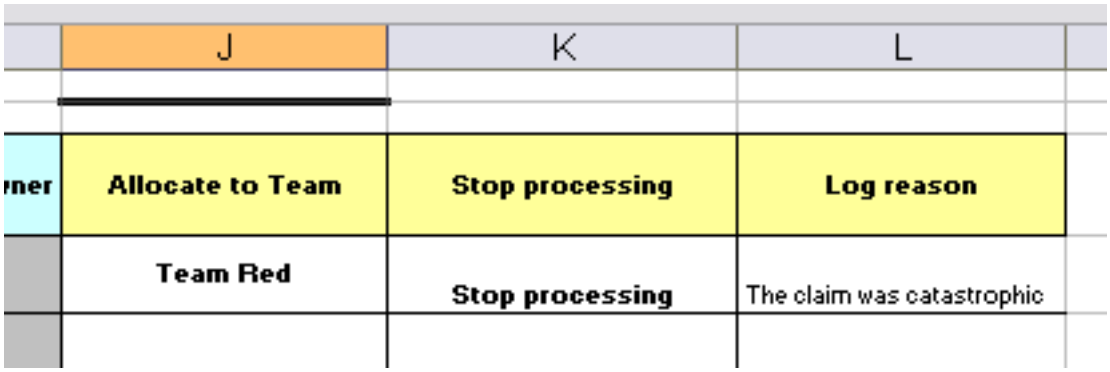
Many businesses already use spreadsheets for managing data, calculations, etc. If you are happy to continue this way, you can also manage your business rules this way. This also assumes you are happy to manage packages of rules in `.xls` or `.csv` files. Decision tables are not recommended for rules that do not follow a set of templates, or where there are a small number of rules (or if there is a dislike towards software like Excel or OpenOffice.org). They are ideal in the sense that there can be control over what *parameters* of rules can be edited, without exposing the rules directly.

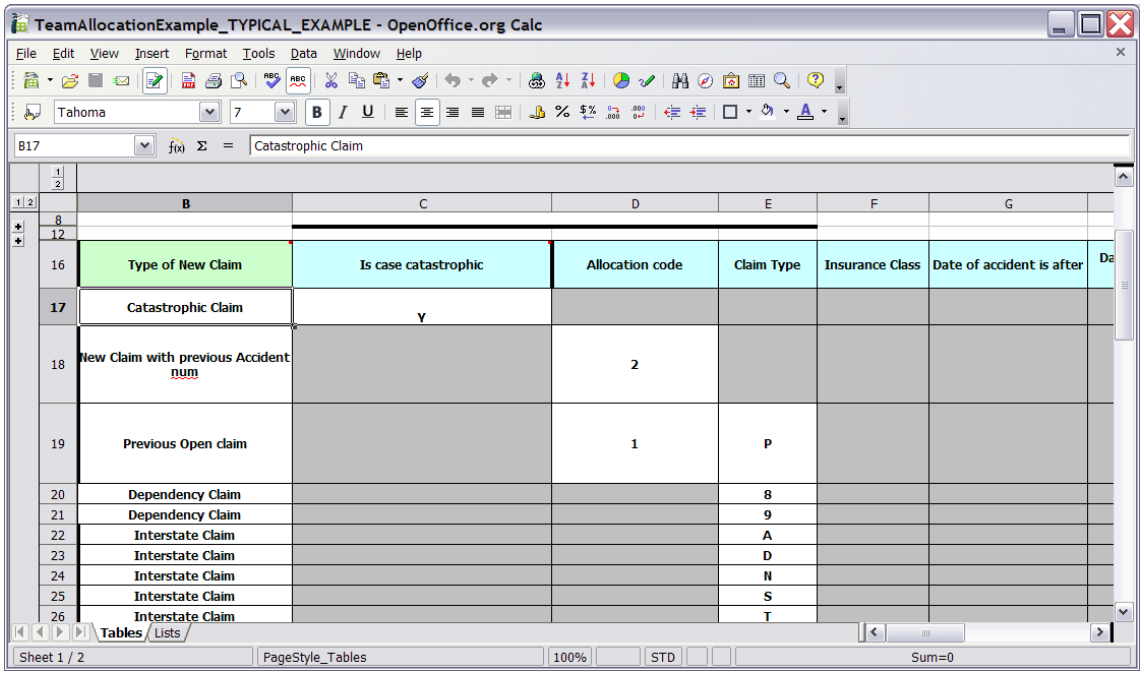
Decision tables also provide a degree of insulation from the underlying object model.

6.1.2. Overview

Here are some examples of real world decision tables (slightly edited to protect the innocent).


Microsoft Excel - TeamAllocationExample_TYPICAL_EXAMPLE.xls
File Edit View Insert Format Tools Data Window Help
Type a question for help
Tahoma 7
B17 Catastrophic Claim
B C D E
Type of New Claim
Is case catastrophic
Allocation code
Claim T
Catastrophic Claim
Y
New Claim with previous Accident num
2
Previous Open claim
1
P
Dependency Claim
8
Dependency Claim
9
Interstate Claim
A
Interstate Claim
D
Interstate Claim
N
Interstate Claim
S
Tables Lists
Ready
NUM


J K L
ner
Allocate to Team
Stop processing
Log reason
Team Red
Stop processing
The claim was catastrophic



	B	C	D	E	F	G
16	Type of New Claim	Is case catastrophic	Allocation code	Claim Type	Insurance Class	Date of accident is after
17	Catastrophic Claim	Y				
18	New Claim with previous Accident num		2			
19	Previous Open claim		1	P		
20	Dependency Claim			8		
21	Dependency Claim			9		
22	Interstate Claim			A		
23	Interstate Claim			D		
24	Interstate Claim			N		
25	Interstate Claim			S		
26	Interstate Claim			T		

In the above examples, the technical aspects of the decision table have been collapsed away (using a standard spreadsheet feature).

The rules start from row 17, with each row resulting in a rule. The conditions are in columns C, D, E, etc., the actions being off-screen. The values in the cells are quite simple, and their meaning is indicated by the headers in Row 16. Column B is just a description. It is customary to use color to make it obvious what the different areas of the table mean.

Note

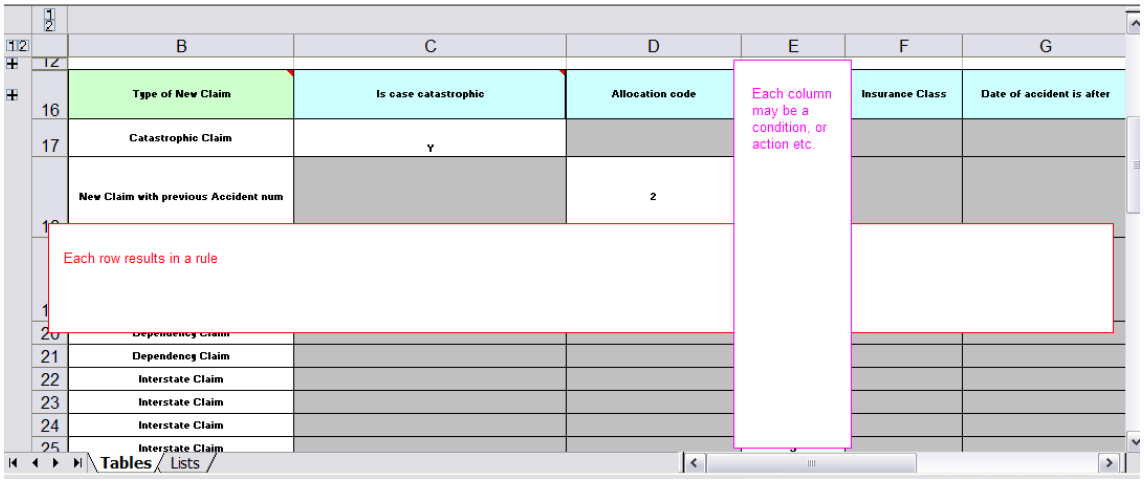
Note that although the decision tables look like they process top down, this is not necessarily the case. Ideally, rules are authored without regard for the order of rows, simply because this makes maintenance easier, as rows will not need to be shifted around all the time.

As each row is a rule, the same principles apply. As the rule engine processes the facts, any rules that match may fire. (Some people are confused by this. It is possible to clear the agenda when a rule fires and simulate a very simple decision table where only the first match effects an action.) Also note that you can have multiple tables on one spreadsheet. This way, rules can be grouped where they share common templates, yet at the end of the day they are all combined into one rule package. Decision tables are essentially a tool to generate DRL rules automatically.

	Module	PRSC[02]			
	RuleSet	Control Cajas[1]			
1.ValidarAperturaCaja (Caja, Registro Estado Sucursal,Transaccion)					
ID_Caso de Uso	Caso de Uso	Identificadores de las Reglas	Prioridades de las Reglas	Nombres de las Reglas	Descripciones
		1	2000	ValidarAperturaCajaSucursal Abierta	Esta Regla tiene por Mision Validar que la sucursal de la se encuentre abierta Trabaja sobre la Caja que se intenta abrir, la Sucursa corresponde a esa caja y la Transacción de Caj apertura
		2	2000	ValidarAperturaCajaMismaFe cha	Esta Regla tiene por Mision Validar que en la sucursal caja se encuentre abierta para la misma fecha de ape de la caja. Trabaja sobre la Caja que se intenta abrir, la Sucursa corresponde a esa caja y la Transacción de Caj apertura
2.ValidarCierreCajasSucursal(Registro Estado Sucursal, TransaccionCaja)					
ID_Caso de Uso	Caso de Uso	Identificadores de las Reglas	Prioridades de las Reglas	Nombres de las Reglas	Descripciones
C_PRSC_503 C_PRSC_504 C_PRSC_513		1	1000	ValidarCierreCajasSucursal	Esta Regla tiene por Misión Validar que al moment efectuarse el Cierre Contable de una Sucursal de FON todas las Cajas de esta última se encuentren en E Cerrado, es decir la Fecha de Cierre de Caja debe ser a la Fecha de cierre de la entidad Registro_Cierre_Suc
3.ValidarTransaccionCaja(Caja, Transaccion_Caja)					
RuleTable[3] ValidarTransaccionCaja(CajaVO caja, MovimientoCajaVO movimientoCaja)					
ID_Caso de Uso	Caso de Uso	Identificador	Prioridad	Nombre	Descripcion

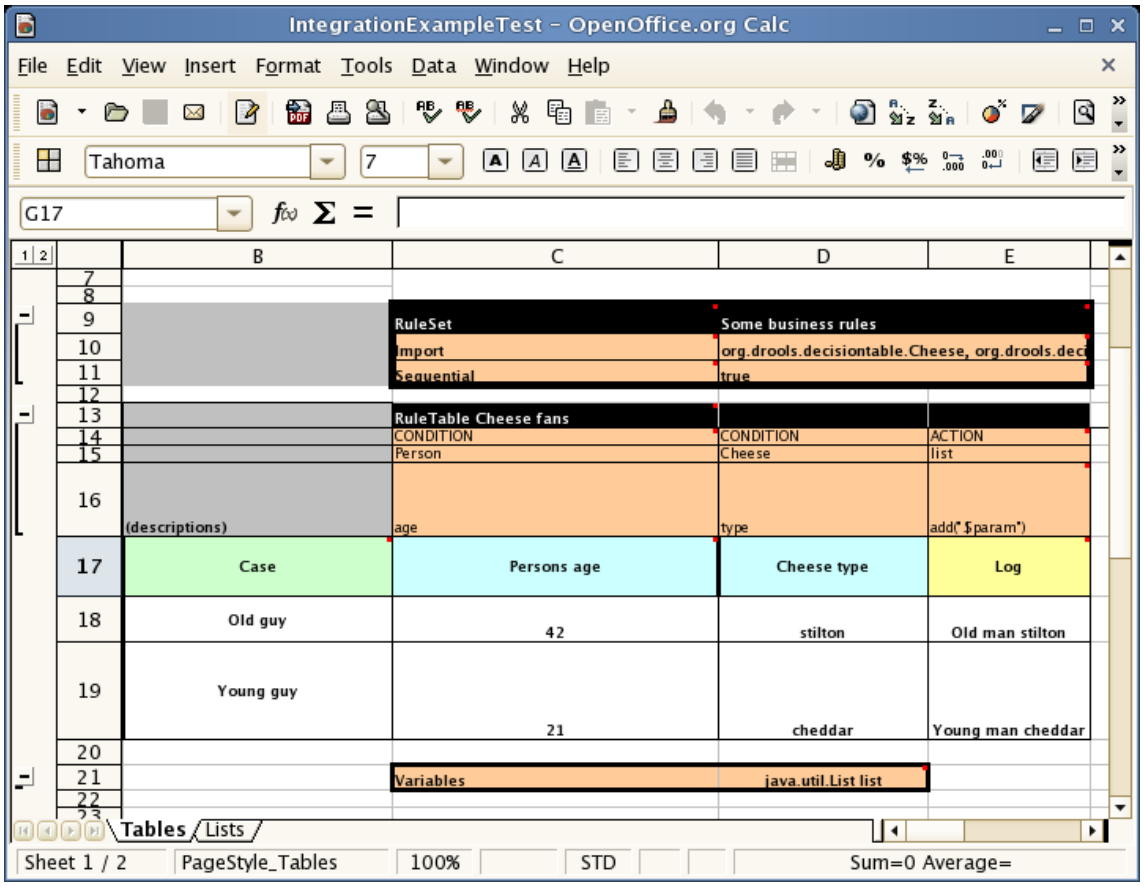
6.1.3. How Decision Tables Work

The key point to keep in mind is that in a decision table each row is a rule, and each column in that row is either a condition or action for that rule.



The spreadsheet looks for the *RuleTable* keyword to indicate the start of a rule table (both the starting row and column). Other keywords are also used to define other package level attributes (covered later). It is important to keep the keywords in one column. By convention the second column ("B") is used for this, but it can be any column (convention is to leave a margin on the left for notes). In the following diagram, C is actually the column where it starts. Everything to the left of this is ignored.

If we expand the hidden sections, it starts to make more sense how it works; note the keywords in column C.



Now the hidden magic which makes it work can be seen. The RuleSet keyword indicates the name to be used in the *rule package* that will encompass all the rules. This name is optional, using a default, but it *must* have the *RuleSet* keyword in the cell immediately to the right.

The other keywords visible in Column C are Import and Sequential which will be covered later. The RuleTable keyword is important as it indicates that a chunk of rules will follow, based on some rule templates. After the RuleTable keyword there is a name, used to prefix the names of the generated rules. The row numbers are appended to guarantee unique rule names. The column of RuleTable indicates the column in which the rules start; columns to the left are ignored.

Note

In general the keywords make up name-value pairs.

Referring to row 14 (the row immediately after RuleTable), the keywords CONDITION and ACTION indicate that the data in the columns below are for either the LHS or the RHS parts of a rule. There are other attributes on the rule which can also be optionally set this way.

Row 15 contains declarations of *ObjectTypes*. The content in this row is optional, but if this option is not in use, the row must be left blank; however this option is usually found to be quite useful. When using this row, the values in the cells below (row 16) become constraints on that object type.

In the above case, it generates `Person(age=="42")` and `Cheese(type=="stilton")`, where 42 and "stilton" come from row 18. In the above example, the "==" is implicit; if just a field name is given the translator assumes that it is to generate an exact match.

Note

An ObjectType declaration can span columns (via merged cells), meaning that all columns below the merged range are to be combined into one set of constraints within a single pattern matching a single fact at a time, as opposed to non-merged cells containing the same ObjectType, but resulting in different patterns, potentially matching different or identical facts.

Row 16 contains the rule templates themselves. They can use the "$param" placeholder to indicate where data from the cells below should be interpolated. (For multiple insertions, use "$1", "$2", etc., indicating parameters from a comma-separated list in a cell below.) Row 17 is ignored; it may contain textual descriptions of the column's purpose.

Rows 18 and 19 show data, which will be combined (interpolated) with the templates in row 15, to generate rules. If a cell contains no data, then its template is ignored. (This would mean that some condition or action does not apply for that rule row.) Rule rows are read until there is a blank row. Multiple RuleTables can exsist in a sheet. Row 20 contains another keyword, and a value. The row positions of keywords like this do not matter (most people put them at the top) but their column should be the same one where the RuleTable or RuleSet keywords should appear. In our case column C has been chosen to be significant, but any other column could be used instead.

In the above example, rules would be rendered like the following (as it uses the "ObjectType" row):

```
//row 18
rule "Cheese_fans_18"
when
    Person(age=="42")
    Cheese(type=="stilton")
then
    list.add("Old man stilton");
end
```

Note

The constraints `age=="42"` and `type=="stilton"` are interpreted as single constraints, to be added to the respective ObjectType in the cell above. If the cells above were spanned, then there could be multiple constraints on one "column".

6.1.4. Spreadsheet Syntax

6.1.4.1. Spreadsheet Structure

There are two types of rectangular areas defining data that is used for generating a DRL file. One, marked by a cell labelled `RuleSet`, defines all DRL items except rules. The other one may occur repeatedly and is to the right and below a cell whose contents begin with `RuleTable`. These areas represent the actual decision tables, each area resulting in a set of rules of similar structure.

A Rule Set area may contain cell pairs, one below the `RuleSet` cell and containing a keyword designating the kind of value contained in the other one that follows in the same row.

The columns of a Rule Table area define patterns and constraints for the left hand sides of the rules derived from it, actions for the consequences of the rules, and the values of individual rule attributes. Thus, a Rule Table area should contain one or more columns, both for conditions and actions, and an arbitrary selection of columns for rule attributes, at most one column for each of these. The first four rows following the row with the cell marked with `RuleTable` are earmarked as header area, mostly used for the definition of code to construct the rules. It is any additional row below these four header rows that spawns another rule, with its data providing for variations in the code defined in the Rule Table header.

All keywords are case insensitive.

Only the first worksheet is examined for decision tables.

6.1.4.2. Rule Set Entries

Entries in a Rule Set area may define DRL constructs (except rules), and specify rule attributes. While entries for constructs may be used repeatedly, each rule attribute may be given at most once, and it applies to all rules unless it is overruled by the same attribute being defined within the Rule Table area.

Entries must be given in a vertically stacked sequence of cell pairs. The first one contains a keyword and the one to its right the value, as shown in the table below. This sequence of cell pairs may be interrupted by blank rows or even a Rule Table, as long as the column marked by `RuleSet` is upheld as the one containing the keyword.

Table 6.1. Entries in the Rule Set area

Keyword	Value	Usage
RuleSet	The package name for the generated DRL file. Optional, the default is `rule_table`.	Must be First entry.
Sequential	"true" or "false". If "true", then salience is used to ensure that rules fire from the top down.	Optional, at most once. If omitted, no firing order is imposed.

Keyword	Value	Usage
Import	A comma-separated list of Java classes to import.	Optional, may be used repeatedly.
Variables	Declarations of DRL globals, i.e., a type followed by a variable name. Multiple global definitions must be separated with a comma.	Optional, may be used repeatedly.
Functions	One or more function definitions, according to DRL syntax.	Optional, may be used repeatedly.
Queries	One or more query definitions, according to DRL syntax.	Optional, may be used repeatedly.

For defining rule attributes that apply to all rules in the generated DRL file you can use any of the entries in the following table. Notice, however, that the proper keyword must be used. Also, each of these attributes may be used only once.

Table 6.2. Rule attribute entries in the Rule Set area

Keyword	Initial	Value
PRIORITY	P	An integer defining the "salience" value for the rule. Overriden by the "Sequential" flag.
DURATION	D	A long integer value defining the "duration" value for the rule.
NO-LOOP	U	A Boolean value. "true" inhibits looping of rules due to changes made by its consequence.
LOCK-ON-ACTIVE	L	A Boolean value. "true" inhibits additional activations of all rules with this flag set within the same ruleflow or agenda group.
AUTO-FOCUS	F	A Boolean value. "true" for a rule within an agenda group causes activations of the rule to automatically give the focus to the group.

Keyword	Initial	Value
ACTIVATION-GROUP	X	A string identifying an activation (or XOR) group. Only one rule within an activation group will fire, i.e., the first one to fire cancels any existing activations of other rules within the same group.
AGENDA-GROUP	G	A string identifying an agenda group, which has to be activated by giving it the "focus", which is one way of controlling the flow between groups of rules.
RULEFLOW-GROUP	R	A string identifying a rule-flow group.

6.1.4.3. Rule Tables

All Rule Tables begin with a cell containing "RuleTable", optionally followed by a string within the same cell. The string is used as the initial part of the name for all rules derived from this Rule Table, with the row number appended for distinction. (This automatic naming can be overridden by using a NAME column.) All other cells defining rules of this Rule Table are below and to the right of this cell.

The next row defines the column type, with each column resulting in a part of the condition or the consequence, or providing some rule attribute, the rule name or a comment. The table below shows which column headers are available; additional columns may be used according to the table showing rule attribute entries given in the preceding section. Note that each attribute column may be used at most once. For a column header, either use the keyword or any other word beginning with the letter given in the "Initial" column of these tables.

Table 6.3. Column Headers in the Rule Table

Keyword	Initial	Value	Usage
NAME	N	Provides the name for the rule generated from that row. The default is constructed from the text following the RuleTable tag and the row number.	At most one column

Keyword	Initial	Value	Usage
DESCRIPTION	I	A text, resulting in a comment within the generated rule.	At most one column
CONDITION	C	Code snippet and interpolated values for constructing a constraint within a pattern in a condition.	At least one per rule table
ACTION	A	Code snippet and interpolated values for constructing an action for the consequence of the rule.	At least one per rule table
METADATA	@	Code snippet and interpolated values for constructing a metadata entry for the rule.	Optional, any number of columns

Given a column headed CONDITION, the cells in successive lines result in a conditional element.

- Text in the first cell below CONDITION develops into a pattern for the rule condition, with the snippet in the next line becoming a constraint. If the cell is merged with one or more neighbours, a single pattern with multiple constraints is formed: all constraints are combined into a parenthesized list and appended to the text in this cell. The cell may be left blank, which means that the code snippet in the next row must result in a valid conditional element on its own.

  To include a pattern without constraints, you can write the pattern in front of the text for another pattern.

  The pattern may be written with or without an empty pair of parentheses. A "from" clause may be appended to the pattern.

  If the pattern ends with "eval", code snippets are supposed to produce boolean expressions for inclusion into a pair of parentheses after "eval".

- Text in the second cell below CONDITION is processed in two steps.

  1. The code snippet in this cell is modified by interpolating values from cells farther down in the column. If you want to create a constraint consisting of a comparison using "==" with the value from the cells below, the field selector alone is sufficient. Any other comparison operator must be specified as the last item within the snippet, and the value from the cells below is appended. For all other constraint forms, you must mark the position for including

the contents of a cell with the symbol `$param`. Multiple insertions are possible by using the symbols `$1`, `$2`, etc., and a comma-separated list of values in the cells below.

A text according to the pattern `forall(`*delimiter*`){`*snippet*`}` is expanded by repeating the *snippet* once for each of the values of the comma-separated list of values in each of the cells below, inserting the value in place of the symbol `$` and by joining these expansions by the given *delimiter*. Note that the forall construct may be surrounded by other text.

2. If the cell in the preceding row is not empty, the completed code snippet is added to the conditional element from that cell. A pair of parentheses is provided automatically, as well as a separating comma if multiple constraints are added to a pattern in a merged cell.

   If the cell above is empty, the interpolated result is used as is.

- Text in the third cell below CONDITION is for documentation only. It should be used to indicate the column's purpose to a human reader.
- From the fourth row on, non-blank entries provide data for interpolation as described above. A blank cell results in the omission of the conditional element or constaint for this rule.

Given a column headed ACTION, the cells in successive lines result in an action statement.

- Text in the first cell below ACTION is optional. If present, it is interpreted as an object reference.
- Text in the second cell below ACTION is processed in two steps.

  1. The code snippet in this cell is modified by interpolating values from cells farther down in the column. For a singular insertion, mark the position for including the contents of a cell with the symbol `$param`. Multiple insertions are possible by using the symbols `$1`, `$2`, etc., and a comma-separated list of values in the cells below.

     A method call without interpolation can be achieved by a text without any marker symbols. In this case, use any non-blank entry in a row below to include the statement.

     The forall construct is available here, too.

  2. If the first cell is not empty, its text, followed by a period, the text in the second cell and a terminating semicolon are stringed together, resulting in a method call which is added as an action statement for the consequence.

     If the cell above is empty, the interpolated result is used as is.

- Text in the third cell below ACTION is for documentation only. It should be used to indicate the column's purpose to a human reader.
- From the fourth row on, non-blank entries provide data for interpolation as described above. A blank cell results in the omission of the action statement for this rule.

Note

Using `$1` instead of `$param` works in most cases, but it will fail if the replacement text contains a comma: then, only the part preceding the first comma is inserted. Use this "abbreviation" judiciously.

Given a column headed METADATA, the cells in successive lines result in a metadata annotation for the generated rules.

- Text in the first cell below METADATA is ignored.
- Text in the second cell below METADATA is subject to interpolation, as described above, using values from the cells in the rule rows. The metadata marker character `@` is prefixed automatically, and thus it should not be included in the text for this cell.
- Text in the third cell below METADATA is for documentation only. It should be used to indicate the column's purpose to a human reader.
- From the fourth row on, non-blank entries provide data for interpolation as described above. A blank cell results in the omission of the metadata annotation for this rule.

6.1.4.4. Examples

The various interpolations are illustrated in the following example.

Example 6.1. Interpolating cell data

If the template is `Foo(bar == $param)` and the cell is `42`, then the result is `Foo(bar == 42)`.

If the template is `Foo(bar < $1, baz == $2)` and the cell contains `42,43`, the result will be `Foo(bar < 42, baz ==43)`.

The template `forall(&&){bar != $}` with a cell containing `42,43` results in `bar != 42 && bar != 43`.

The next example demonstrates the joint effect of a cell defining the pattern type and the code snippet below it.

13	RuleTable Cheese fans	
14	CONDITION	CONDITION
15	Person	
16	age	type
17	Persons age	Cheese type
18	42	stilton
19	21	cheddar

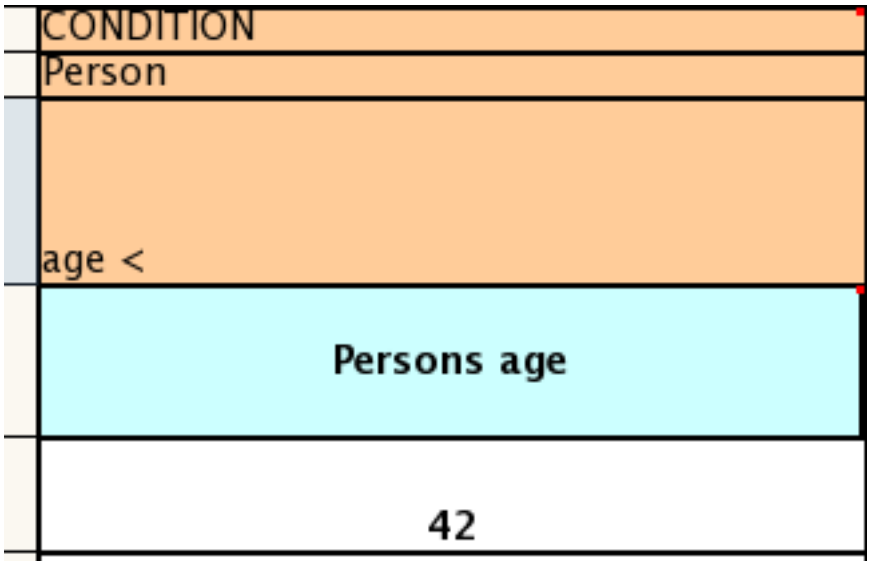
This spreadsheet section shows how the `Person` type declaration spans 2 columns, and thus both constraints will appear as `Person(age == ..., type == ...)`. Since only the field names are present in the snippet, they imply an equality test.

In the following example the marker symbol `$param` is used.

CONDITION
Person
age==“$param”
Persons age
42

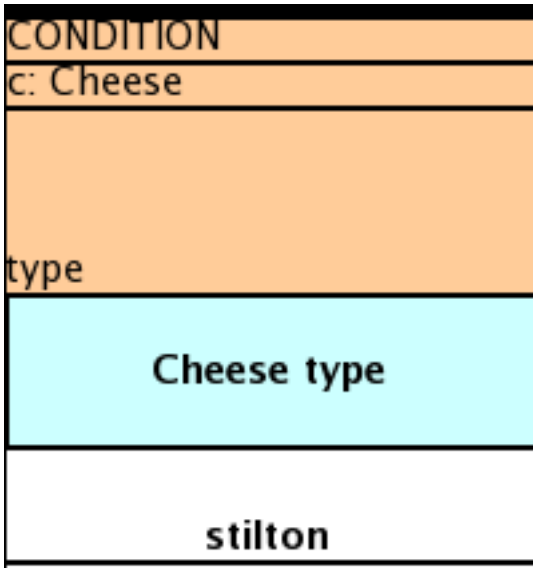
The result of this column is the pattern `Person(age == "42"))`. You may have noticed that the marker and the operator "==" are redundant.

The next example illustrates that a trailing insertion marker can be omitted.



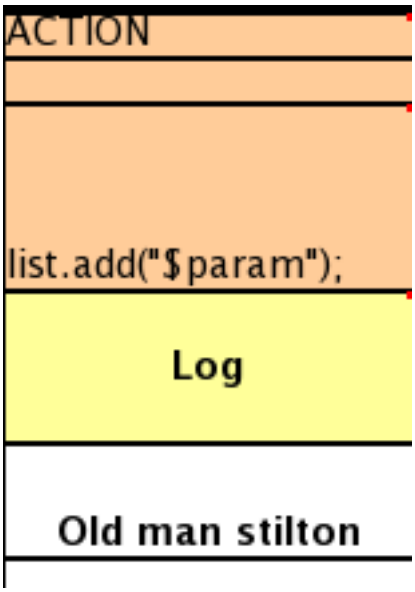
Here, appending the value from the cell is implied, resulting in `Person(age < "42")).`

You can provide the definition of a binding variable, as in the example below. .



Here, the result is `c: Cheese(type == "stilton").` Note that the quotes are provided automatically. Actually, anything can be placed in the object type row. Apart from the definition of a binding variable, it could alse be an additional pattern that is to be inserted literally.

A simple construction of an action statement with the insertion of a single value is shown below.



The cell below the ACTION header is left blank. Using this style, anything can be placed in the consequence, not just a sinle method call. (The same technique is applicable within a CONDITION column as well.)

Below is a comprehensive example, showing the use of various column headers. It is not an error to have no value below a column header (as in the NO-LOOP column): here, the attribute will not be applied in any of the rules.

	B	C	D	E	F	G	H
1							
2		RuleSet	org.acme.insurance.base				
3		import	import org.acme.insurance.base.Approve, import org.acme.insurance.base.Driver				
4		Package	org.acme.insurance.base				
5							
6		RuleTable Old Driver					
7		CONDITION	CONDITION	RULEFLOW-GROUP	NO-LOOP	ACTION	ACTION
8		$driver: Driver					
9	iptions)	licenceYears	priorClaims			insert(new Approve("$param"));	System.out.println("Sta
10	ase	Persons age	Prior Claims			Inserting approvment	Log
11	d guy	30	1	risk assessment		Safe and mature	Old driver Approved
12							
13							
14							
15							
16							

And, finally, here is an example of Import, Variables and Functions.

RuleSet	Control Cajas[1]
Import	foo.Bar, bar.Baz
Variables	Parameters parametros, RulesResult resultado, EvalDate fecha

Functions	function boolean isRango(int iValor, int iRangoInicio, int iRangoFinal) {
	if (iRangoInicio <= iValor && iValor <= iRangoFinal)
	return true;
	return false;
	}
	
	function boolean isIgualTipo(TipoVO tipoVO, int p_tipo, boolean isNull) {
	if (tipoVO == null)
	return isNull;
	return tipoVO.getSecuencia().intValue() == p_tipo;
	}

Multiple package names within the same cell must be separated by a comma. Also, the pairs of type and variable names must be comma-separated. Functions, however, must be written as they appear in a DRL file. This should appear in the same column as the "RuleSet" keyword; it could be above, between or below all the rule rows.

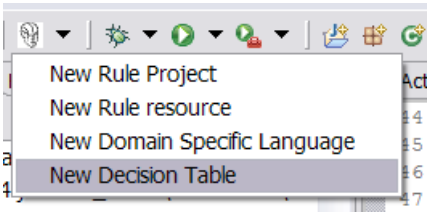
Note

It may be more convenient to use Import, Variables, Functions and Queries repeatedly rather than packing several definitions into a single cell.

6.1.5. Creating and integrating Spreadsheet based Decision Tables

The API to use spreadsheet based decision tables is in the drools-decisiontables module. There is really only one class to look at: `SpreadsheetCompiler`. This class will take spreadsheets in various formats, and generate rules in DRL (which you can then use in the normal way). The `SpreadsheetCompiler` can just be used to generate partial rule files if it is wished, and assemble it into a complete rule package after the fact (this allows the separation of technical and non-technical aspects of the rules if needed).

To get started, a sample spreadsheet can be used as a base. Alternatively, if the plug-in is being used (Rule Workbench IDE), the wizard can generate a spreadsheet from a template (to edit it an xls compatible spreadsheet editor will need to be used).



6.1.6. Managing Business Rules in Decision Tables

6.1.6.1. Workflow and Collaboration

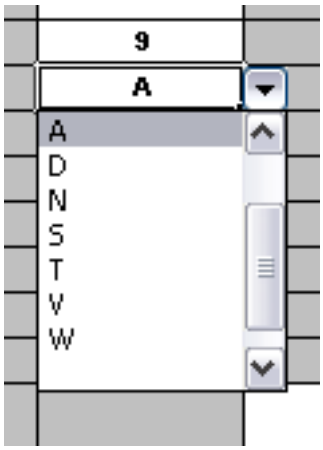
Spreadsheets are well established business tools (in use for over 25 years). Decision tables lend themselves to close collaboration between IT and domain experts, while making the business rules clear to business analysts, it is an ideal separation of concerns.

Typically, the whole process of authoring rules (coming up with a new decision table) would be something like:

1. Business analyst takes a template decision table (from a repository, or from IT)
2. Decision table business language descriptions are entered in the table(s)
3. Decision table rules (rows) are entered (roughly)
4. Decision table is handed to a technical resource, who maps the business language (descriptions) to scripts (this may involve software development of course, if it is a new application or data model)
5. Technical person hands back and reviews the modifications with the business analyst.
6. The business analyst can continue editing the rule rows as needed (moving columns around is also fine etc).
7. In parallel, the technical person can develop test cases for the rules (liaising with business analysts) as these test cases can be used to verify rules and rule changes once the system is running.

6.1.6.2. Using spreadsheet features

Features of applications like Excel can be used to provide assistance in entering data into spreadsheets, such as validating fields. Lists that are stored in other worksheets can be used to provide valid lists of values for cells, like in the following diagram.



Some applications provide a limited ability to keep a history of changes, but it is recommended to use an alternative means of revision control. When changes are being made to rules over time, older versions are archived (many open source solutions exist for this, such as Subversion or Git).

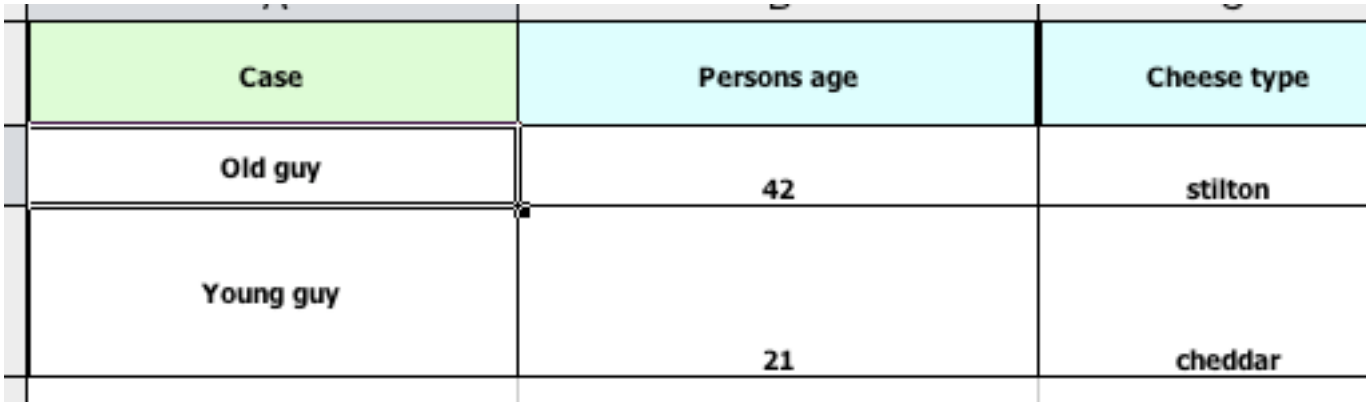
6.1.7. Rule Templates

Related to decision tables (but not necessarily requiring a spreadsheet) are "Rule Templates" (in the drools-templates module). These use any tabular data source as a source of rule data - populating a template to generate many rules. This can allow both for more flexible spreadsheets, but also rules in existing databases for instance (at the cost of developing the template up front to generate the rules).

With Rule Templates the data is separated from the rule and there are no restrictions on which part of the rule is data-driven. So whilst you can do everything you could do in decision tables you can also do the following:

- store your data in a database (or any other format)
- conditionally generate rules based on the values in the data
- use data for any part of your rules (e.g. condition operator, class name, property name)
- run different templates over the same data

As an example, a more classic decision table is shown, but without any hidden rows for the rule meta data (so the spreadsheet only contains the raw data to generate the rules).



Case	Persons age	Cheese type
Old guy	42	stilton
Young guy	21	cheddar

See the `ExampleCheese.xls` in the examples download for the above spreadsheet.

If this was a regular decision table there would be hidden rows before row 1 and between rows 1 and 2 containing rule metadata. With rule templates the data is completely separate from the rules. This has two handy consequences - you can apply multiple rule templates to the same data and your data is not tied to your rules at all. So what does the template look like?

```
1  template header
2  age
3  type
4  log
5
6  package org.drools.examples.templates;
7
8  global java.util.List list;
9
10 template "cheesefans"
11
12 rule "Cheese fans_@{row.rowNumber}"
13 when
14    Person(age == @{age})
15    Cheese(type == "@{type}")
16 then
17    list.add("@{log}");
18 end
19
20 end template
```

Annotations to the preceding program listing:

- Line 1: All rule templates start with `template header`.
- Lines 2-4: Following the header is the list of columns in the order they appear in the data. In this case we are calling the first column `age`, the second `type` and the third `log`.

- Line 5: An empty line signifies the end of the column definitions.
- Lines 6-9: Standard rule header text. This is standard rule DRL and will appear at the top of the generated DRL. Put the package statement and any imports and global and function definitions into this section.
- Line 10: The keyword `template` signals the start of a rule template. There can be more than one template in a template file, but each template should have a unique name.
- Lines 11-18: The rule template - see below for details.
- Line 20: The keywords `end template` signify the end of the template.

The rule templates rely on MVEL to do substitution using the syntax @{token_name}. There is currently one built-in expression, @{row.rowNumber} which gives a unique number for each row of data and enables you to generate unique rule names. For each row of data a rule will be generated with the values in the data substituted for the tokens in the template. With the example data above the following rule file would be generated:

```
package org.drools.examples.templates;

global java.util.List list;

rule "Cheese fans_1"
when
  Person(age == 42)
  Cheese(type == "stilton")
then
  list.add("Old man stilton");
end

rule "Cheese fans_2"
when
  Person(age == 21)
  Cheese(type == "cheddar")
then
  list.add("Young man cheddar");
end
```

The code to run this is simple:

```
DecisionTableConfiguration dtableconfiguration =
    KnowledgeBuilderFactory.newDecisionTableConfiguration();
dtableconfiguration.setInputType( DecisionTableInputType.XLS );
```

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();

kbuilder.add( ResourceFactory.newClassPathResource( getSpreadsheetName(),
                                                    getClass() ),
              ResourceType.DTABLE,
              dtableconfiguration );
```

6.2. Templates

If you discover that you have a group of rules following the same arrangement of patterns, constraints and actions on the RHS, differing only in constants or names for objects or fields, you might think of employing Drool's rule template feature for generating the actual rules. You would write a *rule template* file, containing the textual skeleton of your rule and use the Drools template compiler in combination with a collection of objects providing the actual values for the "flesh" of the rules for their instantiation.

The mechanism is very similar to what a macro processor does. The major advantage proffered by template expansion is that it's nicely integrated in the overall handling of Knowledge Resources.

Caution

This is an experimental feature. In particular, the API is subject to change.

6.2.1. The Rule Template File

A rule template file begins with a header defining the placeholders, or *formal template parameters* for the strings that are to be inserted during instantiation. After the first line, which invariably contains `template header`, you should write a number of lines, each of which contains a single parameter name.

Example 6.2. Rule template file: template header

```
template header
parameter-name-1
...
parameter-name-n
...
```

The template header is followed by the text that is to be replicated and interpolated with the actual parameters. It may begin with a `package` statement, followed by some additional lines. These may be sectioned into one or more templates, each of them between a pair of matching `template` and `end template` statements. The `template` takes an argument, which puts a name to the template.

The name can be a simple unquoted name or an arbitrary string enclosed in double quotes. The template text between these lines may contain one or more rules, constituting the "raw material" for the expansion.

Example 6.3. Rule template file: templates

```
template header
parameter-name-1
...
parameter-name-n
package ...     # optional
header text    # optional
template template-name
...
// template text
...
end template
...
```

The resulting text will begin with the package line and the header text following it, if present. Then, each template text will be expanded individually, yielding one set of rules for each of the actual parameter sets. Therefore, the structure of the template sections affect the order of the generated rules, since the generator iterates over the sections and then over the set of actual parameters.

Any interpolation takes place between a pair of `template` and `end template` statements, when this template is expanded. The template text is scanned for occurrences of *parameter expansions* written according to:

```
@{parameter-name}
```

The name between '@{' and '}' should be one of the parameter names defined in the template header. The substitution is effected anywhere, even within string literals.

An important parameter is available without having to be included in the data source providing the actual values. The parameter substitution **`@{row.rowNumber}`** expands to the integers 0, 1, 2, etc., providing a unique distinction for the instantiation derived from a parameter set. You would use this as part of each rule name, because, without this precaution, there would be duplicate rule names. (You are, of course, free to use your own identification included as an extra parameter.)

6.2.2. Expanding a Template

To expand a template, you must prepare a data source. This can be a spreadsheet, as explained in the previous section. Here, we'll concentrate on expansion driven by Java objects. There

are two straightforward ways of supplying values for a fixed set of names: Java objects, in the JavaBeans style, and Maps. Both of them can be arranged in a `Collection`, whose elements will be processed during the expansion, resulting in an instantiation for each element.

6.2.2.1. Instantiation from Java Objects

You may use a Java object that provides getter methods corresponding to all of the parameter names of your template file. If, for instance, you have defined a header

```
template header
type
limit
word
```

the following Java class could be used:

```
public class ParamSet {
    //...
    public ParamSet( String t, int l, boolean w ) {
        //...
    }
    public String  getType(){...}
    public int     getLimit(){...}
    public boolean isWord(){...}
}
```

Although interpolation is pure text manipulation, the actual values supplied may be of any type, just as long as this type provides a reasonable `toString()` method. (For simple types, the eponymous static method of the related class from `java.lang` is used.)

Assuming that we have created a `Collection<ParamSet>` for a template file `template.drl`, we can now proceed to request its expansion.

```
Collection<ParamSet> paramSets = new ArrayList<ParamSet>();
// populate paramSets
paramSets.add( new ParamSet( "Foo", 42, true ) );
paramSets.add( new ParamSet( "Bar", 13, false ) );
ObjectDataCompiler converter = new ObjectDataCompiler();
InputStream templateStream =
    this.getClass().getResourceAsStream( "template.drl" );
String drl = converter.compile( objs, templateStream );
```

The resulting string contains the expanded rules text. You could write it to a file and proceed as usual, but it's also possible to feed this to a `KnowledgeBuilder` and continue with the resulting Knowledge Packages.

```
KnowledgeBase kBase = KnowledgeBaseFactory.newKnowledgeBase();
KnowledgeBuilder kBuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
Reader rdr = new StringReader( drl );
kBuilder.add( ResourceFactory.newReaderResource( rdr ), ResourceType.DRL );
if( kBuilder.hasErrors() ){
    // ...
    throw new IllegalStateException( "DRL errors" );
}
kBase.addKnowledgePackages( kBuilder.getKnowledgePackages() );
```

6.2.2.2. Instantiation from Maps

A `Map` that provides the values for substituting template parameters should have a (string) key set matching all of the parameter names. Again, values could be from any class, as long as they provide a good `toString()` method. The expansion would use the same approach, just differing in the way the map collection is composed.

```
Collection<Map<String,Object>> paramMaps = new ArrayList<Map<String,Object>>();
// populate paramMaps
ObjectDataCompiler converter = new ObjectDataCompiler();
InputStream templateStream =
    this.getClass().getResourceAsStream( "template.drl" );
String drl = converter.compile( objs, templateStream );
```

6.2.3. Example

The following example illustrates template expansion. It is based on simple objects of class `Item` containing a couple of integer fields and an `enum` field of type `ItemCode`.

```
public class Item {
    // ...
    public Item( String n, int p, int w, ItemCode c ){...}

    public String   getName() {...}
    public int      getWeight() {...}
    public int      getPrice() {...}
    public ItemCode getCode() {...}
```

```
}

public enum ItemCode {
    LOCK,
    STOCK,
    BARREL;
}
```

The rule template contains a single rule. Notice that the field name for the range test is a parameter, which enables us to instantiate the template for different fields.

```
template header
field
lower
upper
codes

package range;
template "inRange"
rule "is in range @{row.rowNumber}"
when
     Item( $name : name, $v : @{field} >= @{lower} && <= @{upper}, $code :
 code @{codes} )
then
     System.out.println( "Item " + $name + " @{field} in range: " + $v + "
 code: " + $code );
end
end template
```

The next code snippet is from the application, where several parameter sets have to be set up. First, there is class `ParamSet`, for storing a set of actual parameters.

```
public class ParamSet {
    //...
    private EnumSet<ItemCode> codeSet;

    public ParamSet( String f, int l, int u, EnumSet<ItemCode> cs ){...}

    public String getField() { return field; }
    public int getLower() { return lower; }
    public int getUpper() { return upper; }

    public String getCodes(){
```

```
        StringBuilder sb = new StringBuilder();
        String conn = "";
        for( ItemCode ic: codeSet ){
             sb.append( conn ).append( " == ItemCode." ).append( ic );
             conn = " ||";
        }
        return sb.toString();
    }
}
```

Note that the method `getCodes()` does returns the `EnumSet<ItemCode>` field value as a `String` value representing a multiple restriction, i.e., a test for one out of a list of values.

The task of expanding a template, passing the resulting DRL text to a Knowledge Builder and adding the resulting Knowledge Packages to a Knowledge Base is generic. The utility class `Expander` takes care of this, using a Knowledge Base, the `InputStream` with the rule template and the collection of parameter sets.

```
public class Expander {

    public void expand( KnowledgeBase kBase, InputStream is, Collection<?> act )
        throws Exception {
        ObjectDataCompiler converter = new ObjectDataCompiler();
        String drl = converter.compile( act, is );

      KnowledgeBuilder kBuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
        Reader rdr = new StringReader( drl );
      kBuilder.add( ResourceFactory.newReaderResource( rdr ), ResourceType.DRL );
        if( kBuilder.hasErrors() ){
            for( KnowledgeBuilderError err: kBuilder.getErrors() ){
                System.err.println( err.toString() );
            }
            throw new IllegalStateException( "DRL errors" );
        }
        kBase.addKnowledgePackages( kBuilder.getKnowledgePackages() );
    }
}
```

We are now all set to prepare the Knowledge Base with some generated rules. First, we define several parameter sets, constructed as `ParamSet` objects, and add them to a `List`, which is passed to the `expand` method shown above. Then we launch a stateful session, insert a few `Item`, and watch what happens.

```

```

```
Collection<ParamSet> cfl = new ArrayList<ParamSet>();
cfl.add( new ParamSet( "weight",  10,  99, EnumSet.of( ItemCode.LOCK, ItemCode.STOCK ) ) );
cfl.add( new ParamSet( "price",   10,  50, EnumSet.of( ItemCode.BARREL ) ) );

KnowledgeBase kBase = KnowledgeBaseFactory.newKnowledgeBase();
Expander ex = new Expander();
InputStream dis = new FileInputStream( new File( "rangeTemp.drl" ) );
ex.expand( kBase, dis, cfl );

StatefulKnowledgeSession session = kBase.newStatefulKnowledgeSession();
session.insert( new Item( "A", 130,  42, ItemCode.LOCK ) );
session.insert( new Item( "B",  44, 100, ItemCode.STOCK ) );
session.insert( new Item( "C", 123, 180, ItemCode.BARREL ) );
session.insert( new Item( "D",  85,   9, ItemCode.LOCK ) );

session.fireAllRules();
```

Notice that the two resulting rules deal with *different* fields, one with an item's weight, the other one with its price. - Below is the output.

```


Item E price in range: 25 code: BARREL
Item A weight in range: 42 code: LOCK
```

Chapter 7. The Java Rule Engine API

7.1. Introduction

Drools provides an implementation of the Java Rule Engine API (known as JSR94), which allows for support of multiple rule engines from a single API. JSR94 does not deal in any way with the rule language itself. W3C is working on the *Rule Interchange Format (RIF)* [http://www.w3.org/TR/2006/WD-rif-ucr-20060323/] and the OMG has started to work on a standard based on *RuleML* [http://ruleml.org/]. Recently Haley Systems has also proposed a rule language standard called RML.

It should be remembered that the JSR94 standard represents the "least common denominator" in features across rule engines. This means that there is less functionality in the JSR94 API than in the standard Knowledge (Drools and jBPM) API. So, by using JSR94, you forfeit the advantage of using the full capabilities of the Drools Rule Engine. It is necessary to expose further functionality, like globals and support for DRL, DSL and XML, via property maps due to the very basic feature set of JSR94; this introduces non-portable functionality. Furthermore, as JSR94 does not provide a rule language, you are only solving a small fraction of the complexity of switching rule engines with very little gain. So, while we support JSR94, for those that insist on using it, we strongly recommend you program against the Knowledge (Drools and jBPM) API.

7.2. How To Use

There are two parts to working with JSR94. The first part is the administrative API that deals with building and registering RuleExecutionSet objects, the second part is runtime session execution of these RuleExecutionSets.

7.2.1. Building and Registering RuleExecutionSets

The RuleServiceProviderManager manages the registration and retrieval of RuleServiceProviders. The Drools RuleServiceProvider implementation is automatically registered via a static block when the class is loaded using Class.forNamem, in much the same way as JDBC drivers.

Example 7.1. Automatic RuleServiceProvider Registration

```
// RuleServiceProviderImpl is registered to "http://drools.org/"
// via a static initialization block
Class.forName("org.drools.jsr94.rules.RuleServiceProviderImpl");

// Get the rule service provider from the provider manager.
```

```
RuleServiceProvider ruleServiceProvider =
  RuleServiceProviderManager.getRuleServiceProvider("http://drools.org/");
```

The RuleServiceProvider provides access to the RuleRuntime and RuleAdministrator APIs. The RuleAdministrator provides an administration API for the management of RuleExecutionSet objects, making it possible to register a RuleExecutionSet that can then be retrieved via the RuleRuntime.

First, you need to create a RuleExecutionSet before it can be registered; RuleAdministrator provides factory methods to return an empty LocalRuleExecutionSetProvider or RuleExecutionSetProvider. The LocalRuleExecutionSetProvider should be used to load a RuleExecutionSets from local sources that are not serializable, like Streams. The RuleExecutionSetProvider can be used to load RuleExecutionSets from serializable sources, like DOM Elements or Packages. Both the "ruleAdministrator.getLocalRuleExecutionSetProvider(null);" and the "ruleAdministrator.getRuleExecutionSetProvider(null);" take null as a parameter, as the properties map for these methods is not currently used.

Example 7.2. Registering a LocalRuleExecutionSet with the RuleAdministrator API

```
// Get the RuleAdministration
RuleAdministrator ruleAdministrator = ruleServiceProvider.getRuleAdministrator();
LocalRuleExecutionSetProvider ruleExecutionSetProvider =
  ruleAdministrator.getLocalRuleExecutionSetProvider( null );

// Create a Reader for the drl
URL drlUrl = new URL("http://mydomain.org/sources/myrules.drl");
Reader drlReader = new InputStreamReader(  drlUrl.openStream()  );

// Create the RuleExecutionSet for the drl
RuleExecutionSet ruleExecutionSet =
  ruleExecutionSetProvider.createRuleExecutionSet( drlReader, null );
```

"ruleExecutionSetProvider.createRuleExecutionSet(reader, null)" in the above example takes a null parameter for the properties map; however it can actually be used to provide configuration for the incoming source. When null is passed the default is used to load the input as a drl. Allowed keys for a map are "source" and "dsl". The key "source" takes "drl" or "xml" as its value; you set "source" to "drl" to load a DRL, or to "xml" to load an XML source; "xml" will ignore any "dsl" key/value settings. The "dsl" key can take a Reader or a String (the contents of the dsl) as a value.

Example 7.3. Specifying a DSL when registering a LocalRuleExecutionSet

```
// Get the RuleAdministration
```

```
RuleAdministration ruleAdministrator = ruleServiceProvider.getRuleAdministrator();
LocalRuleExecutionSetProvider ruleExecutionSetProvider =
  ruleAdministrator.getLocalRuleExecutionSetProvider( null );

// Create a Reader for the drl
URL drlUrl = new URL("http://mydomain.org/sources/myrules.drl");
Reader drlReader = new InputStreamReader(  drlUrl.openStream()  );

// Create a Reader for the dsl and a put in the properties map
URL dslUrl = new URL("http://mydomain.org/sources/myrules.dsl");
Reader dslReader = new InputStreamReader( dslUrl.openStream()  );
Map properties = new HashMap();
properties.put( "source", "drl" );
properties.put( "dsl", dslReader );

// Create the RuleExecutionSet for the drl and dsl
RuleExecutionSet ruleExecutionSet =
  ruleExecutionSetProvider.createRuleExecutionSet( reader, properties );
```

When registering a RuleExecutionSet you must specify the name to be used for its retrieval. There is also a field to pass properties, which is currently unused - so just pass null.

Example 7.4. Register the RuleExecutionSet

```
// Register the RuleExecutionSet with the RuleAdministrator
String uri = ruleExecutionSet.getName();
ruleAdministrator.registerRuleExecutionSet(uri, ruleExecutionSet, null);
```

7.2.2. Using Stateful and Stateless RuleSessions

The Runtime, obtained from the RuleServiceProvider, is used to create stateful and stateless rule engine sessions.

Example 7.5. Getting the RuleRuntime

```
RuleRuntime ruleRuntime = ruleServiceProvider.getRuleRuntime();
```

To create a rule session you must use one of the two RuleRuntime public constants. These are "RuleRuntime.STATEFUL_SESSION_TYPE" and "RuleRuntime.STATELESS_SESSION_TYPE", accompanying the URI to the RuleExecutionSet you wish to instantiate a RuleSession for. The properties map can be null, or it can be used to specify globals, as shown in the next section. The createRuleSession(...) method returns a RuleSession instance which must then be cast to StatefulRuleSession or StatelessRuleSession.

Example 7.6. Stateful Rule

```
(StatefulRuleSession) session =
  ruleRuntime.createRuleSession( uri,
                                 null,
                                 RuleRuntime.STATEFUL_SESSION_TYPE );
session.addObject( new PurchaseOrder( "lots of cheese" ) );
session.executeRules();
```

The StatelessRuleSession has a very simple API; you can only call executeRules(List list) passing a list of objects, and an optional filter, the resulting objects are then returned.

Example 7.7. Stateless

```
(StatelessRuleSession) session =
  ruleRuntime.createRuleSession( uri,
                                 null,
                                 RuleRuntime.STATELESS_SESSION_TYPE );
List list = new ArrayList();
list.add( new PurchaseOrder( "even more cheese" ) );

List results = new ArrayList();
results = session.executeRules( list );
```

7.2.2.1. Globals

It is possible to support globals with JSR94, in a manner that is not portable, by using the properties map passed to the RuleSession factory method. Globals must be defined in the DRL or XML file first, otherwise an exception will be thrown. The key represents the identifier declared in the DRL or XML, and the value is the instance you wish to be used in the execution. In the following example the results are collected in a java.util.List which is used as global:

```
java.util.List globalList = new java.util.ArrayList( );
java.util.Map map = new java.util.HashMap( );
map.put( "list", globalList );
//Open a stateless Session
StatelessRuleSession srs =
  (StatelessRuleSession) runtime.createRuleSession( "SistersRules",
                                                    map,
                                          RuleRuntime.STATELESS_SESSION_TYPE );
...
// Persons added to List
// call executeRules( ) giving a List of Objects as parameter
// There are rules which will put Objects in the List
```

```
// fetch the list from the map
List list = (java.util.List) map.get("list");
```

Do not forget to declare the global "list" in your DRL:

```
package SistersRules;
import org.drools.jsr94.rules.Person;
global java.util.List list
rule FindSisters
when
    $person1 : Person ( $name1:name )
    $person2 : Person ( $name2:name )
    eval( $person1.hasSister($person2) )
then
   list.add($person1.getName() + " and " + $person2.getName() +" are sisters");
   assert( $person1.getName() + " and " + $person2.getName() +" are sisters");
end
```

7.3. References

If you need more information on JSR 94, please refer to the following references

1. Official JCP Specification for Java Rule Engine API (JSR 94)
   - *http://www.jcp.org/en/jsr/detail?id=94*
2. The Java Rule Engine API documentation
   - *http://www.javarules.org/api_doc/api/index.html*
3. The Logic From The Bottom Line: An Introduction to The Drools Project. By N. Alex Rupp, published on TheServiceSide.com in 2004
   - *http://www.theserverside.com/articles/article.tss?l=Drools*
4. Getting Started With the Java Rule Engine API (JSR 94): Toward Rule-Based Applications. By Dr. Qusay H. Mahmoud, published on Sun Developer Network in 2005
   - *http://java.sun.com/developer/technicalArticles/J2SE/JavaRule.html*
5. Jess and the javax.rules API. By Ernest Friedman-Hill, published on TheServerSide.com in 2003
   - *http://www.theserverside.com/articles/article.tss?l=Jess*

Chapter 8. The Rule IDE (Eclipse)

The Eclipse based IDE provides developers (and very technical users) with an environment to edit and test rules in various formats, and integrate it deeply with their applications. In cases where you prefer business rules and web tooling, you will want to look at the BRMS (but using the BRMS and the IDE together is not uncommon).

The Drools IDE is delivered as an Eclipse plug-in, which allows you to author and manage rules from within Eclipse, as well as integrate rules with your application. This is an optional tool, and not all components are required to be used, you can use what components are relevant to you. The Drools IDE is also a part of the Red Hat Developer Studio (formerly known as JBoss IDE).

This guide will cover some of the features of JBoss Drools, in as far as the IDE touches on them (it is assumed that the reader has some familiarity with rule engines, and Drools in particular. It is important to note that none of the underlying features of the rule engine are dependent on Eclipse, and integrators are free to use their tools of choice, as always ! Plenty of people use IntelliJ with rules, for instance.

Note

You can get the plug-in either as a zip to download, or from an update site. Refer to the chapter on installation.

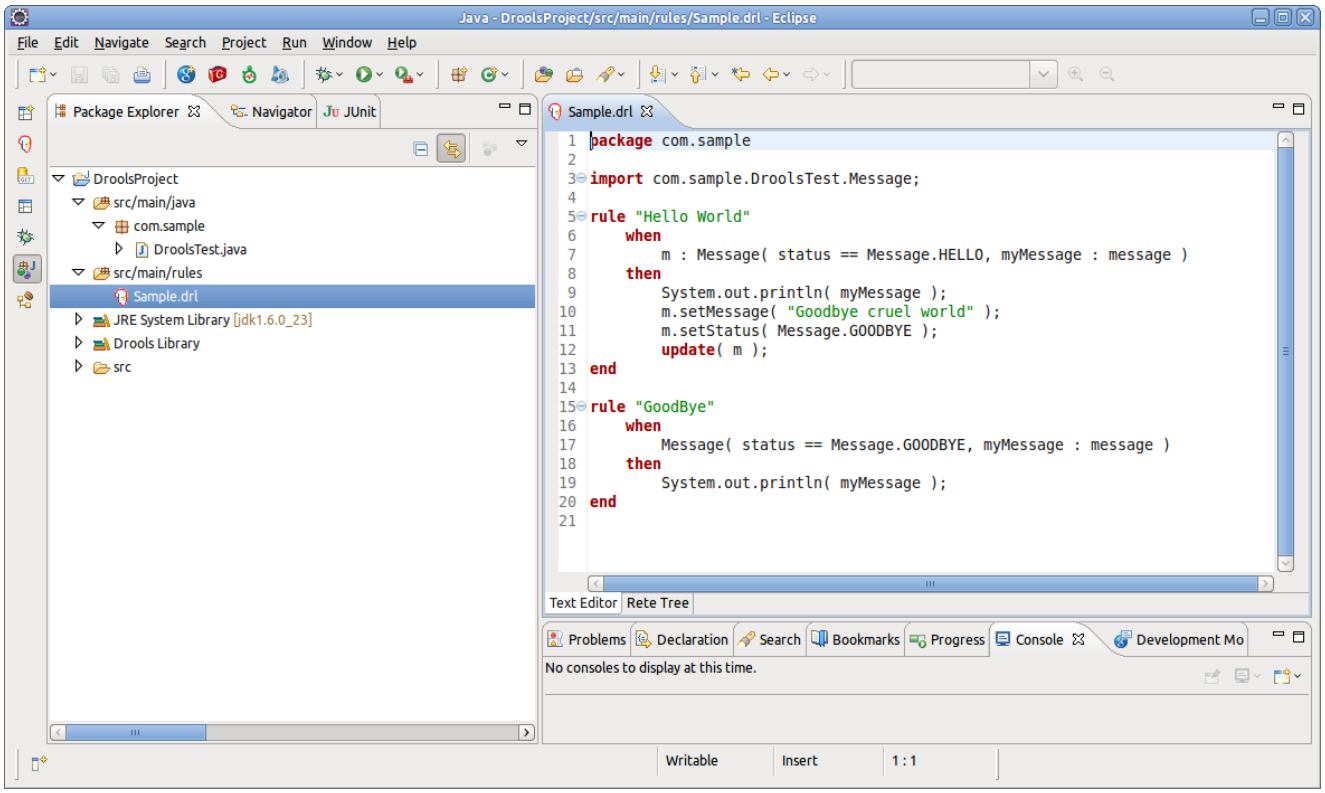


Figure 8.1. Overview

8.1. Features Outline

The rules IDE has the following features

1. Textual/graphical rule editor
   a. An editor that is aware of DRL syntax, and provides content assistance (including an outline view)
   b. An editor that is aware of DSL (domain specific langauge) extensions, and provides content assistance.
2. RuleFlow graphical editor

   You can edit visual graphs which represent a process (a rule flow). The RuleFlow can then be applied to your rule package to have imperative control.
3. Wizards for fast creation of
   a. a "rules" project
   b. a rule resource, either as a DRL file or a "guided rule editor" file (.brl)
   c. a Domain Specific language

   d. a decision table

   e. a ruleflow

4. A domain specific language editor

   a. Create and manage mappings from your user's language to the rule language

5. Rule validation

   a. As rules are entered, the rule is "built" in the background and errors reported via the problem view where possible

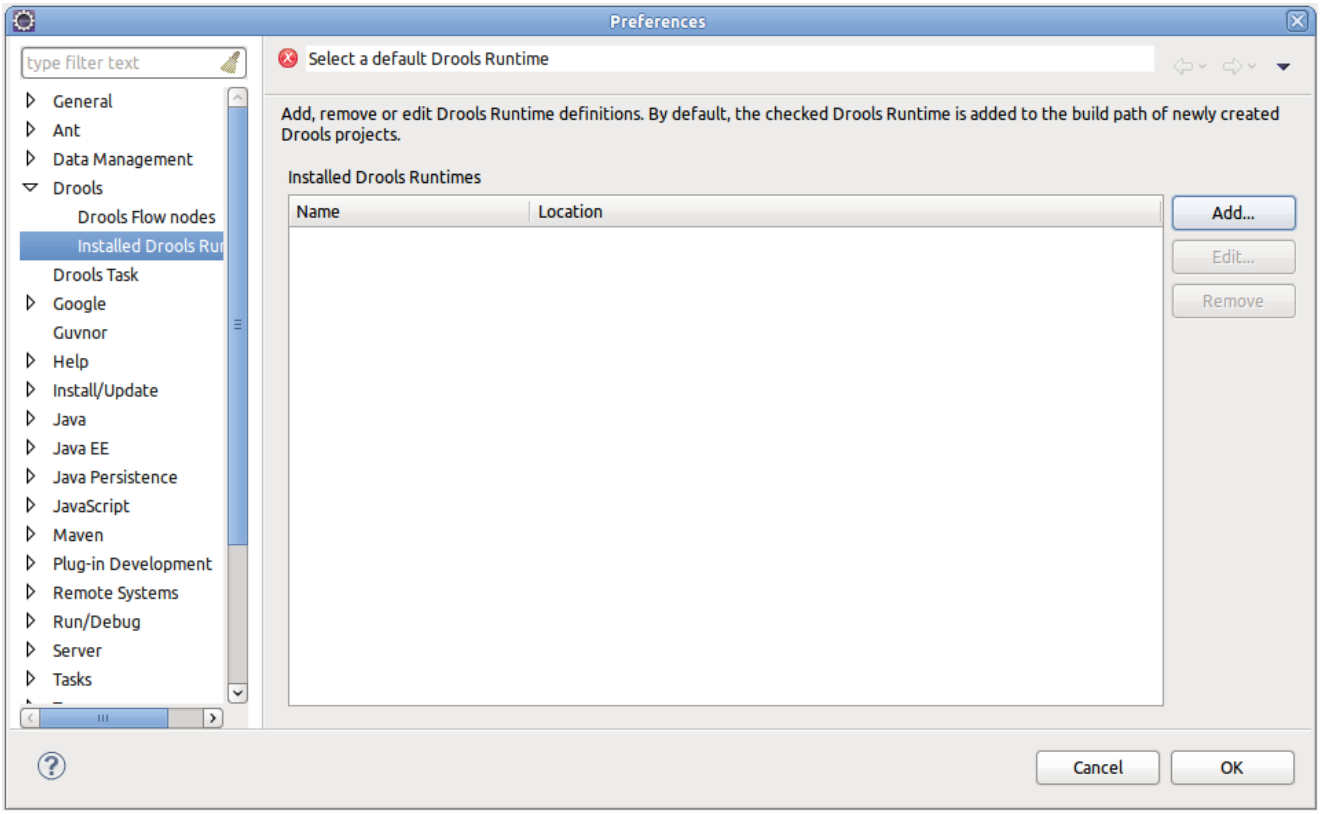
The above features make use of Eclipse infrastructure and features, with all of the power of Eclipse being available.

8.2. Drools Runtimes

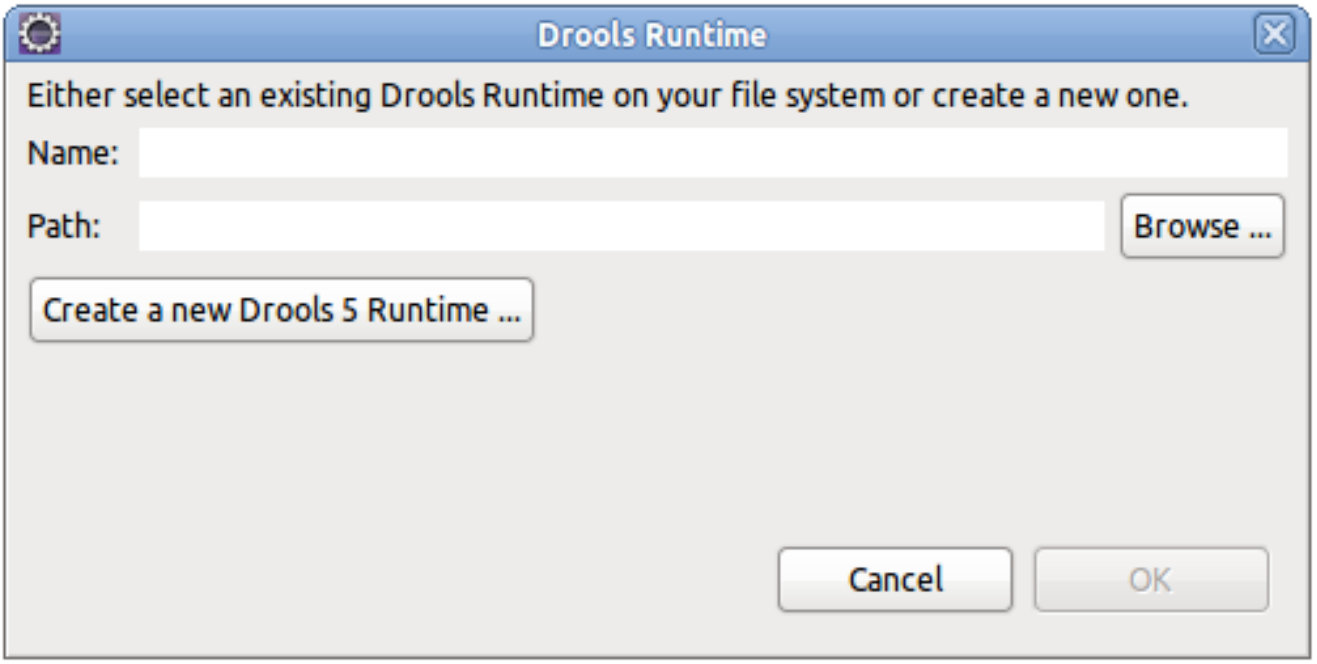
A Drools runtime is a collection of jar files that represent one specific release of the Drools project jars. To create a runtime, you must point the IDE to the release of your choice. If you want to create a new runtime based on the latest Drools project jars included in the plugin itself, you can also easily do that. You are required to specify a default Drools runtime for your Eclipse workspace, but each individual project can override the default and select the appropriate runtime for that project specifically.

8.2.1. Defining a Drools Runtime

To define one or more Drools runtimes using the Eclipse preferences view you open up your Preferences, by selecting the "Preferences" menu item in the menu "Window". A "Preferences" dialog should show all your settings. On the left side of this dialog, under the Drools category, select "Installed Drools runtimes". The panel on the right should then show the currently defined Drools runtimes. If you have not yet defined any runtimes, it should look like the figure below.



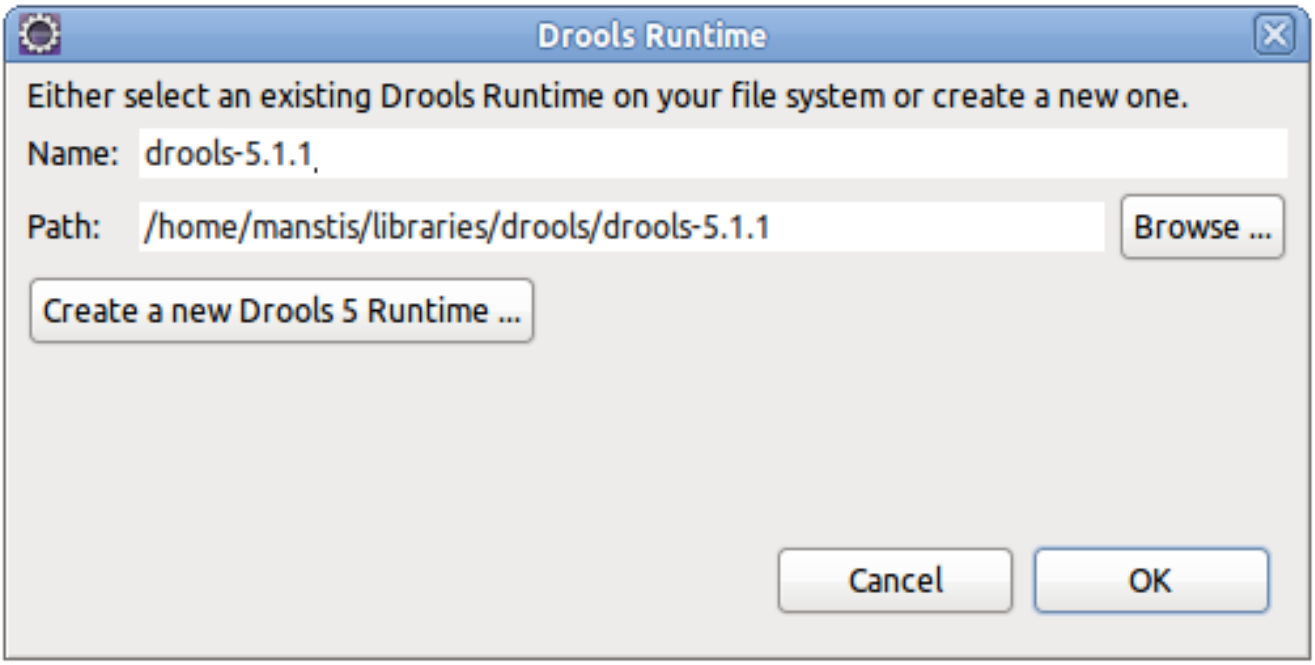
To define a new Drools runtime, click on the add button. A dialog such as the one shown below should pop up, asking for the name of your runtime and the location on your file system where it can be found.



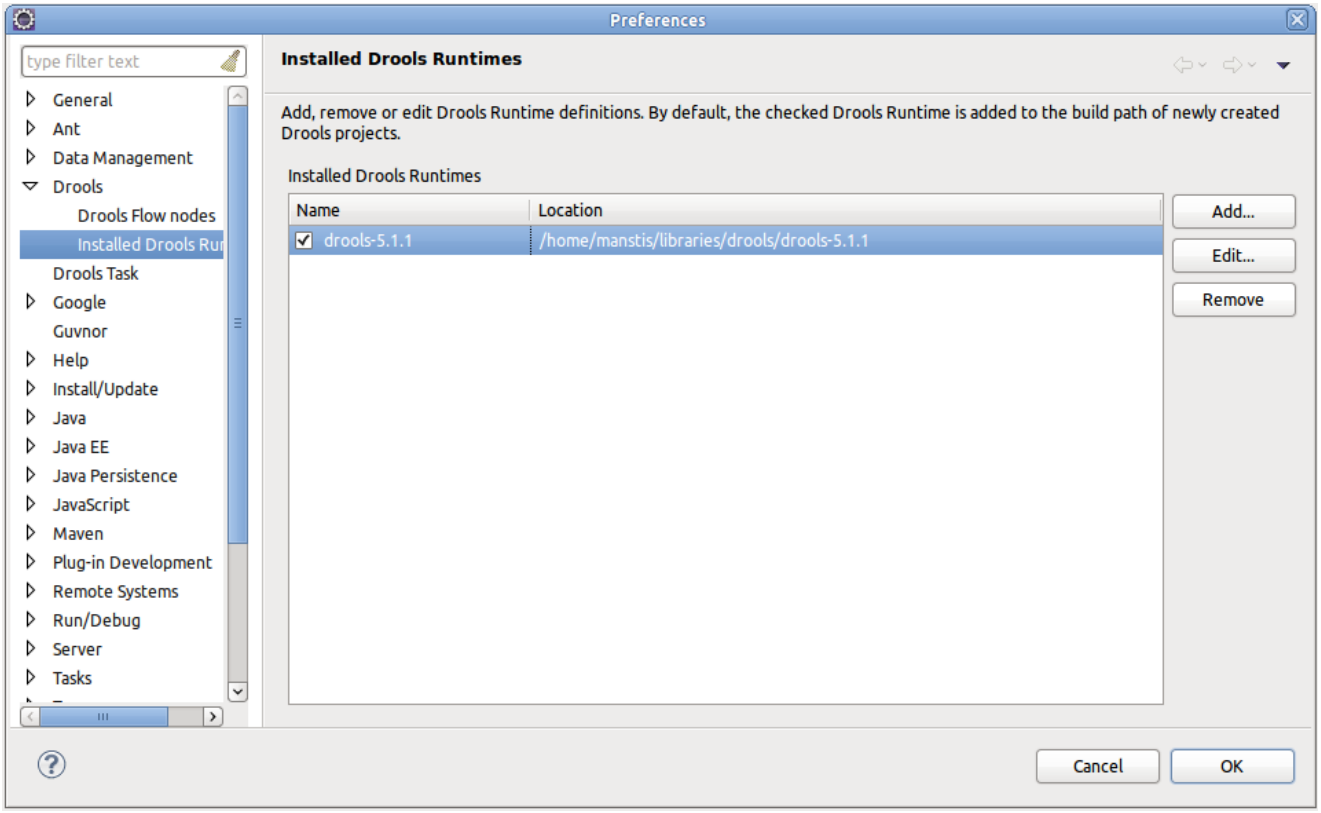
In general, you have two options:

1. If you simply want to use the default jar files as included in the Drools Eclipse plugin, you can create a new Drools runtime automatically by clicking the "Create a new Drools 5 runtime ..." button. A file browser will show up, asking you to select the folder on your file system where you want this runtime to be created. The plugin will then automatically copy all required dependencies to the specified folder. After selecting this folder, the dialog should look like the figure shown below.

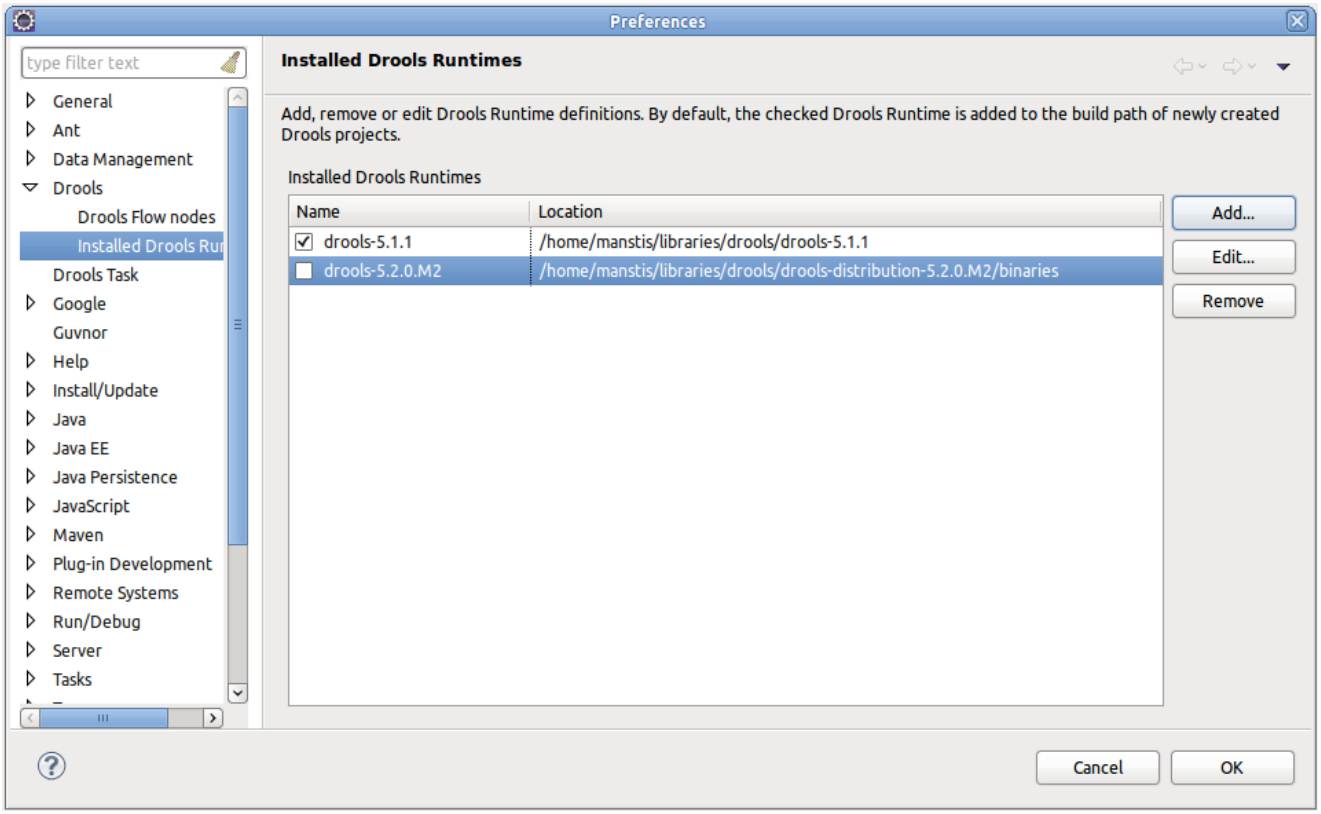
2. If you want to use one specific release of the Drools project, you should create a folder on your file system that contains all the necessary Drools libraries and dependencies. Instead of creating a new Drools runtime as explained above, give your runtime a name and select the location of this folder containing all the required jars.



After clicking the OK button, the runtime should show up in your table of installed Drools runtimes, as shown below. Click on checkbox in front of the newly created runtime to make it the default Drools runtime. The default Drools runtime will be used as the runtime of all your Drools project that have not selected a project-specific runtime.



You can add as many Drools runtimes as you need. For example, the screenshot below shows a configuration where two runtimes have been defined: a Drools 5.1.1 runtime and a Drools 5.2.0.M2 runtime. The Drools 5.1.1 runtime is selected as the default one.

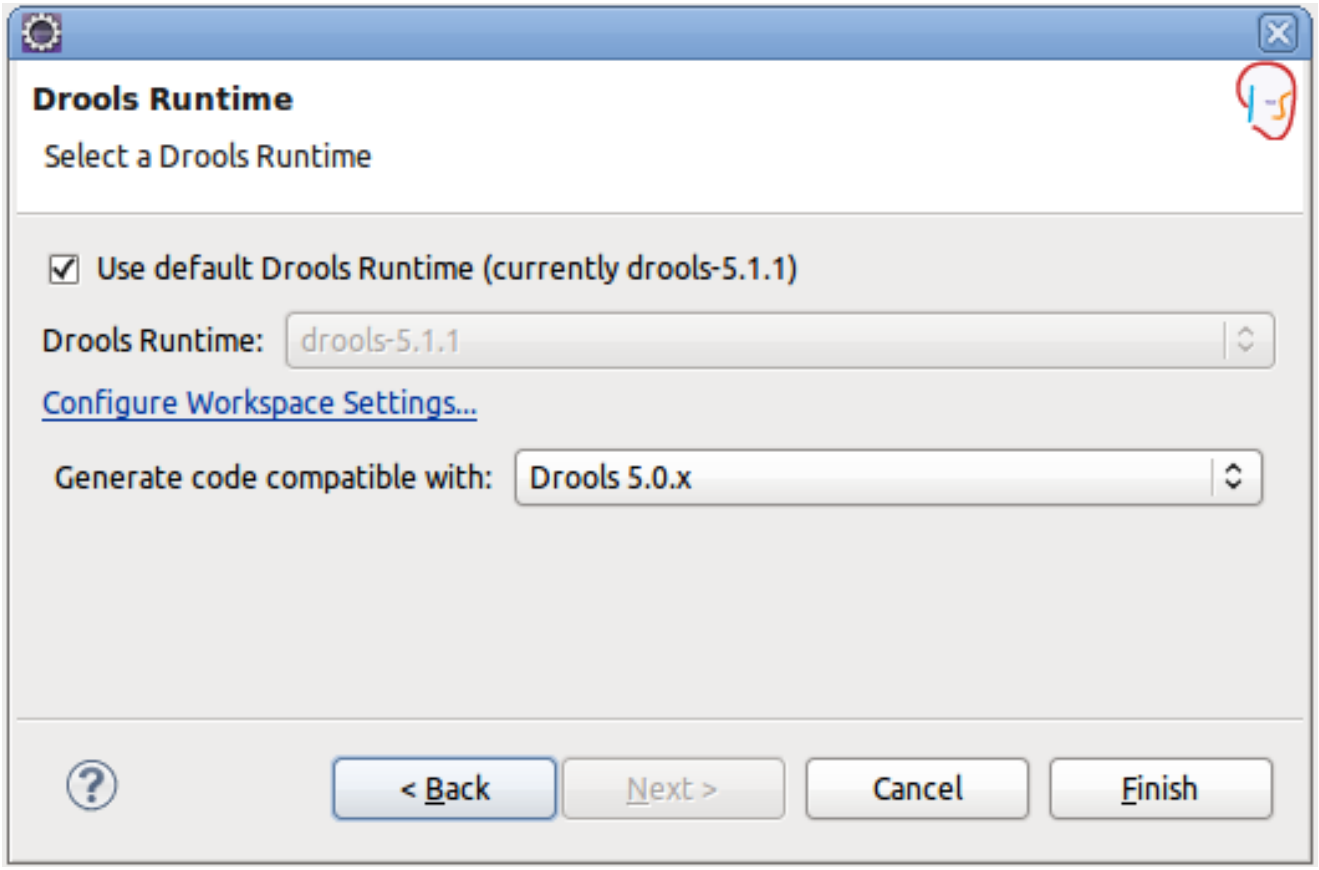


Note that you will need to restart Eclipse if you changed the default runtime and you want to make sure that all the projects that are using the default runtime update their classpath accordingly.

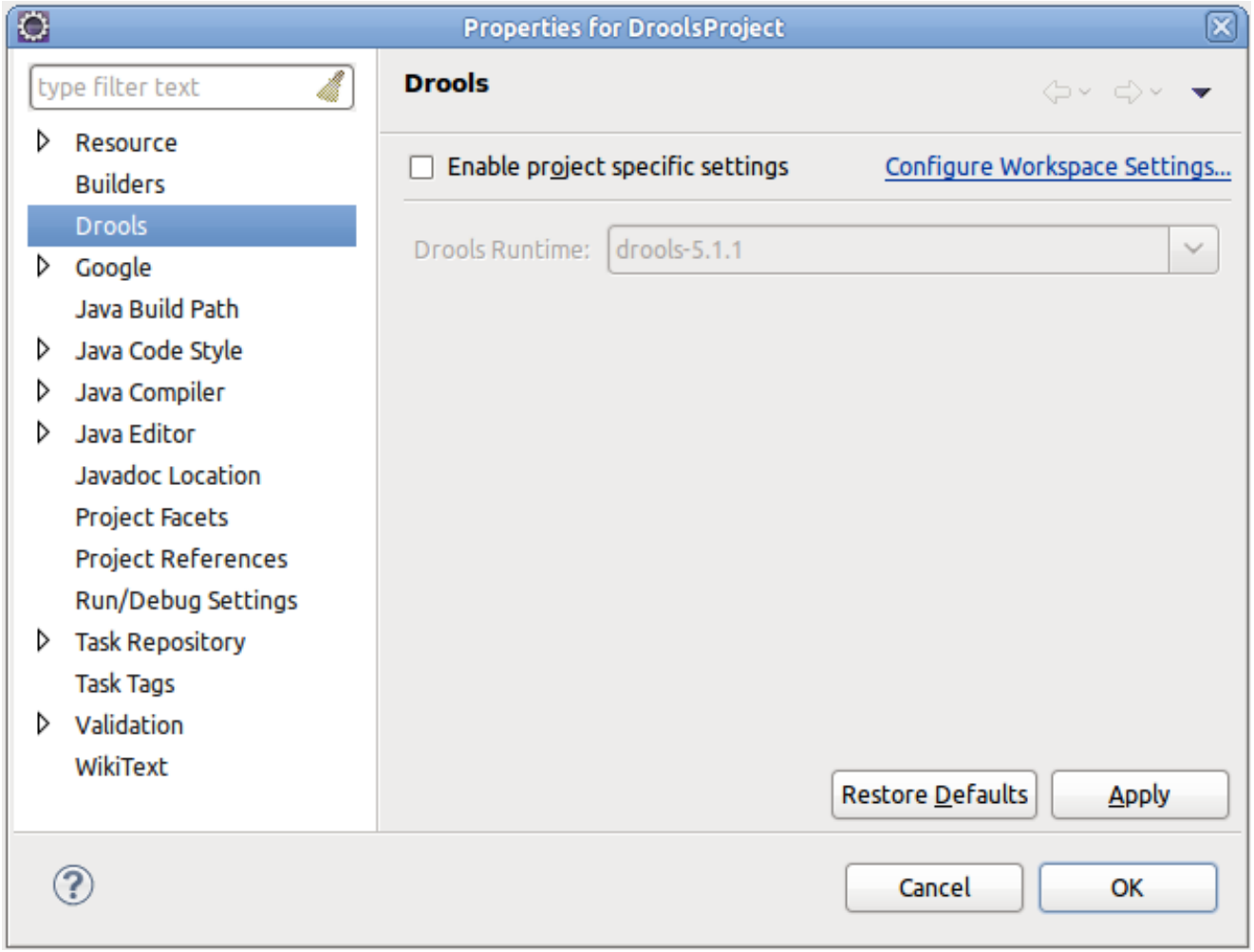
8.2.2. Selecting a runtime for your Drools project

Whenever you create a Drools project (using the New Drools Project wizard or by converting an existing Java project to a Drools project using the action "Convert to Drools Project" that is shown when you are in the Drools perspective and you right-click an existing Java project), the plugin will automatically add all the required jars to the classpath of your project.

When creating a new Drools project, the plugin will automatically use the default Drools runtime for that project, unless you specify a project-specific one. You can do this in the final step of the New Drools Project wizard, as shown below, by deselecting the "Use default Drools runtime" checkbox and selecting the appropriate runtime in the drop-down box. If you click the "Configure workspace settings ..." link, the workspace preferences showing the currently installed Drools runtimes will be opened, so you can add new runtimes there.



You can change the runtime of a Drools project at any time by opening the project properties and selecting the Drools category, as shown below. Mark the "Enable project specific settings" checkbox and select the appropriate runtime from the drop-down box. If you click the "Configure workspace settings ..." link, the workspace preferences showing the currently installed Drools runtimes will be opened, so you can add new runtimes there. If you deselect the "Enable project specific settings" checkbox, it will use the default runtime as defined in your global preferences.



8.3. Creating a Rule Project

The aim of the new project wizard is to set up an executable scaffold project to start using rules immediately. This will set up a basic structure, the classpath, sample rules and a test case to get you started.

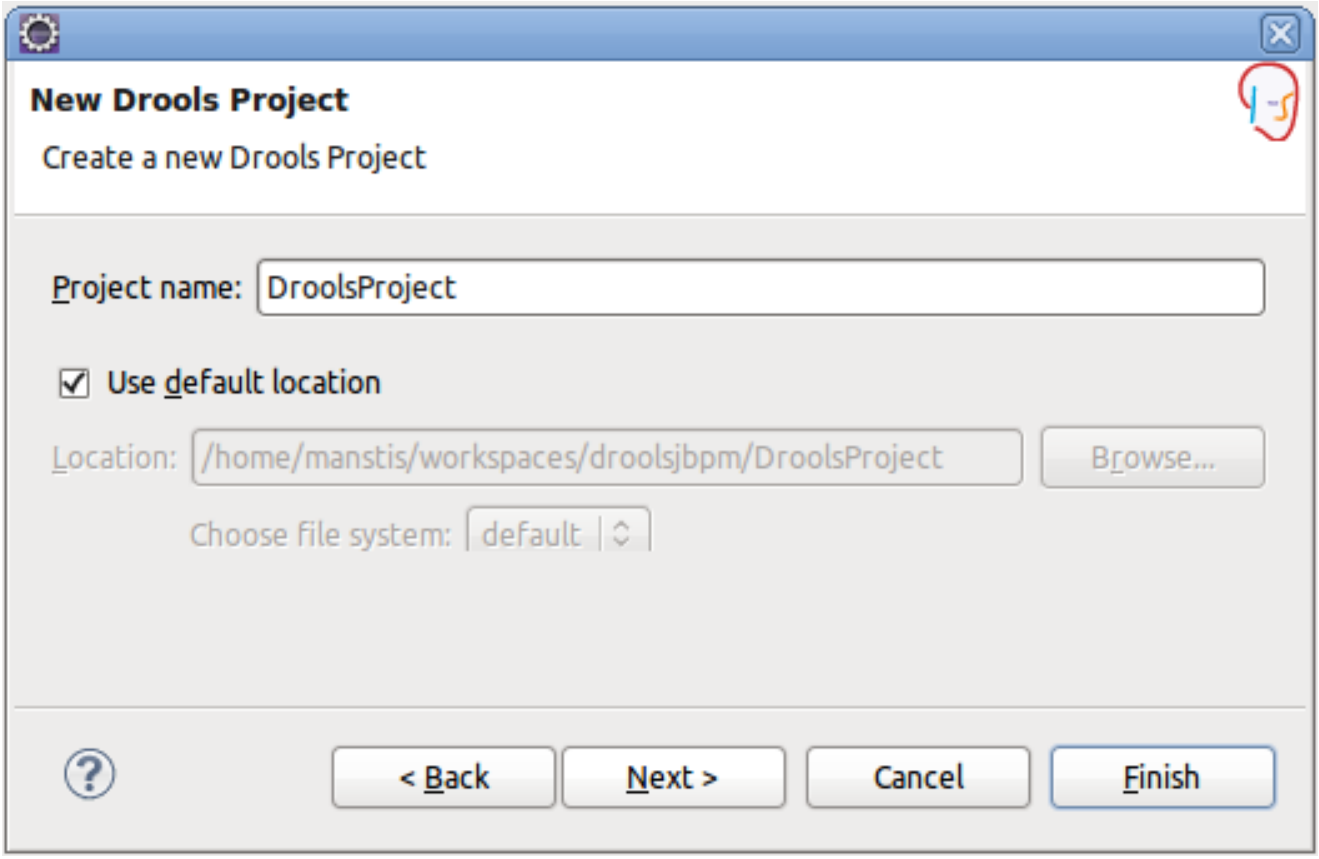


Figure 8.2. New rule project scaffolding

When you choose to create a new "rule project" you will get a choice to add some default artifacts to it, like rules, decision tables, ruleflows, etc. These can serve as a starting point, and will give you something executable almost immediately, which you can then modify and mould to your needs. The simplest case (a hello world rule) is shown below. Feel free to experiment with the plug-in at this point.

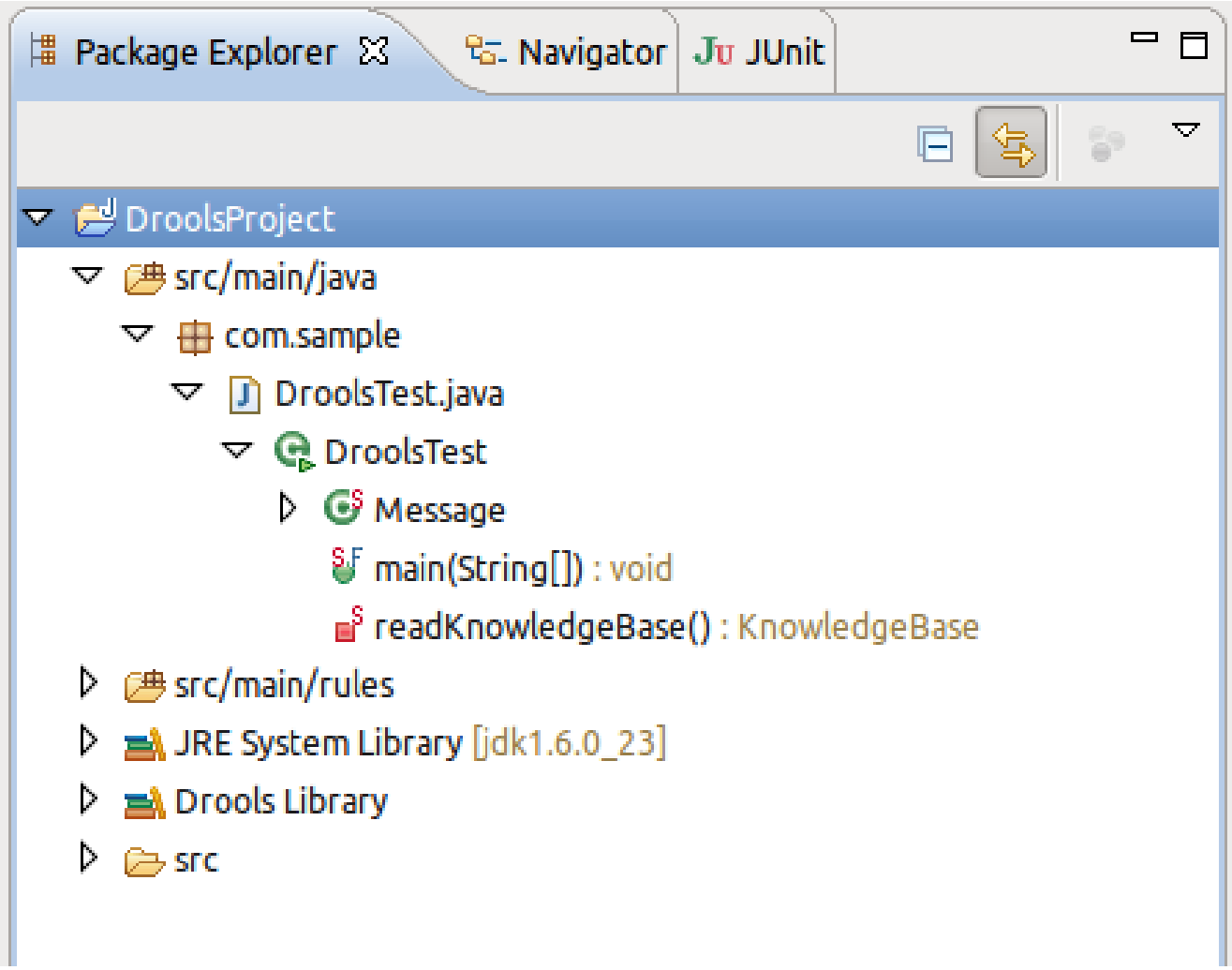


Figure 8.3. New rule project result

The newly created project contains an example rule file (Sample.drl) in the src/rules directory and an example Java file (DroolsTest.java) that can be used to execute the rules in a Drools engine. You'll find this in the folder src/java, in the com.sample package. All the other jars that are necessary during execution are also added to the classpath in a custom classpath container called Drools Library. Rules do not have to be kept in "Java" projects at all, this is just a convenience for people who are already using Eclipse as their Java IDE.

Important note: The Drools plug-in adds a "Drools Builder" capability to your Eclipse instance. This means you can enable a builder on any project that will build and validate your rules when resources change. This happens automatically with the Rule Project Wizard, but you can also enable it manually on any project. One downside of this is that if you have rule files with a large number of rules (more than 500 rules per file), it means that the background builder may be doing a lot of work to build the rules on each change. An option here is to turn off the builder, or put the large rules into .rule files, where you can still use the rule editor, but it won't build them in the background. To fully validate the rules you will need to run them in a unit test of course.

8.4. Creating a New Rule and Wizards

You can create a rule simple as an empty text ".drl" file, or use the wizard to do so. The wizard menu can be invoked with Control+N, or by choosing it from the toolbar, where there is a menu with the JBoss Drools icon.

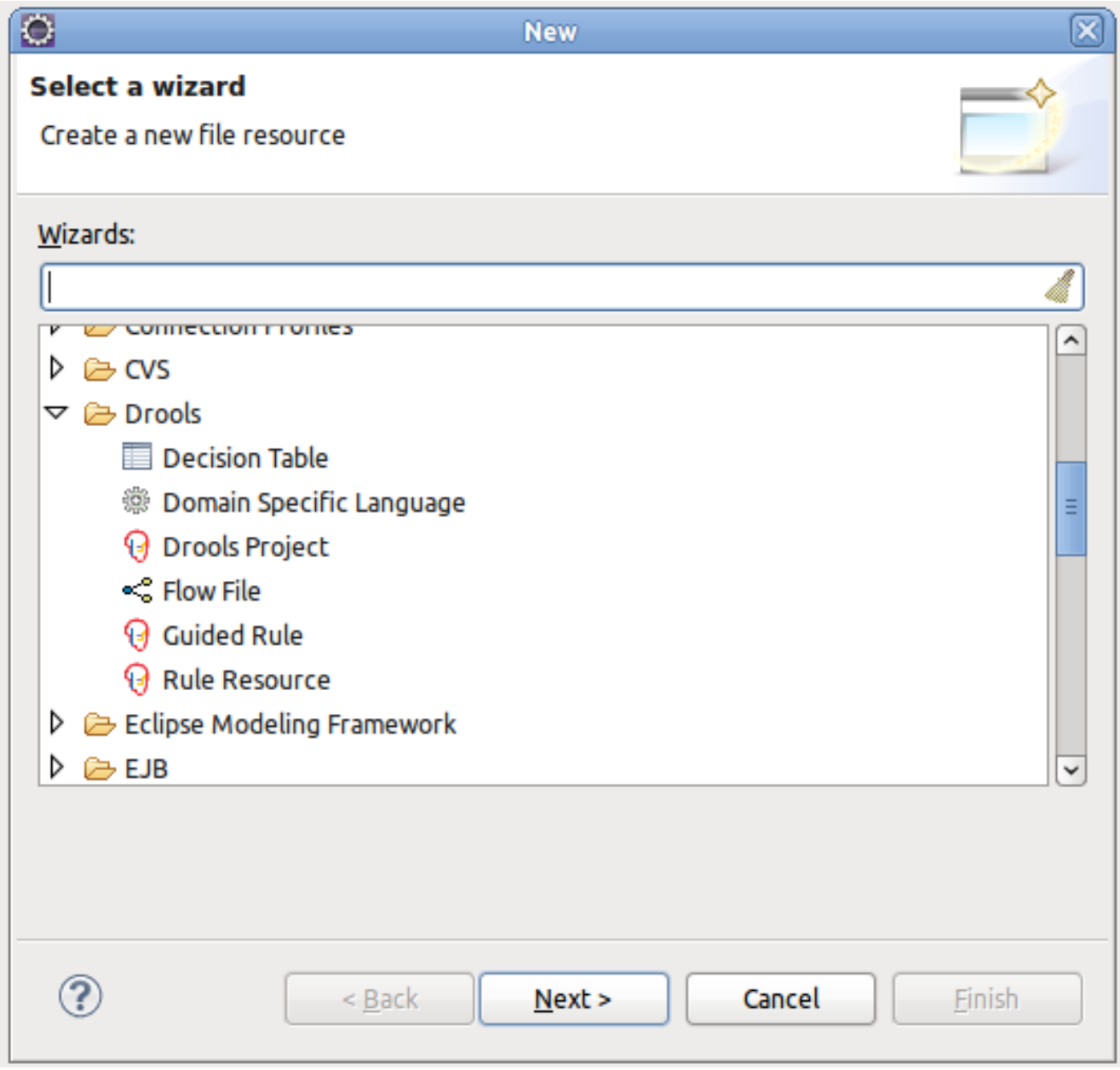


Figure 8.4. The wizard menu

The wizard will ask for some basic options for generating a rule resource. These are just hints - you can change your mind later. For storing rule files you would typically create a directory src/rules and create suitably named subdirectories. The package name is mandatory, and is similar to a package name in Java; i.e., it establishes a namespace for grouping related rules.

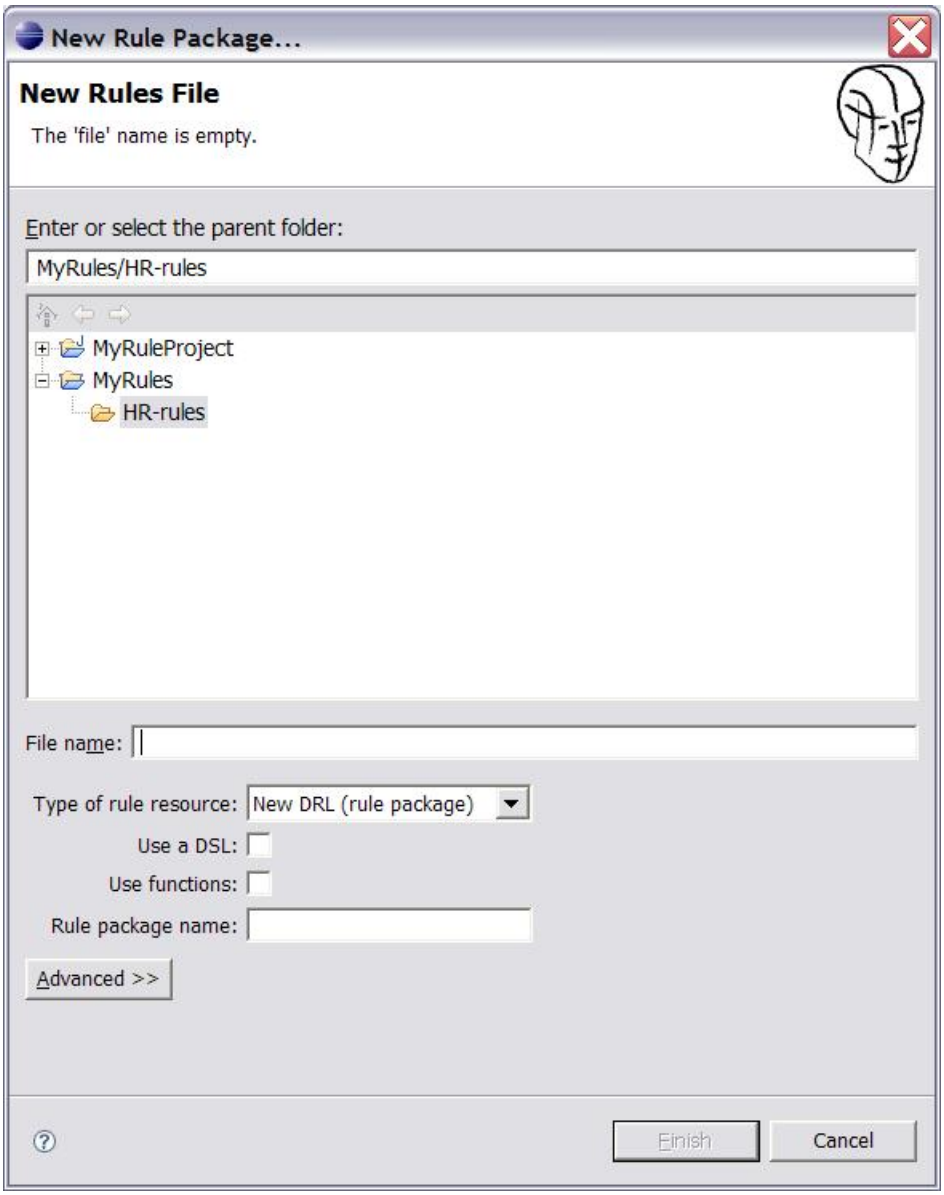


Figure 8.5. New rule wizard

The result of this wizard is a rule skeleton, for you to expand. As with all wizards, they are an optional help - you don't have to use them if you don't want to.

8.5. Textual Rule Editor

The rule editor is where rule managers and developers will be spending most of their time. The rule editor follows the pattern of a normal text editor in Eclipse, with all the customary features of a text editor. On top of this, the rule editor provides pop-up content assistance. You invoke pop-up content assistance the "normal" way by pressing Control+Space.

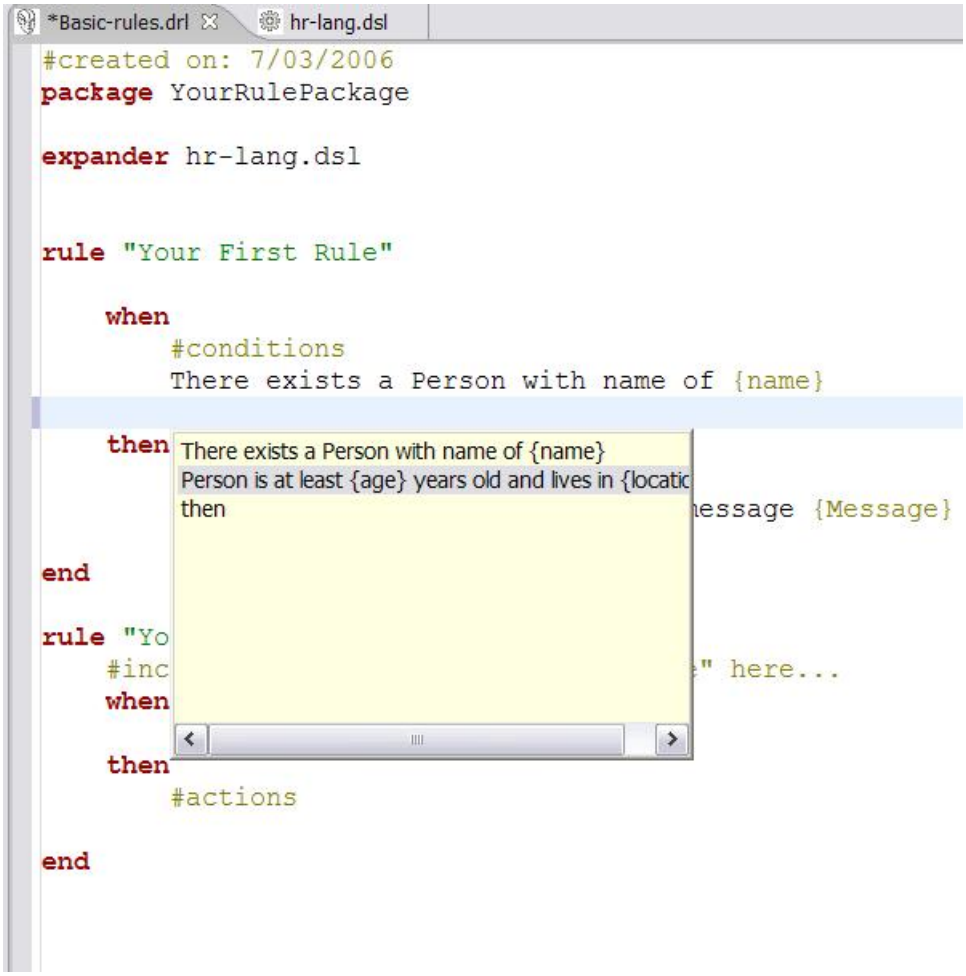


Figure 8.6. The rule editor in action

The rule editor works on files that have a .drl (or .rule) extension. Usually these contain related rules, but it would also be possible to have rules in individual files, grouped by being in the same package "namespace", if you so prefer. These DRL files are plain text files.

You can see from the example above that the rule group is using a domain specific language. Note the expander keyword, which tells the rule compiler to look for a dsl file of that name, to resolve the rule language. Even with the domain specific language (DSL) the rules are still stored as plain text as you see it onscreen, which allows simpler management of rules and versions, e.g., comparing versions of rules.

The editor has an outline view that is kept in sync with the structure of the rules; it is updated on save. This provides a quick way of navigating around rules by name, even in a file which may have hundreds of rules. The items are sorted alphabetically by default.

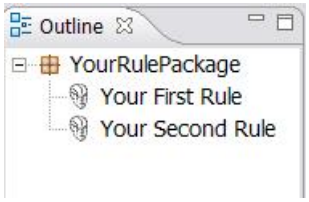


Figure 8.7. The rule outline view

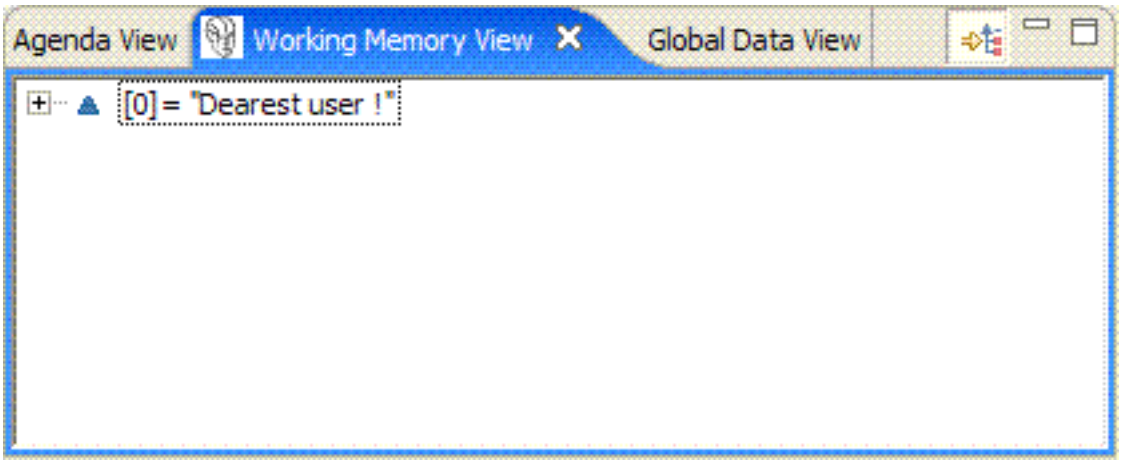
8.6. Drools Views

When debugging an application using a Drools engine, these views can be used to check the state of the Drools engine itself: the Working Memory View, the Agenda View, and the Global Data View. To be able to use these views, create breakpoints in your code invoking the working memory. For example, the line where you call workingMemory.fireAllRules() is a good candidate. If the debugger halts at that joinpoint, you should select the working memory variable in the debug variables view. The available views can then be used to show the details of the selected working memory:

1. The Working Memory View shows all elements of the Drools working memory.
2. The Agenda View shows all elements on the agenda. For each rule on the agenda, the rule name and bound variables are shown.
3. The Global Data View shows all global data currently defined in the Drools working memory.

The Audit view can be used to display audit logs containing events that were logged during the execution of a rules engine, in tree form.

8.6.1. The Working Memory View

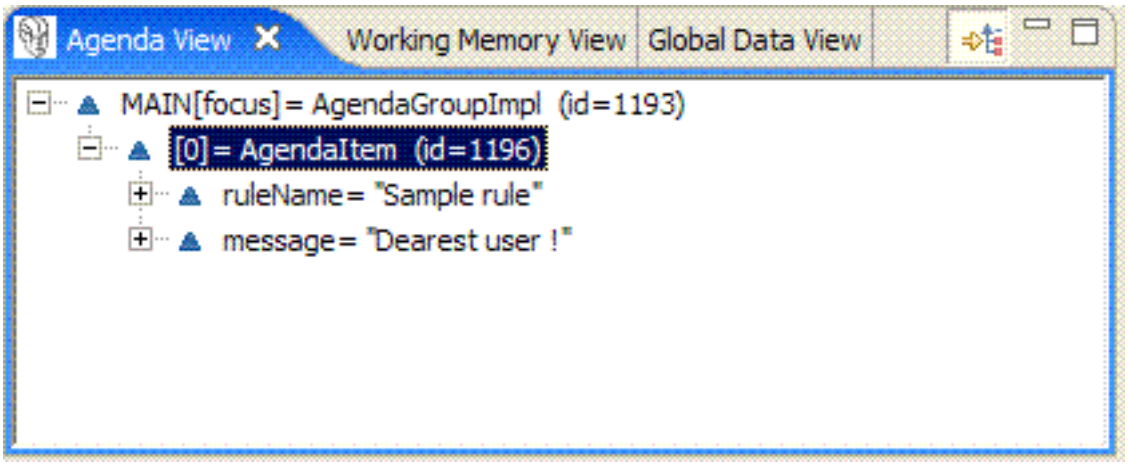


The Working Memory View shows all elements in the working memory of the Drools engine.

An action is added to the right of the view, to customize what is shown:

1. The Show Logical Structure toggles showing the logical structure of the elements in the working memory, or all their details. Logical structures allow for visualizing sets of elements in a more obvious way.

8.6.2. The Agenda View

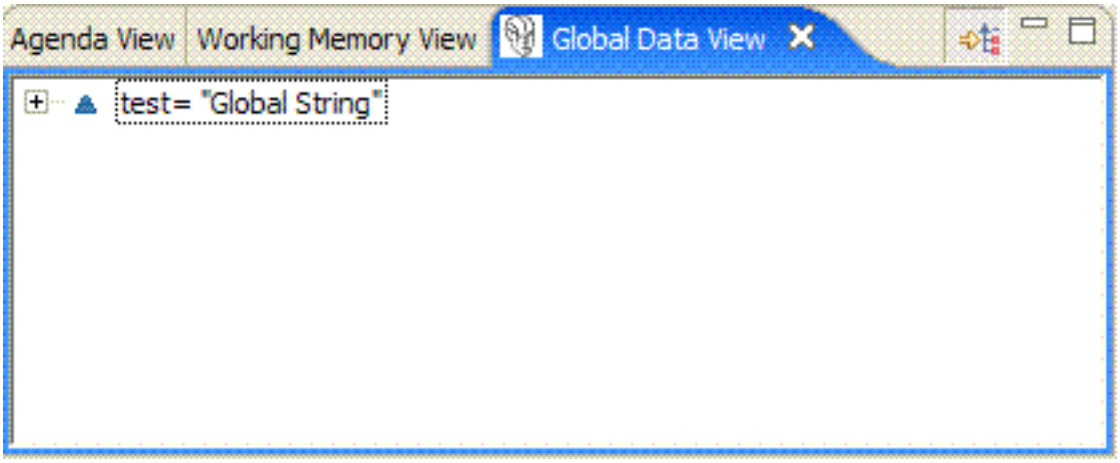


The Agenda View shows all elements on the agenda. For each rule on the agenda, the rule name and bound variables are shown.

An action is added to the right of the view, to customize what is shown:

1. The Show Logical Structure toggles showing the logical structure of the agenda item, or all their details. Logical structures allow for example visualizing sets of elements in a more obvious way. The logical structure of AgendaItems shows the rule that is represented by the AgendaItem, and the values of all the parameters used in the rule.

8.6.3. The Global Data View

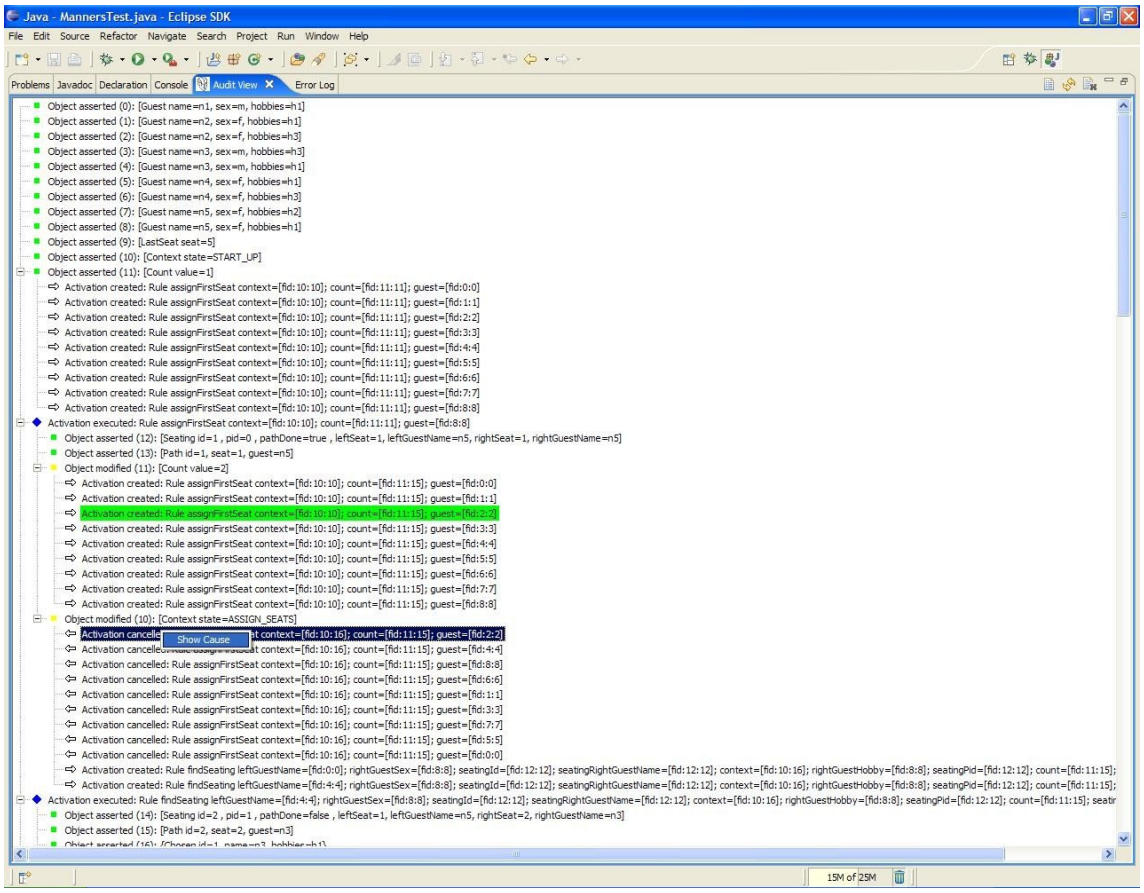


The Global Data View shows all global data currently defined in the Drools engine.

An action is added to the right of the view, to customize what is shown:

1. The Show Logical Structure toggles showing the logical structure of the elements in the working memory, or all their details. Logical structures allow for example visualizing sets of elements in a more obvious way.

8.6.4. The Audit View



The audit view visualizes an audit log, that is optionally created when executing the rules engine. To create an audit log, use the following code:

```
StatefulSession session = ruleBase.newStatefulSession();
// Create a new Working Memory Logger, that logs to file.
WorkingMemoryFileLogger logger = new WorkingMemoryFileLogger(session);
// An event.log file is created in the subdirectory log dir (which must exist)
 of the working directory
logger.setFileName("log/event");

        session.insert(...);
        session.fireAllRules();

// stop logging
logger.writeToDisk();
```

Open the log by clicking the Open Log action, the first icon in the Audit View, and select the file. The Audit View now shows all events that where logged during the executing of the rules. There are different types of events, each with a different icon:

1. Object inserted, a green square:

2. Object updated, a yellow square:

3. Object removed, a red square:

4. Activation created, a right arrow:

5. Activation cancelled, a left arrow:

6. Activation executed, a blue diamond:

7. Ruleflow start or end, the "process" icon:

8. Ruleflow-group activation or deactivation, the "activity" icon:

9. Rule package addition or removal, the Drools icon:

10. Rule addition or removal, the Drools icon:

All these events show extra information concerning the event, like the id and toString representation of the object in case of working memory events (insert, modify and retract), the name of the rule and all the variables bound in the activation in case of an activation event (created, cancelled or executed). If an event occurs when executing an activation, it is shown as a child of the activation's execution event. For some events, you can retrieve the "cause":

1. The cause of an object modified or retracted event is the last object event for that object. This is either the object asserted event, or the last object modified event for that object.

2. The cause of an activation cancelled or executed event is the corresponding activation created event.

When selecting an event, the cause of that event is shown in green in the audit view (if visible of course). You can also right click the action and select the "Show Cause" menu item. This will scroll you to the cause of the selected event.

8.7. Domain Specific Languages

Domain Specific Languages (DSL) enable you to create a language that allows your rules to look like - rules! Most often the domain specific language reads like natural language. Typically you would look at how a business analyst would describe the rule, in their own words, and then map this to your object model, via rule constructs. A side benefit of this is that it can provide an insulation layer between your domain objects and the rules themselves (as we know you like to refactor). A domain specific language will grow as the rules grow, and works best when there are common terms used over an over, with different parameters.

To aid with this, the rule workbench provides an editor for Domain Specific Languages. They are stored in a plain text format, so you can use any editor of your choice; this format is simply a slightly enhanced version of the "Properties" file format. The editor will be invoked on any files with a .dsl extension. There is also a wizard to create a sample DSL.

8.7.1. Editing languages

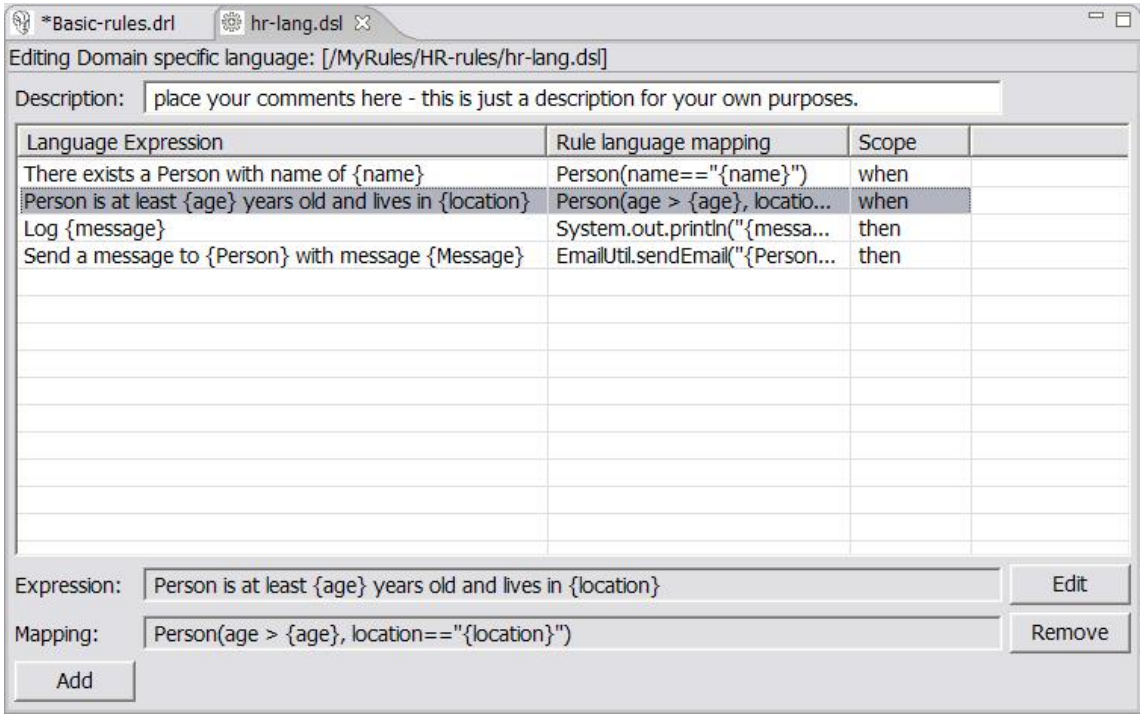


Figure 8.8. The Domain Specific Language editor

The DSL editor provides a tabular view of the mapping of Language to Rule Expressions. The Language Expression is what is used in the rules. This also feeds the content assistance for the

rule editor, so that it can suggest Language Expressions from the DSL configuration. (The rule editor loads the DSL configuration when the rule resource is loaded for editing.) The Rule language mapping defines the "code" for the rules into which the language expression will be compiled by the rule engine compiler. The form of this Rule language expression depends on it being intended for the condition or the action part of a rule. (For the RHS it may be a snippet of Java, for instance). The "scope" item indicates where the expression belongs, "when" indicating the LHS, "then" the RHS, and "*" meaning anywhere. It's also possible to create aliases for keywords.

By selecting a mapping item (a row in the table) you can see the expression and mapping in the text fields below the table. Double clicking or pressing the edit button will open the edit dialog. Other buttons let you remove and add mappings. Don't remove mappings while they are still in use.

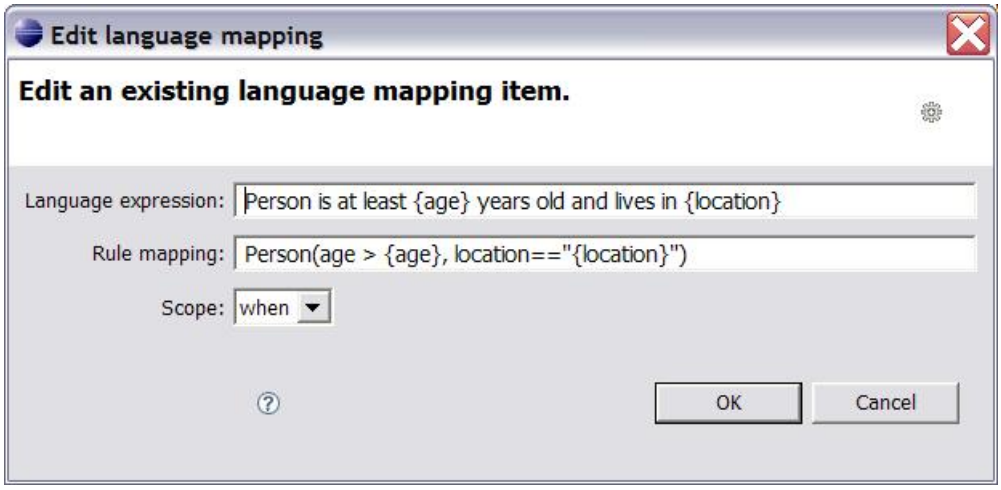


Figure 8.9. Language Mapping editor dialog

Here is a short description of the DSL translation process. The parser reads the rule text in a DSL, line by line, and tries to match some "Language Expression", depending on the scope. After a match, the values that correspond to a placeholder between curly braces (e.g., {age}) are extracted from the rule source. The placeholders in the corresponding "Rule Expression" are replaced by their corresponding value. In the example above, the natural language expression maps to two constraints on a fact of type Person, based on the fields age and location, and the {age} and {location} values are extracted from the original rule text.

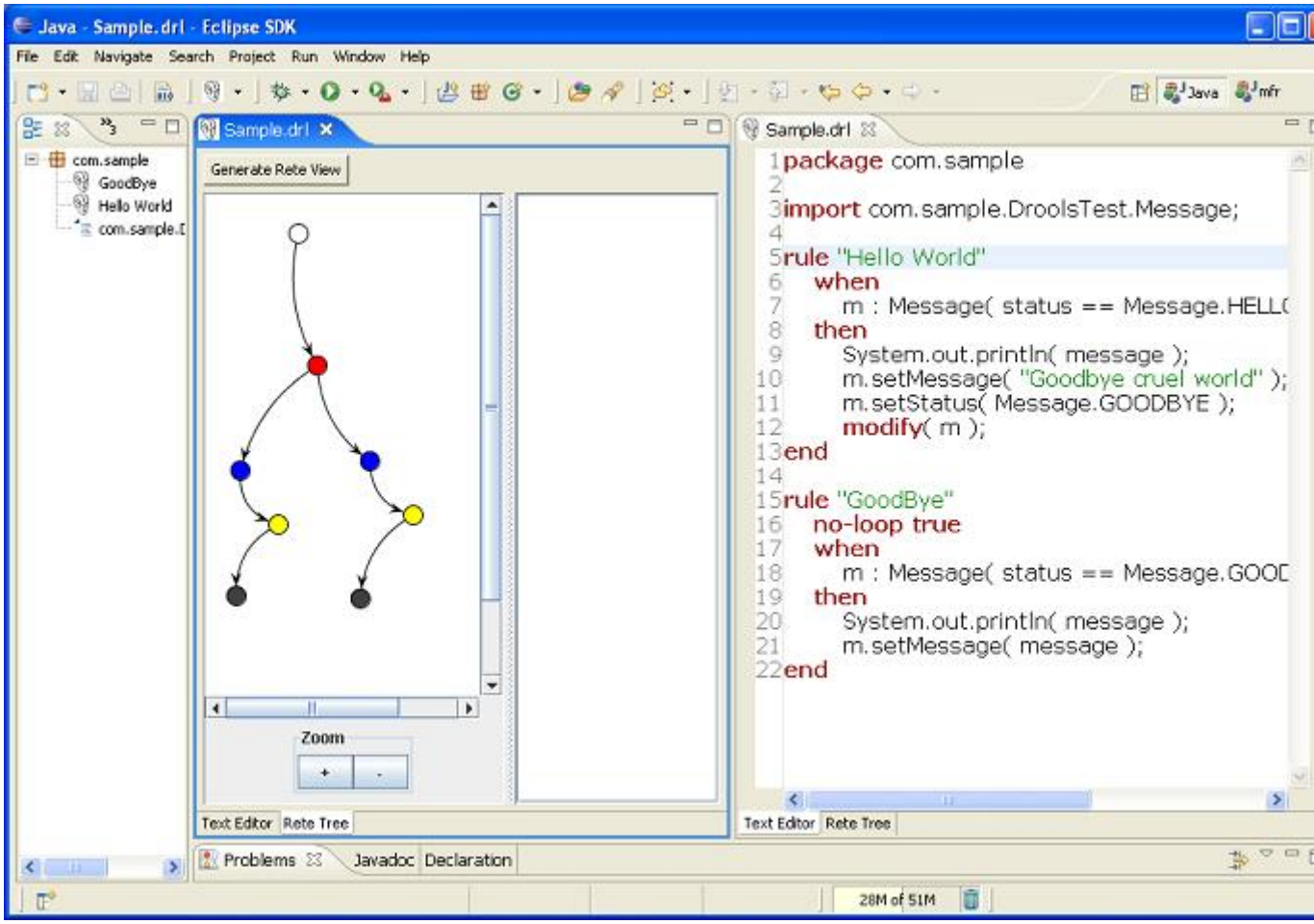
If you do not wish to use a language mapping for a particular rule in a drl, prefix the expression with > and the compiler will not try to translate it according to the language definition. Also note that Domain Specific Languages are optional. When the rule is compiled, the .dsl file will also need to be available.

8.8. The Rete View

The Rete Tree View shows you the current Rete Network for your DRL file. You display it by clicking on the tab "Rete Tree" at the bottom of the DRL Editor window. With the Rete Network visualization being open, you can use drag-and-drop on individual nodes to arrange optimal network overview. You may also select multiple nodes by dragging a rectangle over them; then the entire group can

be moved around. The Eclips toolbar icons for zooming in and out can be used in the customary manner.

In the current release there is no export function to creates a gif or jpeg file. Meanwhile, please use ctrl + alt + print to create a copy of your current Eclipse window, and cut it off.



The Rete View is an advanced feature which takes full advantage of the Eclipse Graphical Editing Framework (GEF).

The Rete view works only in Drools Rule Projects, where the Drools Builder is set in the project ´s properties.

If you are using Drools in another type of project where you are not having a Drools Rule Project with the appropriate Drools Builder, you can use a workaround: Set up a little Drools Rule Project next to it, putting needed libraries into it, and the DRLs you want to inspect with the Rete View. Just click on the right tab below in the DRL Editor, followed by a click on "Generate Rete View".

8.9. Large DRL Files

Depending on the JDK you use, it may be necessary to increase the permanent generation max size. Both the SUN and the IBM JDK have a permanent generation, whereas BEA JRockit does not.

To increase the permanent generation, start Eclipse with -XX:MaxPermSize=###m

Example: c:\Eclipse\Eclipse.exe -XX:MaxPermSize=128m

Rulesets of 4,000 rules or greater should set the permanent generation to at least 128Mb.

Note

This may also apply to compiling large numbers of rules in general, as there is generally one or more classes per rule.

As an alternative to the above, you may put rules in a file with the ".rule" extension, and the background builder will not try to compile them with each change, which may provide performance improvements if your IDE becomes sluggish with very large numbers of rules.

8.10. Debugging Rules

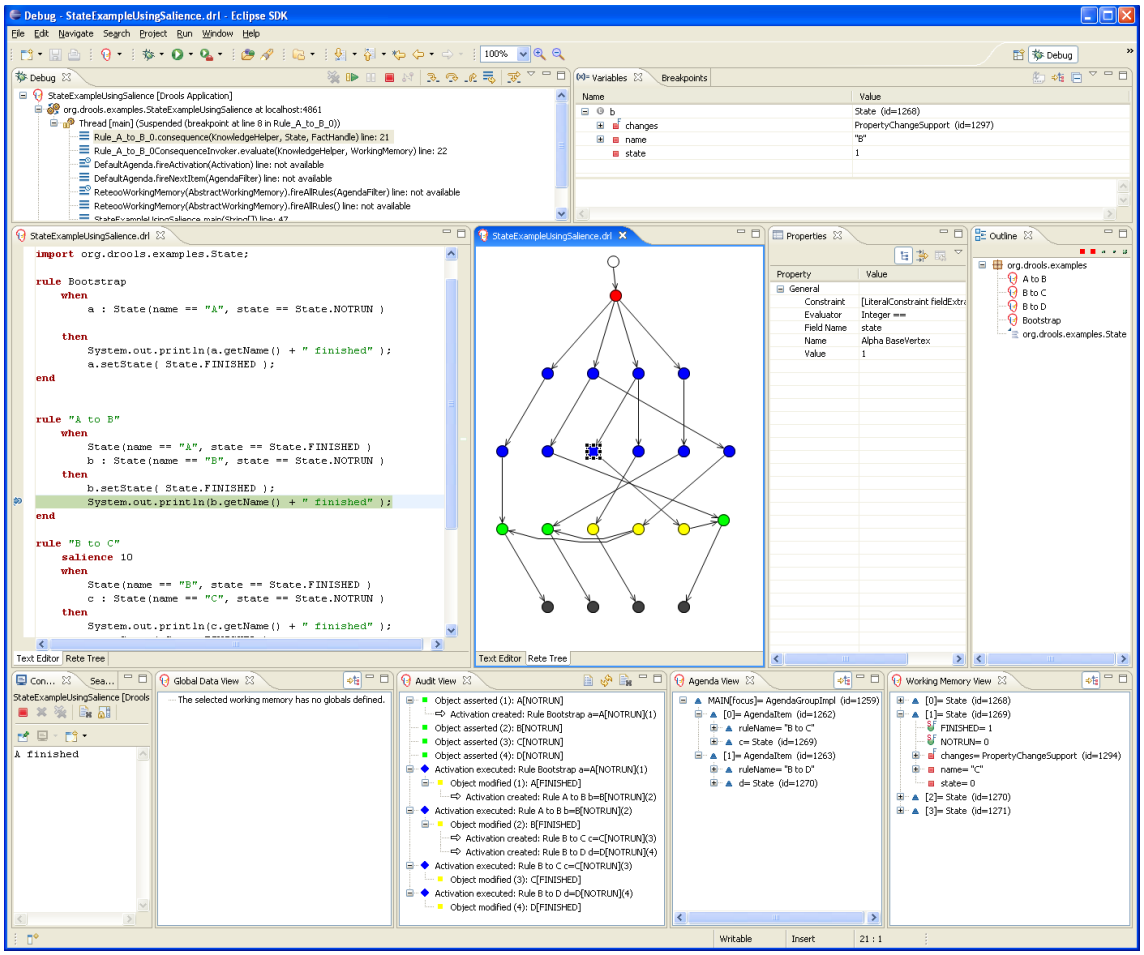


Figure 8.10. Debugging

You can debug rules during the execution of your Drools application. You can add breakpoints in the consequences of your rules, and whenever such a breakpoint is encountered during the

execution of the rules, execution is halted. You can then inspect the variables known at that point and use any of the default debugging actions to decide what should happen next: step over, continue, etc. You can also use the debug views to inspect the content of the working memory and the Agenda.

8.10.1. Creating Breakpoints

You can add and remove rule breakpoints in DRL files in two ways, similar to adding breakpoints to Java files:

1. Double-click the ruler of the DRL editor at the line where you want to add a breakpoint. Note that rule breakpoints can only be created in the consequence of a rule. Double-clicking on a line where no breakpoint is allowed will do nothing. A breakpoint can be removed by double-clicking the ruler once more.

2. If you right-click the ruler, a popup menu will show up, containing the "Toggle breakpoint" action. Note that rule breakpoints can only be created in the consequence of a rule. The action is automatically disabled if no rule breakpoint is allowed at that line. Clicking the action will add a breakpoint at the selected line, or remove it if there was one already.

The Debug Perspective contains a Breakpoints view which can be used to see all defined breakpoints, get their properties, enable/disable or remove them, etc.

8.10.2. Debugging Rules

Drools breakpoints are only enabled if you debug your application as a Drools Application. You can do this like this:

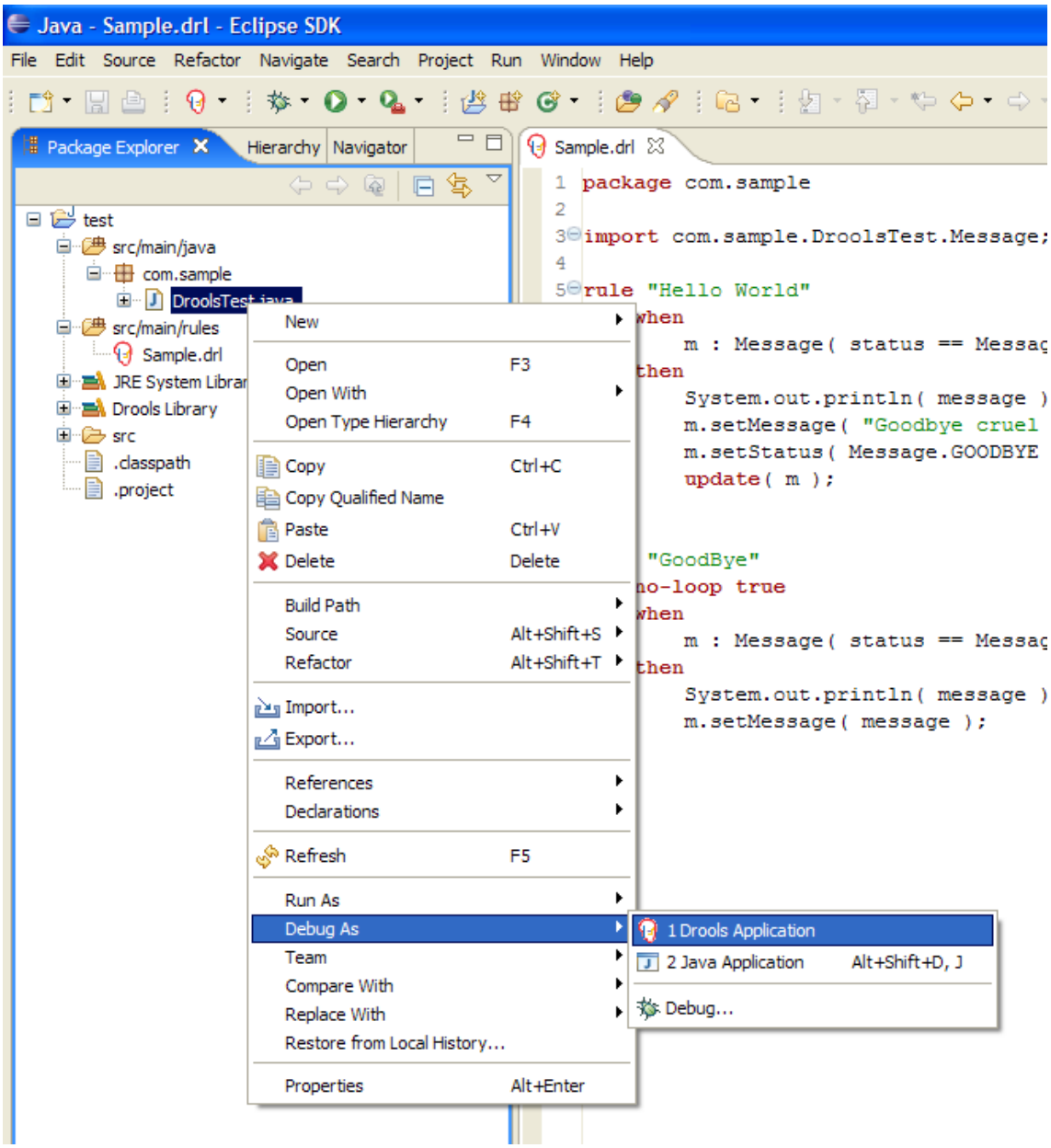


Figure 8.11. Debug as Drools Application

1. Select the main class of your application. Right click it and select the "Debug As >" sub-menu and select Drools Application. Alternatively, you can also select the "Debug ..." menu item to open a new dialog for creating, managing and running debug configurations (see the screenshot below).

2. Select the "Drools Application" item in the left tree and click the "New launch configuration" button (leftmost icon in the toolbar above the tree). This will create a new configuration with some of the properties (like project and main class)already filled in, based on the main class you selected in the beginning. All properties shown here are the same as for any standard Java program.

3. Change the name of your debug configuration to something meaningful. You can just accept the defaults for all other properties. For more information about these properties, please check the Eclipse JDT documentation.

4. Click the "Debug" button on the bottom to start debugging your application. You only have to define your debug configuration once. The next time you run your Drools application, you don't have to create a new one but select the previously defined one in the tree on the left, as a sub-element of the "Drools Application" tree node, and then click the Debug button. The Eclipse toolbar also contains shortcut buttons to quickly re-execute one of your previous configurations (at least when one of the Java, Java Debug, or Drools perspectives has been selected).

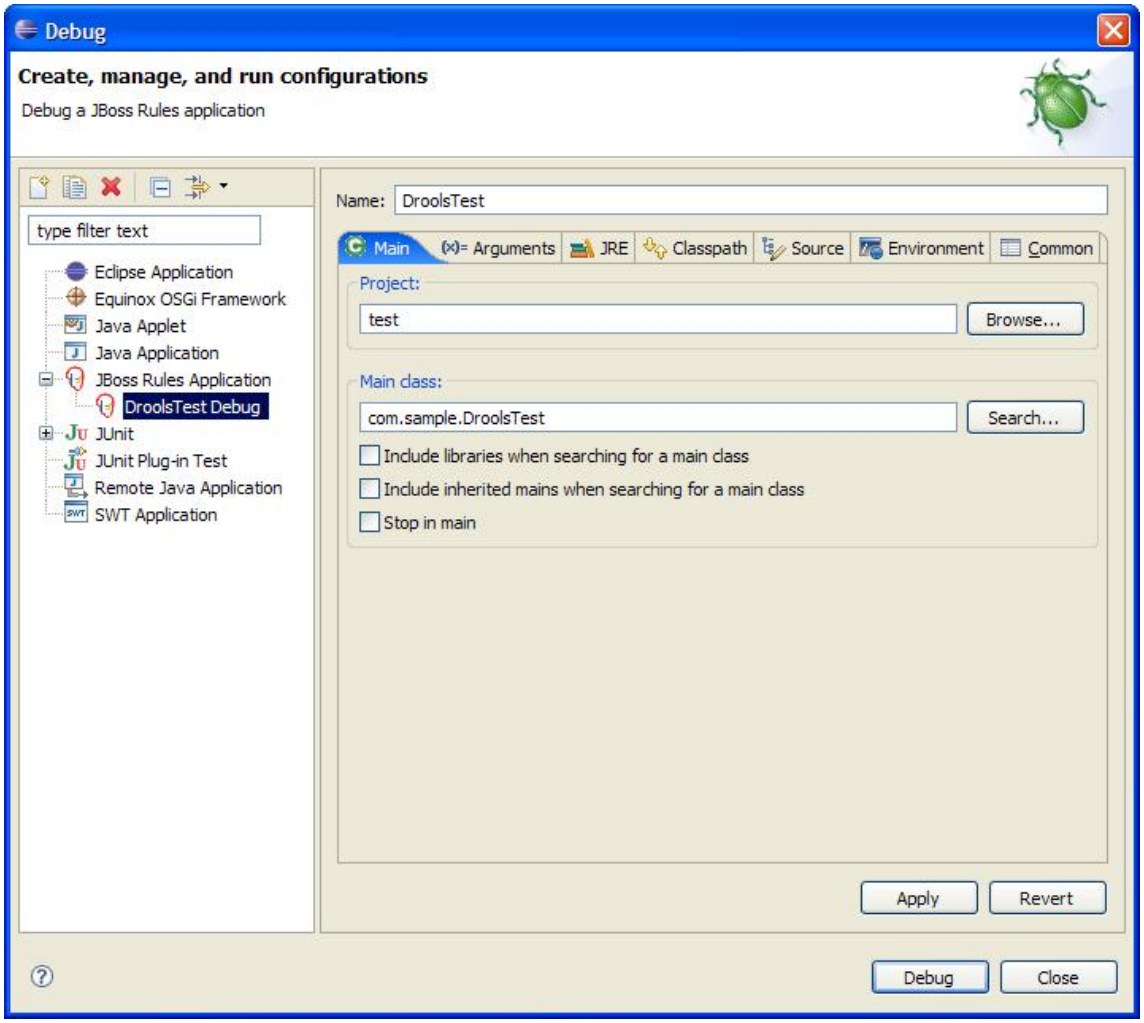


Figure 8.12. Debug as Drools Application Configuration

After clicking the "Debug" button, the application starts executing and will halt if any breakpoint is encountered. This can be a Drools rule breakpoint, or any other standard Java breakpoint. Whenever a Drools rule breakpoint is encountered, the corresponding DRL file is opened and the active line is highlighted. The Variables view also contains all rule parameters and their value. You can then use the default Java debug actions to decide what to do next: resume, terminate, step over, etc. The debug view can also be used to inspect the contents of the Working Memory and

the Agenda at that time as well. You don't have to select a Working Memory now, as the current executing working memory is automatically shown.

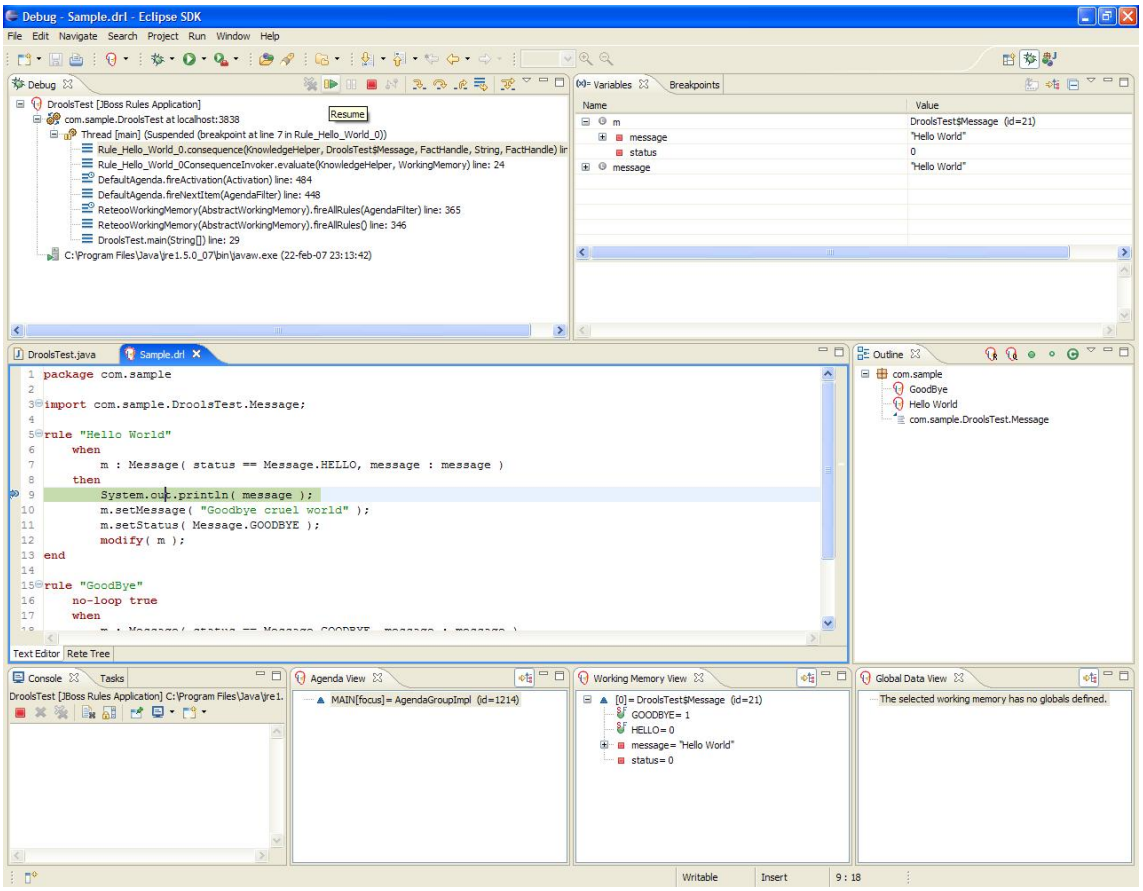


Figure 8.13. Debugging

Chapter 9. Examples

9.1. Getting the Examples

Make sure the Drools Eclipse plugin is installed, which needs the Graphical Editing Framework (GEF) dependency installed first. Then download and extract the drools-examples zip file, which includes an already created Eclipse project. Import that project into a new Eclipse workspace. The rules all have example classes that execute the rules. If you want to try the examples in another project (or another IDE) then you will need to set up the dependencies by hand, of course. Many, but not all of the examples are documented below, enjoy!

Some examples require Java 1.6 to run.

9.2. Hello World

```
Name: Hello World
Main class: org.drools.examples.helloworld.HelloWorldExample
Module: drools-examples
Type: Java application
Rules file: HelloWorld.drl
Objective: demonstrate basic rules in use
```

The "Hello World" example shows a simple example of rules usage, and both the MVEL and Java dialects.

This example demonstrates how to build Knowledge Bases and Sessions. Also, audit logging and debug outputs are shown, which is ommitted from other examples as it's all very similar. A `KnowledgeBuilder` is used to turn a DRL source file into `Package` objects which the Knowledge Base can consume. The add method takes a `Resource` interface and a Resource Type as parameters. The `Resource` can be used to retrieve a DRL source file from various locations; in this case the DRL file is being retrieved from the classpath using a `ResourceFactory`, but it could come from a disk file or a URL. Here, we only add a single DRL source file, but multiple DRL files can be added. Also, DRL files with different namespaces can be added, where the Knowledge Builder creates a package for each namespace. Multiple packages of different namespaces can be added to the same Knowledge Base. When all the DRL files have been added, we should check the builder for errors. While the Knowledge Base will validate the package, it will only have access to the error information as a String, so if you wish to debug the error information you should do it on the `KnowledgeBuilder` instance. Once you know the builder is error free, get the `Package` collection, instantiate a `KnowledgeBase` from the `KnowledgeBaseFactory` and add the package collection.

Example 9.1. HelloWorld: Creating the KnowledgeBase and Session

```
final KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
```

```
// this will parse and compile in one step
kbuilder.add(ResourceFactory.newClassPathResource("HelloWorld.drl",
        HelloWorldExample.class), ResourceType.DRL);

// Check the builder for errors
if (kbuilder.hasErrors()) {
    System.out.println(kbuilder.getErrors().toString());
    throw new RuntimeException("Unable to compile \"HelloWorld.drl\".");
}

// get the compiled packages (which are serializable)
final Collection<KnowledgePackage> pkgs = kbuilder.getKnowledgePackages();

// add the packages to a knowledgebase (deploy the knowledge packages).
final KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
kbase.addKnowledgePackages(pkgs);

final StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();
```

Drools has an event model that exposes much of what's happening internally. Two default debug listeners are supplied, `DebugAgendaEventListener` and `DebugWorkingMemoryEventListener` which print out debug event information to the `System.err` stream displayed in the Console window. Adding listeners to a Session is trivial, as shown below. The `KnowledgeRuntimeLogger` provides execution auditing, the result of which can be viewed in a graphical viewer. The logger is actually a specialised implementation built on the Agenda and Working Memory listeners. When the engine has finished executing, `logger.close()` must be called.

Most of the examples use the Audit logging features of Drools to record execution flow for later inspection.

Example 9.2. HelloWorld: Event logging and Auditing

```
// setup the debug listeners
ksession.addEventListener( new DebugAgendaEventListener() );
ksession.addEventListener( new DebugWorkingMemoryEventListener() );

// setup the audit logging
KnowledgeRuntimeLogger logger =
  KnowledgeRuntimeLoggerFactory.newFileLogger(ksession, "log/helloworld");
```

The single class used in this example is very simple. It has two fields: the message, which is a String and the status which can be one of the two integers `HELLO` or `GOODBYE`.

Example 9.3. HelloWorld example: Message Class

```
public static class Message {
    public static final int HELLO   = 0;
    public static final int GOODBYE = 1;

    private String          message;
    private int             status;
    ...
}
```

A single `Message` object is created with the message text "Hello World" and the status `HELLO` and then inserted into the engine, at which point `fireAllRules()` is executed. Remember that all the network evaluation is done during the insert time, so that by the time the program execution reaches the `fireAllRules()` method call the engine already knows which rules are fully matches and able to fire.

Example 9.4. HelloWorld: Execution

```
final Message message = new Message();
message.setMessage("Hello World");
message.setStatus(Message.HELLO);
ksession.insert(message);

ksession.fireAllRules();

logger.close();

ksession.dispose();
```

To execute the example as a Java application:

1. Open the class org.drools.examples.helloworld.HelloWorldExample in your Eclipse IDE

2. Right-click the class and select "Run as..." and then "Java application"

If we put a breakpoint on the `fireAllRules()` method and select the `ksession` variable, we can see that the "Hello World" rule is already activated and on the Agenda, confirming that all the pattern matching work was already done during the insert.

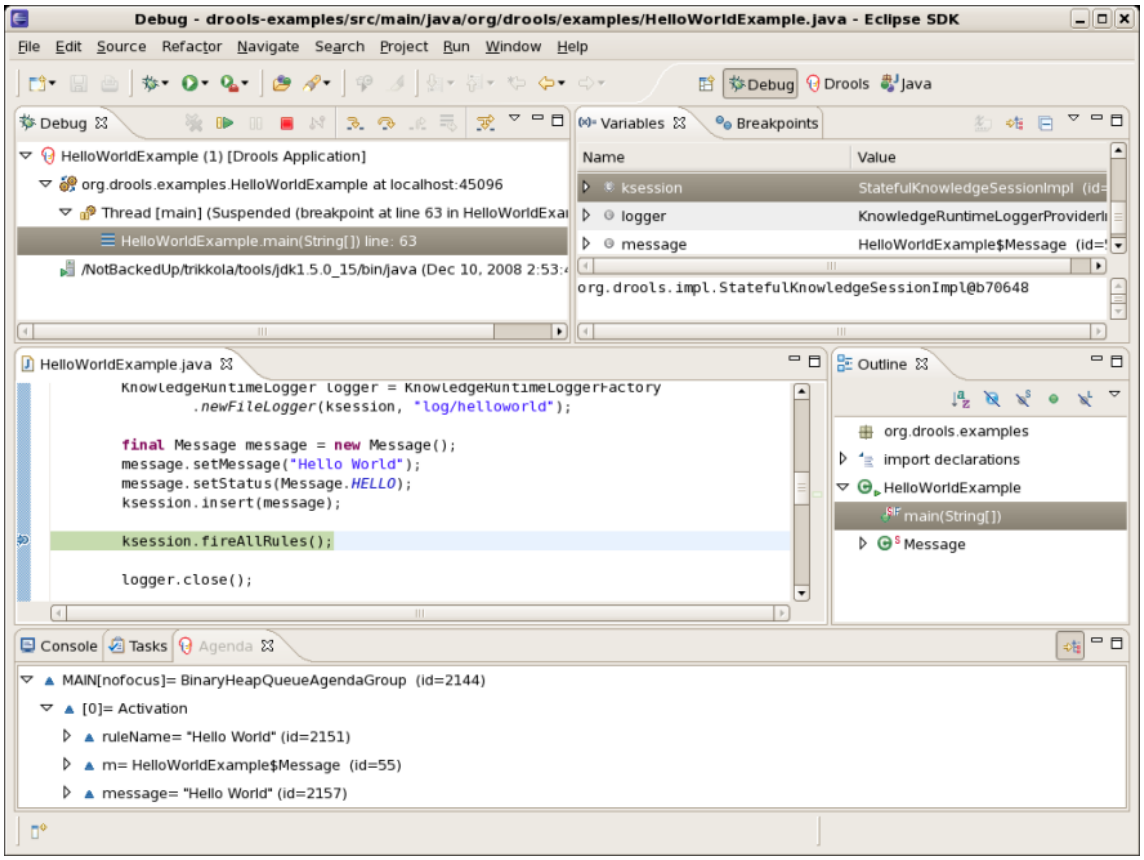


Figure 9.1. Hello World: fireAllRules Agenda View

The may application print outs go to to System.out while the debug listener print outs go to System.err.

Example 9.5. HelloWorld: System.out in the Console window

```
Hello World
Goodbye cruel world
```

Example 9.6. HelloWorld: System.err in the Console window

```
==>[ActivationCreated(0): rule=Hello World;
                tuple=[fid:1:1:org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96]]
[ObjectInserted:

$Message@17cec96];
                        object=org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96]
[BeforeActivationFired: rule=Hello World;
```

```
                tuple=[fid:1:1:org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96]]
==>[ActivationCreated(4): rule=Good Bye;
                tuple=[fid:1:2:org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96]]
[ObjectUpdated:

$Message@17cec96];
                    old_object=org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96;
                    new_object=org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96]
[AfterActivationFired(0): rule=Hello World]
[BeforeActivationFired: rule=Good Bye;
                tuple=[fid:1:2:org.drools.examples.helloworld.HelloWorldExample
$Message@17cec96]]
[AfterActivationFired(4): rule=Good Bye]
```

The LHS (after `when`) section of the rule states that it will be activated for each `Message` object inserted into the Working Memory whose status is `Message.HELLO`. Besides that, two variable bindings are created: the variable `message` is bound to the `message` attribute and the variable `m` is bound to the matched `Message` object itself.

The RHS (after `then`) or consequence part of the rule is written using the MVEL expression language, as declared by the rule's attribute `dialect`. After printing the content of the bound variable `message` to `System.out`, the rule changes the values of the `message` and `status` attributes of the `Message` object bound to `m`. This is done MVEL's `modify` statement, which allows you to apply a block of assignments in one statement, with the engine being automatically notified of the changes at the end of the block.

Example 9.7. HelloWorld: rule "Hello World"

```
rule "Hello World"
      dialect "mvel"
  when
      m : Message( status == Message.HELLO, message : message )
  then
      System.out.println( message );
      modify ( m ) { message = "Goodbyte cruel world",
                     status = Message.GOODBYE };
end
```

We can set a breakpoint into the DRL, on the `modify` call, and inspect the Agenda view again during the execution of the rule's consequence. This time we start the execution via "Debug As" and "Drools application" and not by running a "Java application":

1. Open the class `org.drools.examples.HelloWorld` in your Eclipse IDE.

2. Right-click the class and select "Debug as..." and then "Drools application".

Now we can see that the other rule `"Good Bye"`, which uses the Java dialect, is activated and placed on the Agenda.

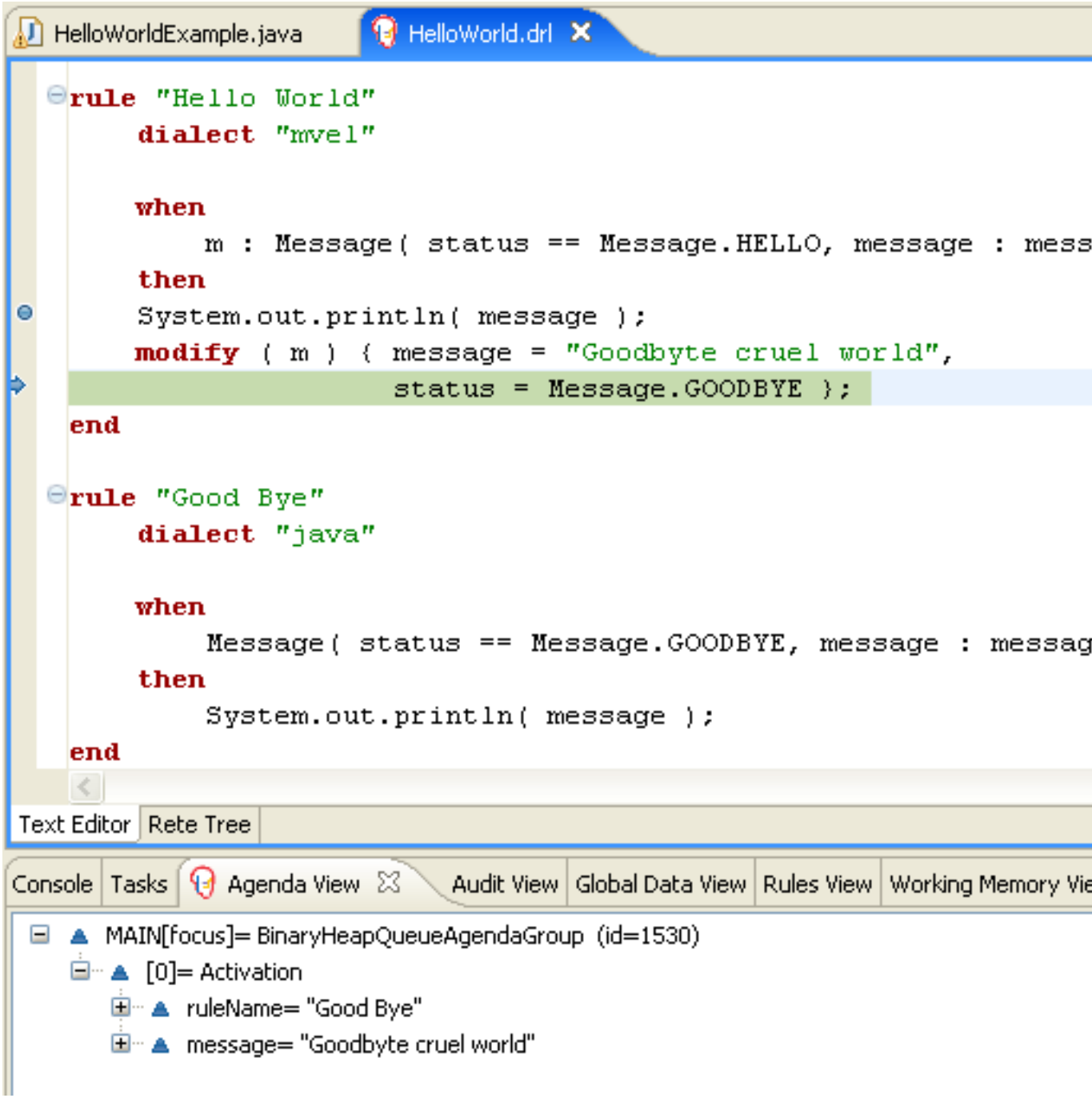


Figure 9.2. Hello World: rule "Hello World" Agenda View

The "Good Bye" rule, which specifies the "java" dialect, is similar to the "Hello World" rule except that it matches `Message` objects whose status is `Message.GOODBYE`.

Example 9.8. HelloWorld: rule "Good Bye"

```
rule "Good Bye"
      dialect "java"
  when
      Message( status == Message.GOODBYE, message : message )
  then
      System.out.println( message );
end
```

Remember the Java code where we used the `KnowledgeRuntimeLoggerFactory` method `newFileLogger` to create a `KnowledgeRuntimeLogger` and called `logger.close()` at the end. This created an audit log file that can be shown in the Audit view. We use the Audit view in many of the examples to demostrate the example execution flow. In the view screen shot below we can see that the object is inserted, which creates an activation for the "Hello World" rule; the activation is then executed which updates the `Message` object causing the "Good Bye" rule to activate; finally the "Good Bye" rule also executes. Selecting an event in the Audit view highlights the origin event in green; therefore the "Activation created" event is highlighted in green as the origin of the "Activation executed" event.

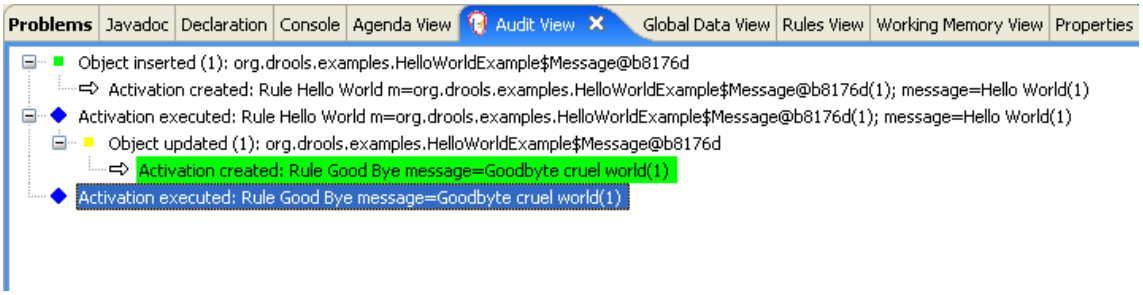


Figure 9.3. Hello World: Audit View

9.3. State Example

This example is implemented in three different versions to demonstrate different ways of implementing the same basic behavior: forward chaining, i.e., the ability the engine has to evaluate, activate and fire rules in sequence, based on changes on the facts in the Working Memory.

9.3.1. Understanding the State Example

Name: State Example
Main class: org.drools.examples.state.StateExampleUsingSalience
Module: drools-examples
Type: Java application

```
Rules file: StateExampleUsingSalience.drl
Objective: Demonstrates basic rule use
  and Conflict Resolution for rule firing priority.
```

Each `State` class has fields for its name and its current state (see the class `org.drools.examples.state.State`). The two possible states for each objects are:

- `NOTRUN`
- `FINISHED`

Example 9.9. State Class

```
public class State {
    public static final int NOTRUN   = 0;
    public static final int FINISHED = 1;

    private final PropertyChangeSupport changes =
        new PropertyChangeSupport( this );

    private String name;
    private int    state;

    ... setters and getters go here...
}
```

Ignoring the `PropertyChangeSupport`, which will be explained later, we see the creation of four `State` objects named A, B, C and D. Initially their states are set to `NOTRUN`, which is default for the used constructor. Each instance is asserted in turn into the Session and then `fireAllRules()` is called.

Example 9.10. Salience State: Execution

```
State a = new State( "A" );
State b = new State( "B" );
State c = new State( "C" );
final State d = new State( "D" );

// By setting dynamic to TRUE, Drools will use JavaBean
// PropertyChangeListeners so you don't have to call modify or update().
boolean dynamic = true;

session.insert( a, dynamic );
session.insert( b, dynamic );
session.insert( c, dynamic );
```

```
session.insert( d, dynamic );

session.fireAllRules();
session.dispose(); // Stateful rule session must always be disposed when finished
```

To execute the application:

1. Open the class `org.drools.examples.state.StateExampleUsingSalience` in your Eclipse IDE.
2. Right-click the class and select "Run as..." and then "Java application"

You will see the following output in the Eclipse console window:

Example 9.11. Salience State: Console Output

```
A finished
B finished
C finished
D finished
```

There are four rules in total. First, the `Bootstrap` rule fires, setting A to state `FINISHED`, which then causes B to change its state to `FINISHED`. C and D are both dependent on B, causing a conflict which is resolved by the salience values. Let's look at the way this was executed.

The best way to understand what is happening is to use the Audit Logging feature to graphically see the results of each operation. To view the Audit log generated by a run of this example:

1. If the Audit View is not visible, click on "Window" and then select "Show View", then "Other..." and "Drools" and finally "Audit View".
2. In the "Audit View" click the "Open Log" button and select the file "<drools-examples-dir>/log/state.log".

After that, the "Audit view" will look like the following screenshot:

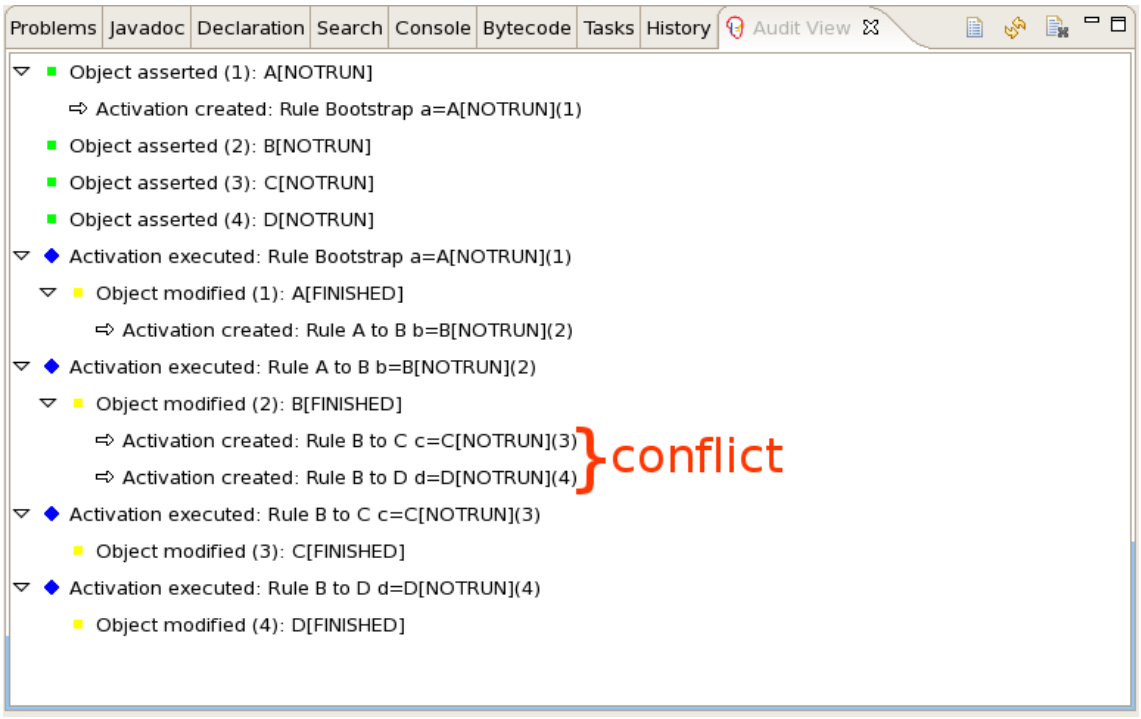


Figure 9.4. Salience State Example Audit View

Reading the log in the "Audit View", top to bottom, we see every action and the corresponding changes in the Working Memory. This way we observe that the assertion of the State object A in the state `NOTRUN` activates the `Bootstrap` rule, while the assertions of the other `State` objects have no immediate effect.

Example 9.12. Salience State: Rule "Bootstrap"

```
rule Bootstrap
    when
        a : State(name == "A", state == State.NOTRUN )
    then
        System.out.println(a.getName() + " finished" );
        a.setState( State.FINISHED );
end
```

The execution of rule Bootstrap changes the state of A to `FINISHED`, which, in turn, activates rule "A to B".

Example 9.13. Salience State: Rule "A to B"

```
rule "A to B"
    when
        State(name == "A", state == State.FINISHED )
```

```
        b : State(name == "B", state == State.NOTRUN )
    then
        System.out.println(b.getName() + " finished" );
        b.setState( State.FINISHED );
end
```

The execution of rule "A to B" changes the state of B to `FINISHED`, which activates both, rules "B to C" and "B to D", placing their Activations onto the Agenda. From this moment on, both rules may fire and, therefore, they are said to be "in conflict". The conflict resolution strategy allows the engine's Agenda to decide which rule to fire. As rule "B to C" has the **higher salience value** (10 versus the default salience value of 0), it fires first, modifying object C to state `FINISHED`. The Audit view shown above reflects the modification of the `State` object in the rule "A to B", which results in two activations being in conflict. The Agenda view can also be used to investigate the state of the Agenda, with debug points being placed in the rules themselves and the Agenda view opened. The screen shot below shows the breakpoint in the rule "A to B" and the state of the Agenda with the two conflicting rules.

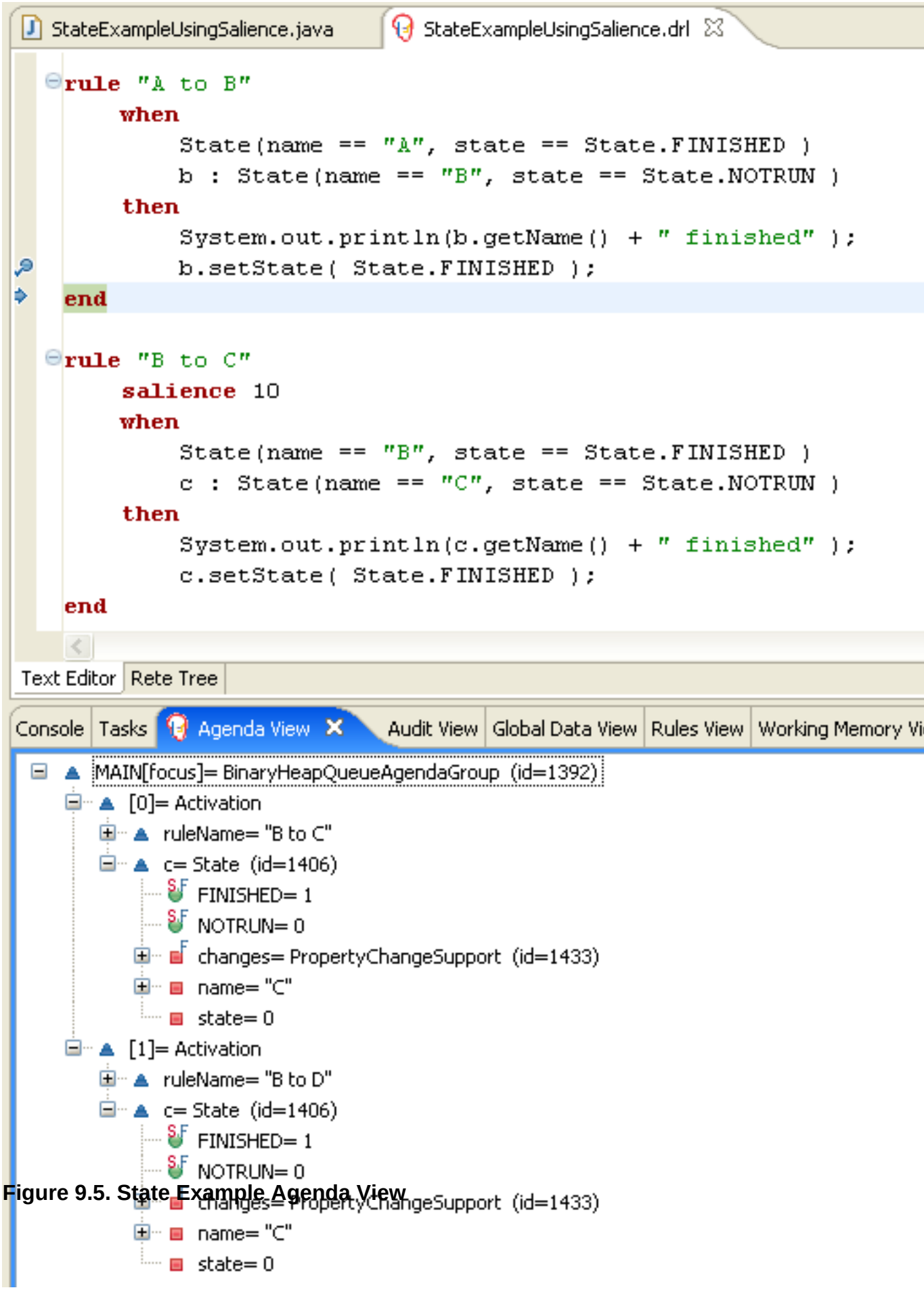


Figure 9.5. State Example Agenda View

Example 9.14. Salience State: Rule "B to C"

```
rule "B to C"
        salience 10
    when
        State(name == "B", state == State.FINISHED )
        c : State(name == "C", state == State.NOTRUN )
    then
        System.out.println(c.getName() + " finished" );
        c.setState( State.FINISHED );
end
```

Rule "B to D" fires last, modifying object D to state `FINISHED`.

Example 9.15. Salience State: Rule "B to D"

```
rule "B to D"
    when
        State(name == "B", state == State.FINISHED )
        d : State(name == "D", state == State.NOTRUN )
    then
        System.out.println(d.getName() + " finished" );
        d.setState( State.FINISHED );
end
```

There are no more rules to execute and so the engine stops.

Another notable concept in this example is the use of *dynamic facts*, based on `PropertyChangeListener` objects. As described in the documentation, in order for the engine to see and react to changes of fact properties, the application must tell the engine that changes occurred. This can be done explicitly in the rules by using the `modify` statement, or implicitly by letting the engine know that the facts implement `PropertyChangeSupport` as defined by the *JavaBeans specification*. This example demonstrates how to use `PropertyChangeSupport` to avoid the need for explicit `modify` statements in the rules. To make use of this feature, ensure that your facts implement `PropertyChangeSupport`, the same way the class `org.drools.example.State` does, and use the following code to insert the facts into the Working Memory:

Example 9.16. Inserting a Dynamic Fact

```
// By setting dynamic to TRUE, Drools will use JavaBean
// PropertyChangeListeners so you don't have to call modify or update().
final boolean dynamic = true;
```

```
session.insert( fact, dynamic );
```

When using `PropertyChangeListener` objects, each setter must implement a little extra code for the notification. Here is the setter for `state` in the class `org.drools.examples`:
:

Example 9.17. Setter Example with PropertyChangeSupport

```
public void setState(final int newState) {
    int oldState = this.state;
    this.state = newState;
    this.changes.firePropertyChange( "state",
                                     oldState,
                                     newState );
}
```

There are two other classes in this example: `StateExampleUsingAgendGroup` and `StateExampleWithDynamicRules`. Both execute from A to B to C to D, as just shown. The `StateExampleUsingAgendGroup` uses agenda-groups to control the rule conflict and which one fires first. `StateExampleWithDynamicRules` shows how an additional rule can be added to an already running Working Memory with all the existing data applying to it at runtime.

Agenda groups are a way to partition the Agenda into groups and to control which groups can execute. By default, all rules are in the agenda group "MAIN". The "agenda-group" attribute lets you specify a different agenda group for the rule. Initially, a Working Memory has its focus on the Agenda group "MAIN". A group's rules will only fire when the group receives the focus. This can be achieved either ny using the method by `setFocus()` or the rule attribute `auto-focus`. "auto-focus" means that the rule automatically sets the focus to its agenda group when the rule is matched and activated. It is this "auto-focus" that enables rule "B to C" to fire before "B to D".

Example 9.18. Agenda Group State Example: Rule "B to C"

```
rule "B to C"
      agenda-group "B to C"
      auto-focus true
  when
      State(name == "B", state == State.FINISHED )
      c : State(name == "C", state == State.NOTRUN )
  then
      System.out.println(c.getName() + " finished" );
      c.setState( State.FINISHED );
            kcontext.getKnowledgeRuntime().getAgenda().getAgendaGroup(  "B  to
 D" ).setFocus();
end
```

The rule "B to C" calls `setFocus()` on the agenda group "B to D", allowing its active rules to fire, which allows the rule "B to D" to fire.

Example 9.19. Agenda Group State Example: Rule "B to D"

```
rule "B to D"
      agenda-group "B to D"
  when
      State(name == "B", state == State.FINISHED )
      d : State(name == "D", state == State.NOTRUN )
  then
      System.out.println(d.getName() + " finished" );
      d.setState( State.FINISHED );
end
```

The example `StateExampleWithDynamicRules` adds another rule to the Rule Base after `fireAllRules()`. The added rule is just another state transition.

Example 9.20. Dynamic State Example: Rule "D to E"

```
rule "D to E"
  when
      State(name == "D", state == State.FINISHED )
      e : State(name == "E", state == State.NOTRUN )
  then
      System.out.println(e.getName() + " finished" );
      e.setState( State.FINISHED );
end
```

This produces the following expected output:

Example 9.21. Dynamic Sate Example Output

```
A finished
B finished
C finished
D finished
E finished
```

9.4. Fibonacci Example

Name: Fibonacci
Main class: org.drools.examples.fibonacci.FibonacciExample

```
Module: drools-examples
Type: Java application
Rules file: Fibonacci.drl
Objective: Demonstrates Recursion,
  the CE not and cross product matching
```

The Fibonacci Numbers (see *http://en.wikipedia.org/wiki/Fibonacci_number*) discovered by Leonardo of Pisa (see *http://en.wikipedia.org/wiki/Fibonacci*) is a sequence that starts with 0 and 1. The next Fibonacci number is obtained by adding the two preceding Fibonacci numbers. The Fibonacci sequence begins with 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, 1597, 2584, 4181, 6765, 10946,... The Fibonacci Example demonstrates recursion and conflict resolution with salience values.

The single fact class `Fibonacci` is used in this example. It has two fields, sequence and value. The sequence field is used to indicate the position of the object in the Fibonacci number sequence. The value field shows the value of that Fibonacci object for that sequence position, using -1 to indicate a value that still needs to be computed.

Example 9.22. Fibonacci Class

```
public static class Fibonacci {
    private int  sequence;
    private long value;

    public Fibonacci( final int sequence ) {
        this.sequence = sequence;
        this.value = -1;
    }

    ... setters and getters go here...
}
```

Execute the example:

1. Open the class `org.drools.examples.fibonacci.FibonacciExample` in your Eclipse IDE.

2. Right-click the class and select "Run as..." and then "Java application"

Eclipse shows the following output in its console window (with "...snip..." indicating lines that were removed to save space):

Example 9.23. Fibonacci Example: Console Output

```
recurse for 50
```

```
recurse for 49
recurse for 48
recurse for 47
...snip...
recurse for 5
recurse for 4
recurse for 3
recurse for 2
1 == 1
2 == 1
3 == 2
4 == 3
5 == 5
6 == 8
...snip...
47 == 2971215073
48 == 4807526976
49 == 7778742049
50 == 12586269025
```

To kick this off from Java we only insert a single Fibonacci object, with a sequence field of 50. A recursive rule is then used to insert the other 49 `Fibonacci` objects. This example doesn't use `PropertyChangeSupport`. It uses the MVEL dialect, which means we can use the `modify` keyword, which allows a block setter action which also notifies the engine of changes.

Example 9.24. Fibonacci Example: Execution

```
ksession.insert( new Fibonacci( 50 ) );
ksession.fireAllRules();
```

The rule Recurse is very simple. It matches each asserted `Fibonacci` object with a value of -1, creating and asserting a new `Fibonacci` object with a sequence of one less than the currently matched object. Each time a Fibonacci object is added while the one with a sequence field equal to 1 does not exist, the rule re-matches and fires again. The `not` conditional element is used to stop the rule's matching once we have all 50 Fibonacci objects in memory. The rule also has a salience value, because we need to have all 50 `Fibonacci` objects asserted before we execute the Bootstrap rule.

Example 9.25. Fibonacci Example: Rule "Recurse"

```
rule Recurse
    salience 10
    when
        f : Fibonacci ( value == -1 )
        not ( Fibonacci ( sequence == 1 ) )
```

```
    then
        insert( new Fibonacci( f.sequence - 1 ) );
        System.out.println( "recurse for " + f.sequence );
end
```

The Audit view shows the original assertion of the `Fibonacci` object with a sequence field of 50, done from Java code. From there on, the Audit view shows the continual recursion of the rule, where each asserted `Fibonacci` object causes the Recurse rule to become activated and to fire again.

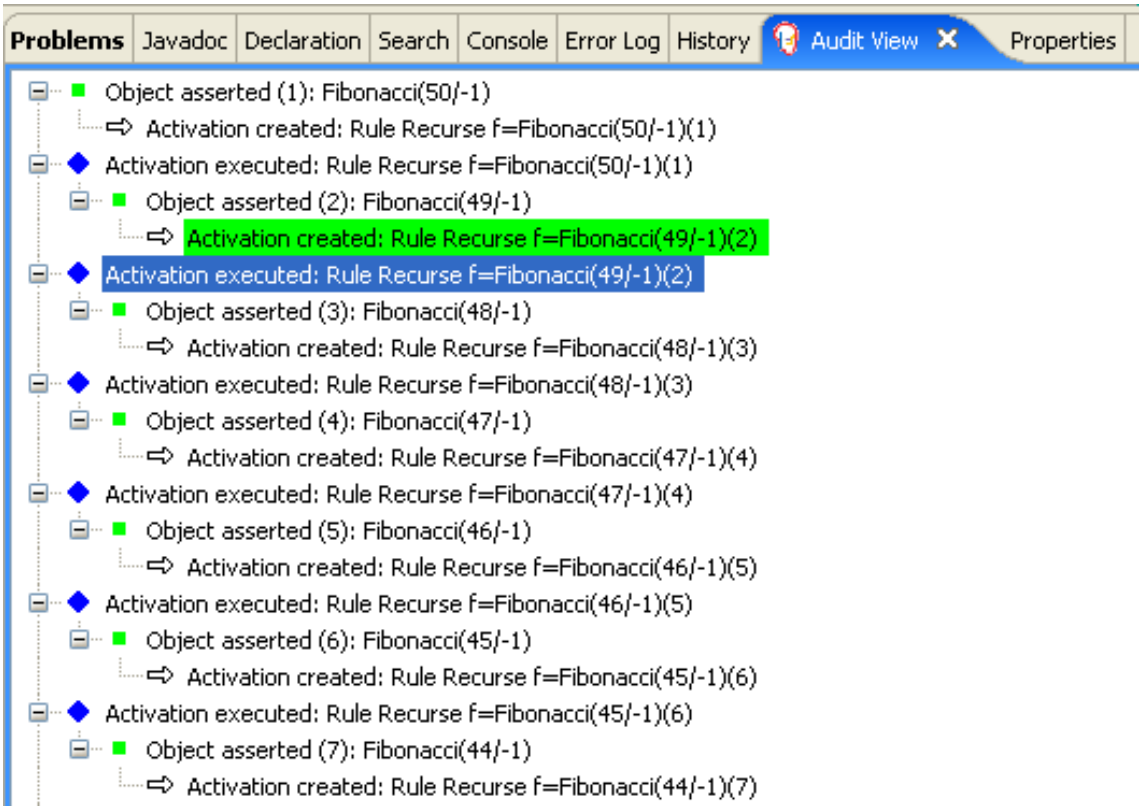


Figure 9.6. Fibonacci Example: "Recurse" Audit View 1

When a `Fibonacci` object with a sequence field of 2 is asserted the "Bootstrap" rule is matched and activated along with the "Recurse" rule. Note the multi-restriction on field `sequence`, testing for equality with 1 or 2.

Example 9.26. Fibonacci Example: Rule "Bootstrap"

```
rule Bootstrap
    when
        f : Fibonacci( sequence == 1 || == 2, value == -1 ) // multi-restriction
    then
        modify ( f ){ value = 1 };
```

```
        System.out.println( f.sequence + " == " + f.value );
end
```

At this point the Agenda looks as shown below. However, the "Bootstrap" rule does not fire because the "Recurse" rule has a higher salience.

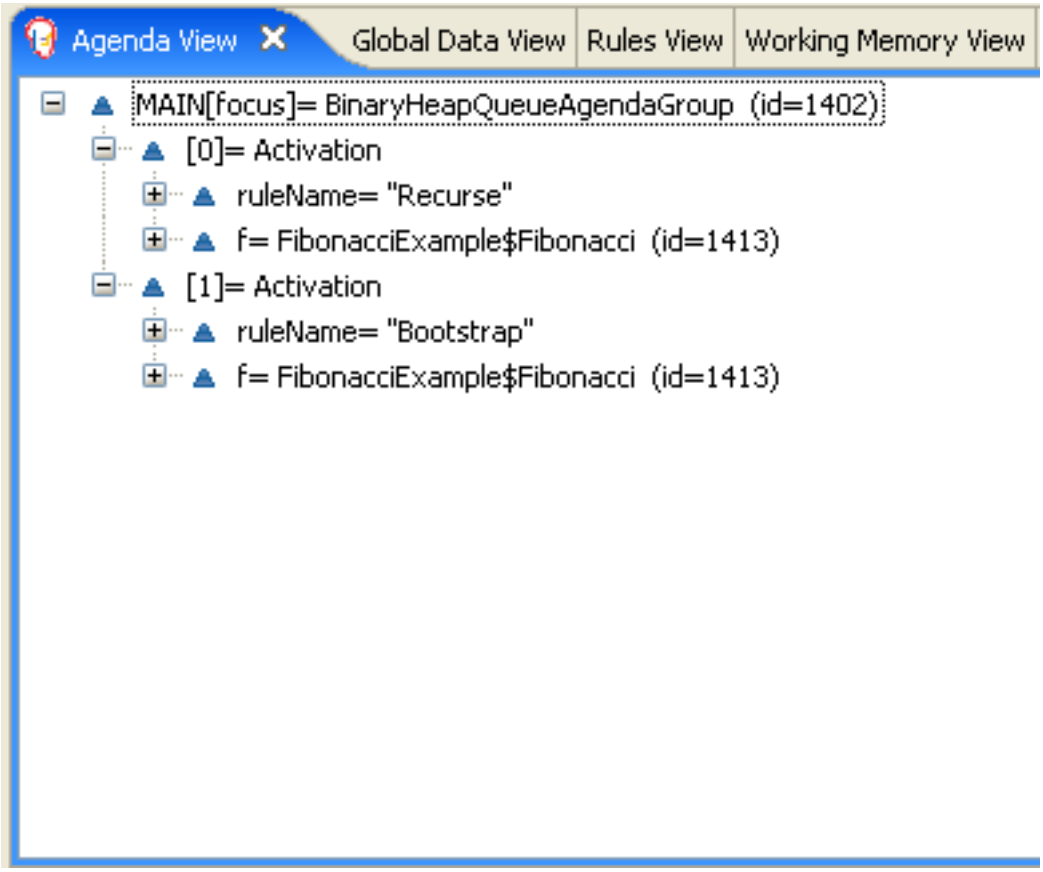


Figure 9.7. Fibonacci Example: "Recurse" Agenda View 1

When a `Fibonacci` object with a sequence of 1 is asserted the Bootstrap rule is matched again, causing two activations for this rule. Note that the "Recurse" rule does not match and activate because the `not` conditional element stops the rule's matching as soon as a `Fibonacci` object with a sequence of 1 exists.

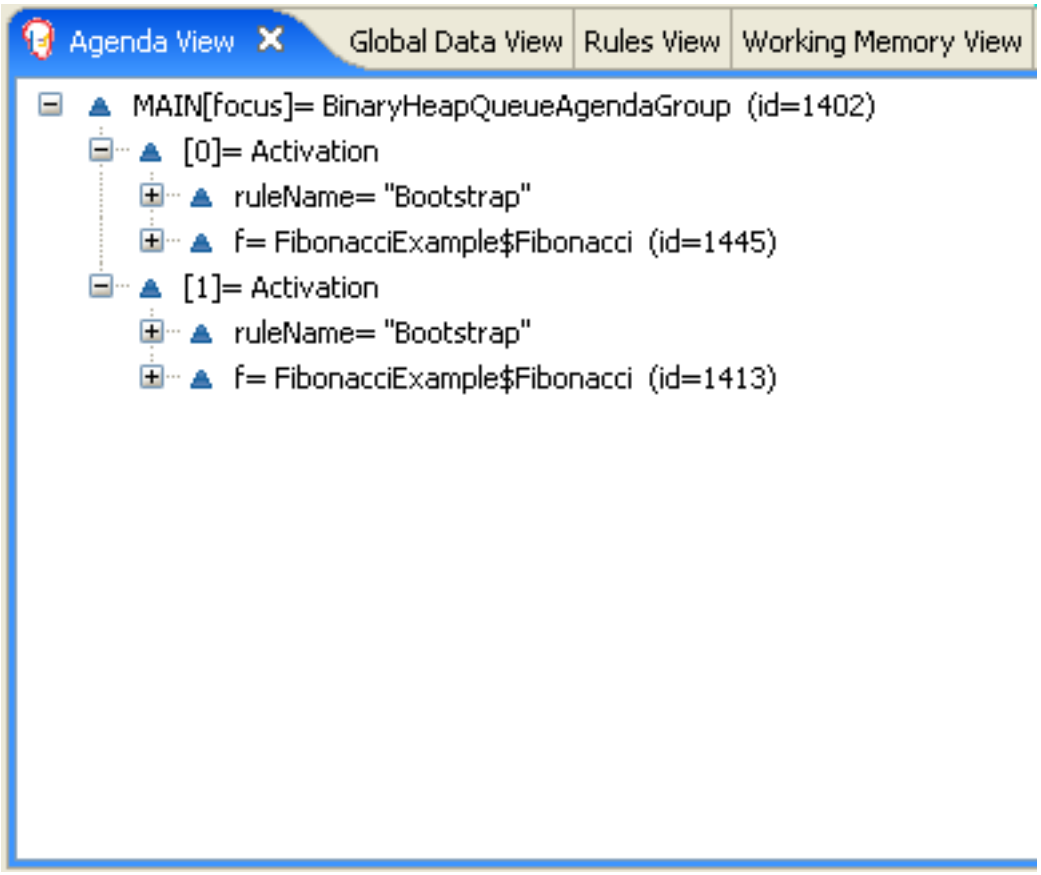


Figure 9.8. Fibonacci Example: "Recurse" Agenda View 2

Once we have two `Fibonacci` objects with values not equal to -1 the "Calculate" rule is able to match. It was the "Bootstrap" rule that set the objects with sequence 1 and 2 to values of 1. At this point we have 50 Fibonacci objects in the Working Memory. Now we need to select a suitable triple to calculate each of their values in turn. Using three Fibonacci patterns in a rule without field constraints to confine the possible cross products would result in 50x49x48 possible combinations, leading to about 125,000 possible rule firings, most of them incorrect. The "Calculate" rule uses field constraints to correctly constraint the thee Fibonacci patterns in the correct order; this technique is called *cross product matching*. The first pattern finds any Fibonacci with a value != -1 and binds both the pattern and the field. The second Fibonacci does this, too, but it adds an additional field constraint to ensure that its sequence is greater by one than the Fibonacci bound to `f1`. When this rule fires for the first time, we know that only sequences 1 and 2 have values of 1, and the two constraints ensure that `f1` references sequence 1 and `f2` references sequence 2. The final pattern finds the Fibonacci with a value equal to -1 and with a sequence one greater than `f2`. At this point, we have three `Fibonacci` objects correctly selected from the available cross products, and we can calculate the value for the third `Fibonacci` object that's bound to `f3`.

Example 9.27. Fibonacci Example: Rule "Calculate"

```
rule Calculate
    when
        // Bind f1 and s1
        f1 : Fibonacci( s1 : sequence, value != -1 )
        // Bind f2 and v2; refer to bound variable s1
        f2 : Fibonacci( sequence == (s1 + 1), v2 : value != -1 )
        // Bind f3 and s3; alternative reference of f2.sequence
        f3 : Fibonacci( s3 : sequence == (f2.sequence + 1 ), value == -1 )
    then
        // Note the various referencing rechniques.
        modify ( f3 ) { value = f1.value + v2 };
        System.out.println( s3 + " == " + f3.value );
end
```

The `modify` statement updated the value of the `Fibonacci` object bound to `f3`. This means we now have another new Fibonacci object with a value not equal to -1, which allows the "Calculate" rule to rematch and calculate the next Fibonacci number. The Audit view below shows how the firing of the last "Bootstrap" modifies the `Fibonacci` object, enabling the "Calculate" rule to match, which then modifies another Fibonacci object allowing the "Calculate" rule to match again. This continues till the value is set for all `Fibonacci` objects.

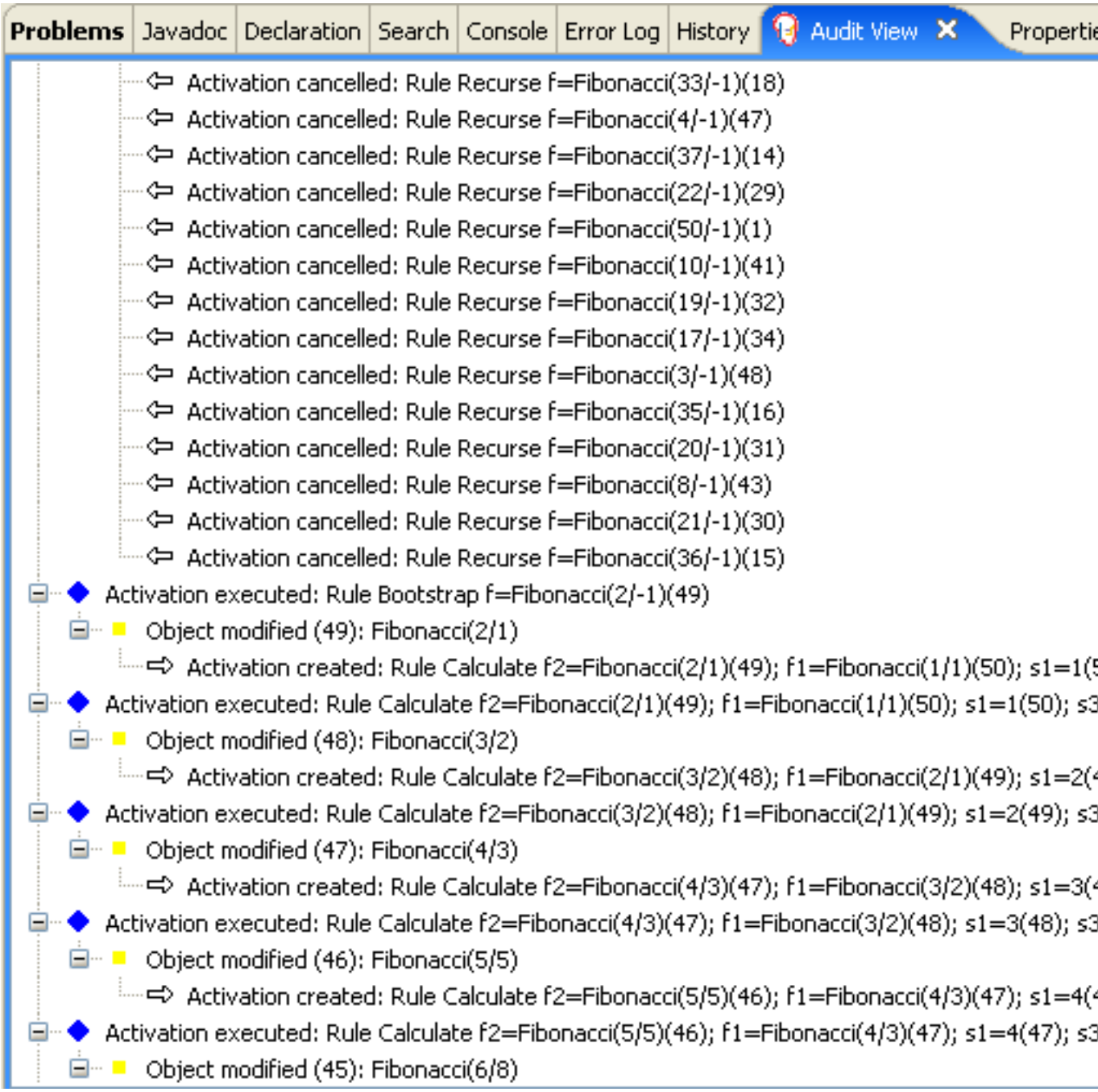


Figure 9.9. Fibonacci Example: "Bootstrap" Audit View

9.5. Banking Tutorial

```
Name: BankingTutorial
Main class: org.drools.tutorials.banking.BankingExamplesApp.java
Module: drools-examples
Type: Java application
Rules file: org.drools.tutorials.banking.*.drl
```

Objective: Demonstrate pattern matching, basic sorting and calculation rules.

This tutorial demonstrates the process of developing a complete personal banking application to handle credits and debits on multiple accounts. It uses a set of design patterns that have been created for the process.

The class `RuleRunner` is a simple harness to execute one or more DRL files against a set of data. It compiles the Packages and creates the Knowledge Base for each execution, allowing us to easily execute each scenario and inspect the outputs. In reality this is not a good solution for a production system, where the Knowledge Base should be built just once and cached, but for the purposes of this tutorial it shall suffice.

Example 9.28. Banking Tutorial: RuleRunner

```
public class RuleRunner {

    public RuleRunner() {
    }

    public void runRules(String[] rules,
                         Object[] facts) throws Exception {

        KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
      KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();

        for ( int i = 0; i < rules.length; i++ ) {
            String ruleFile = rules[i];
            System.out.println( "Loading file: " + ruleFile );
            kbuilder.add( ResourceFactory.newClassPathResource( ruleFile,
                                                                RuleRunner.class ),
                          ResourceType.DRL );
        }

        Collection<KnowledgePackage> pkgs = kbuilder.getKnowledgePackages();
        kbase.addKnowledgePackages( pkgs );
       StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();

        for ( int i = 0; i < facts.length; i++ ) {
            Object fact = facts[i];
            System.out.println( "Inserting fact: " + fact );
            ksession.insert( fact );
        }

        ksession.fireAllRules();
    }
}
```

The first of our sample Java classes loads and executes a single DRL file, `Example.drl`, but without inserting any data.

Example 9.29. Banking Tutorial : Java Example1

```
public class Example1 {
    public static void main(String[] args) throws Exception {
        new RuleRunner().runRules( new String[] { "Example1.drl" },
                                   new Object[0] );
    }
}
```

The first simple rule to execute has a single `eval` condition that will alway be true, so that this rule will match and fire, once, after the start.

Example 9.30. Banking Tutorial: Rule in Example1.drl

```
rule "Rule 01"
    when
        eval( 1==1 )
    then
        System.out.println( "Rule 01 Works" );
endh
```

The output for the rule is below, showing that the rule matches and executes the single print statement.

Example 9.31. Banking Tutorial: Output of Example1.java

```
Loading file: Example1.drl
Rule 01 Works
```

The next step is to assert some simple facts and print them out.

Example 9.32. Banking Tutorial: Java Example2

```
public class Example2 {
    public static void main(String[] args) throws Exception {
        Number[] numbers = new Number[] {wrap(3), wrap(1), wrap(4), wrap(1), wrap(5)};
        new RuleRunner().runRules( new String[] { "Example2.drl" },
                                   numbers );
    }
```

```
    private static Integer wrap( int i ) {
        return new Integer(i);
    }
}
```

This doesn't use any specific facts but instead asserts a set of `java.lang.Integer` objects. This is not considered "best practice" as a number is not a useful fact, but we use it here to demonstrate basic techniques before more complexity is added.

Now we will create a simple rule to print out these numbers.

Example 9.33. Banking Tutorial: Rule in Example2.drl

```
rule "Rule 02"
    when
        Number( $intValue : intValue )
    then
        System.out.println( "Number found with value: " + $intValue );
end
```

Once again, this rule does nothing special. It identifies any facts that are `Number` objects and prints out the values. Notice the use of the abstract class `Number`: we inserted `Integer` objects but we now look for any kind of number. The pattern matching engine is able to match interfaces and superclasses of asserted objects.

The output shows the DRL being loaded, the facts inserted and then the matched and fired rules. We can see that each inserted number is matched and fired and thus printed.

Example 9.34. Banking Tutorial: Output of Example2.java

```
Loading file: Example2.drl
Inserting fact: 3
Inserting fact: 1
Inserting fact: 4
Inserting fact: 1
Inserting fact: 5
Number found with value: 5
Number found with value: 1
Number found with value: 4
Number found with value: 1
Number found with value: 3
```

There are certainly many better ways to sort numbers than using rules, but since we will need to apply some cashflows in date order when we start looking at banking rules we'll develop simple rule based sorting technique.

Example 9.35. Banking Tutorial: Example3.java

```
public class Example3 {
    public static void main(String[] args) throws Exception {
        Number[] numbers = new Number[] {wrap(3), wrap(1), wrap(4), wrap(1), wrap(5)};
        new RuleRunner().runRules( new String[] { "Example3.drl" },
                                   numbers );
    }

    private static Integer wrap(int i) {
        return new Integer(i);
    }
}
```

Again we insert our `Integer` objects, but this time the rule is slightly different:

Example 9.36. Banking Tutorial: Rule in Example3.drl

```
rule "Rule 03"
    when
        $number : Number( )
        not Number( intValue < $number.intValue )
    then
        System.out.println("Number found with value: " + $number.intValue() );
        retract( $number );
end
```

The first line of the rule identifies a `Number` and extracts the value. The second line ensures that there does not exist a smaller number than the one found by the first pattern. We might expect to match only one number - the smallest in the set. However, the retraction of the number after it has been printed means that the smallest number has been removed, revealing the next smallest number, and so on.

The resulting output shows that the numbers are now sorted numerically.

Example 9.37. Banking Tutorial: Output of Example3.java

```
Loading file: Example3.drl
Inserting fact: 3
Inserting fact: 1
```

```
Inserting fact: 4
Inserting fact: 1
Inserting fact: 5
Number found with value: 1
Number found with value: 1
Number found with value: 3
Number found with value: 4
Number found with value: 5
```

We are ready to start moving towards our personal accounting rules. The first step is to create a `Cashflow` object.

Example 9.38. Banking Tutorial: Class Cashflow

```
public class Cashflow {
    private Date   date;
    private double amount;

    public Cashflow() {
    }

    public Cashflow(Date date, double amount) {
        this.date = date;
        this.amount = amount;
    }

    public Date getDate() {
        return date;
    }

    public void setDate(Date date) {
        this.date = date;
    }

    public double getAmount() {
        return amount;
    }

    public void setAmount(double amount) {
        this.amount = amount;
    }

    public String toString() {
        return "Cashflow[date=" + date + ",amount=" + amount + "]";
    }
}
```

Class `Cashflow` has two simple attributes, a date and an amount. (Note that using the type `double` for monetary units is generally *not* a good idea because floating point numbers cannot represent most numbers accurately.) There is also an overloaded constructor to set the values, and a method `toString` to print a cashflow. The Java code of `Example4.java` inserts five Cashflow objects, with varying dates and amounts.

Example 9.39. Banking Tutorial: Example4.java

```
public class Example4 {
    public static void main(String[] args) throws Exception {
        Object[] cashflows = {
            new Cashflow(new SimpleDate("01/01/2007"), 300.00),
            new Cashflow(new SimpleDate("05/01/2007"), 100.00),
            new Cashflow(new SimpleDate("11/01/2007"), 500.00),
            new Cashflow(new SimpleDate("07/01/2007"), 800.00),
            new Cashflow(new SimpleDate("02/01/2007"), 400.00),
        };

        new RuleRunner().runRules( new String[] { "Example4.drl" },
                                   cashflows );
    }
}
```

The convenience class `SimpleDate` extends `java.util.Date`, providing a constructor taking a String as input and defining a date format. The code is listed below

Example 9.40. Banking Tutorial: Class SimpleDate

```
public class SimpleDate extends Date {
     private static final SimpleDateFormat format = new SimpleDateFormat("dd/
MM/yyyy");

    public SimpleDate(String datestr) throws Exception {
        setTime(format.parse(datestr).getTime());
    }
}
```

Now, let's look at `Example4.drl` to see how we print the sorted `Cashflow` objects:

Example 9.41. Banking Tutorial: Rule in Example4.drl

```
rule "Rule 04"
    when
        $cashflow : Cashflow( $date : date, $amount : amount )
```

```
        not Cashflow( date < $date)
    then
        System.out.println("Cashflow: "+$date+" :: "+$amount);
        retract($cashflow);
end
```

Here, we identify a `Cashflow` and extract the date and the amount. In the second line of the rule we ensure that there is no Cashflow with an earlier date than the one found. In the consequence, we print the `Cashflow` that satisfies the rule and then retract it, making way for the next earliest `Cashflow`. So, the output we generate is:

Example 9.42. Banking Tutorial: Output of Example4.java

```
Loading file: Example4.drl
Inserting fact: Cashflow[date=Mon Jan 01 00:00:00 GMT 2007,amount=300.0]
Inserting fact: Cashflow[date=Fri Jan 05 00:00:00 GMT 2007,amount=100.0]
Inserting fact: Cashflow[date=Thu Jan 11 00:00:00 GMT 2007,amount=500.0]
Inserting fact: Cashflow[date=Sun Jan 07 00:00:00 GMT 2007,amount=800.0]
Inserting fact: Cashflow[date=Tue Jan 02 00:00:00 GMT 2007,amount=400.0]
Cashflow: Mon Jan 01 00:00:00 GMT 2007 :: 300.0
Cashflow: Tue Jan 02 00:00:00 GMT 2007 :: 400.0
Cashflow: Fri Jan 05 00:00:00 GMT 2007 :: 100.0
Cashflow: Sun Jan 07 00:00:00 GMT 2007 :: 800.0
Cashflow: Thu Jan 11 00:00:00 GMT 2007 :: 500.0
```

Next, we extend our `Cashflow`, resulting in a `TypedCashflow` which can be a credit or a debit operation. (Normally, we would just add this to the `Cashflow` type, but we use extension to keep the previous version of the class intact.)

Example 9.43. Banking Tutorial: Class TypedCashflow

```
public class TypedCashflow extends Cashflow {
    public static final int CREDIT = 0;
    public static final int DEBIT  = 1;

    private int             type;

    public TypedCashflow() {
    }

    public TypedCashflow(Date date, int type, double amount) {
        super( date, amount );
        this.type = type;
    }
```

```
    public int getType() {
        return type;
    }

    public void setType(int type) {
        this.type = type;
    }

    public String toString() {
        return "TypedCashflow[date=" + getDate() +
               ",type=" + (type == CREDIT ? "Credit" : "Debit") +
               ",amount=" + getAmount() + "]";
    }
}
```

There are lots of ways to improve this code, but for the sake of the example this will do.

Now let's create Example5, a class for running our code.

Example 9.44. Banking Tutorial: Example5.java

```
public class Example5 {
    public static void main(String[] args) throws Exception {
        Object[] cashflows = {
            new TypedCashflow(new SimpleDate("01/01/2007"),
                              TypedCashflow.CREDIT, 300.00),
            new TypedCashflow(new SimpleDate("05/01/2007"),
                              TypedCashflow.CREDIT, 100.00),
            new TypedCashflow(new SimpleDate("11/01/2007"),
                              TypedCashflow.CREDIT, 500.00),
            new TypedCashflow(new SimpleDate("07/01/2007"),
                              TypedCashflow.DEBIT, 800.00),
            new TypedCashflow(new SimpleDate("02/01/2007"),
                              TypedCashflow.DEBIT, 400.00),
        };

        new RuleRunner().runRules( new String[] { "Example5.drl" },
                                   cashflows );
    }
}
```

Here, we simply create a set of `Cashflow` objects which are either credit or debit operations. We supply them and `Example5.drl` to the RuleEngine.

Now, let's look at a rule printing the sorted `Cashflow` objects.

Example 9.45. Banking Tutorial: Rule in Example5.drl

```
rule "Rule 05"
    when
        $cashflow : TypedCashflow( $date : date,
                                   $amount : amount,
                                   type == TypedCashflow.CREDIT )
        not TypedCashflow( date < $date,
                           type == TypedCashflow.CREDIT )
    then
        System.out.println("Credit: "+$date+" :: "+$amount);
        retract($cashflow);
end
```

Here, we identify a `Cashflow` fact with a type of `CREDIT` and extract the date and the amount. In the second line of the rule we ensure that there is no `Cashflow` of the same type with an earlier date than the one found. In the consequence, we print the cashflow satisfying the patterns and then retract it, making way for the next earliest cashflow of type `CREDIT`.

So, the output we generate is

Example 9.46. Banking Tutorial: Output of Example5.java

```
Loading file: Example5.drl
Inserting fact: TypedCashflow[date=Mon Jan 01 00:00:00 GMT
 2007,type=Credit,amount=300.0]
Inserting fact: TypedCashflow[date=Fri Jan 05 00:00:00 GMT
 2007,type=Credit,amount=100.0]
Inserting fact: TypedCashflow[date=Thu Jan 11 00:00:00 GMT
 2007,type=Credit,amount=500.0]
Inserting fact: TypedCashflow[date=Sun Jan 07 00:00:00 GMT
 2007,type=Debit,amount=800.0]
Inserting fact: TypedCashflow[date=Tue Jan 02 00:00:00 GMT
 2007,type=Debit,amount=400.0]
Credit: Mon Jan 01 00:00:00 GMT 2007 :: 300.0
Credit: Fri Jan 05 00:00:00 GMT 2007 :: 100.0
Credit: Thu Jan 11 00:00:00 GMT 2007 :: 500.0
```

Continuing our banking exercise, we are now going to process both credits and debits on two bank accounts, calculating the account balance. In order to do this, we create two separate `Account` objects and inject them into the `Cashflows` objects before passing them to the Rule Engine. The reason for this is to provide easy access to the correct account without having to resort to helper classes. Let's take a look at the `Account` class first. This is a simple Java object with an account number and balance:

Example 9.47. Banking Tutorial: Class Account

```
public class Account {
    private long   accountNo;
    private double balance = 0;

    public Account() {
    }

    public Account(long accountNo) {
        this.accountNo = accountNo;
    }

    public long getAccountNo() {
        return accountNo;
    }

    public void setAccountNo(long accountNo) {
        this.accountNo = accountNo;
    }

    public double getBalance() {
        return balance;
    }

    public void setBalance(double balance) {
        this.balance = balance;
    }

    public String toString() {
      return "Account[" + "accountNo=" + accountNo + ",balance=" + balance + "]";
    }
}
```

Now let's extend our `TypedCashflow`, resulting in `AllocatedCashflow`, to include an `Account` reference.

Example 9.48. Banking Tutorial: Class AllocatedCashflow

```
public class AllocatedCashflow extends TypedCashflow {
    private Account account;

    public AllocatedCashflow() {
    }

   public AllocatedCashflow(Account account, Date date, int type, double amount) {
```

```
        super( date, type, amount );
        this.account = account;
    }

    public Account getAccount() {
        return account;
    }

    public void setAccount(Account account) {
        this.account = account;
    }

    public String toString() {
        return "AllocatedCashflow[" +
               "account=" + account +
               ",date=" + getDate() +
               ",type=" + (getType() == CREDIT ? "Credit" : "Debit") +
               ",amount=" + getAmount() + "]";
    }
}
```

The Java code of `Example5.java` creates two `Account` objects and passes one of them into each cashflow, in the constructor call.

Example 9.49. Banking Tutorial: Example5.java

```
public class Example6 {
    public static void main(String[] args) throws Exception {
        Account acc1 = new Account(1);
        Account acc2 = new Account(2);

        Object[] cashflows = {
            new AllocatedCashflow(acc1,new SimpleDate("01/01/2007"),
                                  TypedCashflow.CREDIT, 300.00),
            new AllocatedCashflow(acc1,new SimpleDate("05/02/2007"),
                                  TypedCashflow.CREDIT, 100.00),
            new AllocatedCashflow(acc2,new SimpleDate("11/03/2007"),
                                  TypedCashflow.CREDIT, 500.00),
            new AllocatedCashflow(acc1,new SimpleDate("07/02/2007"),
                                  TypedCashflow.DEBIT,  800.00),
            new AllocatedCashflow(acc2,new SimpleDate("02/03/2007"),
                                  TypedCashflow.DEBIT,  400.00),
            new AllocatedCashflow(acc1,new SimpleDate("01/04/2007"),
                                  TypedCashflow.CREDIT, 200.00),
            new AllocatedCashflow(acc1,new SimpleDate("05/04/2007"),
                                  TypedCashflow.CREDIT, 300.00),
            new AllocatedCashflow(acc2,new SimpleDate("11/05/2007"),
```

```
                                    TypedCashflow.CREDIT, 700.00),
            new AllocatedCashflow(acc1,new SimpleDate("07/05/2007"),
                                    TypedCashflow.DEBIT,  900.00),
            new AllocatedCashflow(acc2,new SimpleDate("02/05/2007"),
                                    TypedCashflow.DEBIT,  100.00)
        };

        new RuleRunner().runRules( new String[] { "Example6.drl" },
                                    cashflows );
    }
}
```

Now, let's look at the rule in `Example6.drl` to see how we apply each cashflow in date order and calculate and print the balance.

Example 9.50. Banking Tutorial: Rule in Example6.drl

```
rule "Rule 06 - Credit"
    when
        $cashflow : AllocatedCashflow( $account : account,
                                       $date : date,
                                       $amount : amount,
                                       type == TypedCashflow.CREDIT )
        not AllocatedCashflow( account == $account, date < $date)
    then
        System.out.println("Credit: " + $date + " :: " + $amount);
        $account.setBalance($account.getBalance()+$amount);
        System.out.println("Account: " + $account.getAccountNo() +
                           " - new balance: " + $account.getBalance());
        retract($cashflow);
end

rule "Rule 06 - Debit"
    when
        $cashflow : AllocatedCashflow( $account : account,
                            $date : date,
                            $amount : amount,
                            type == TypedCashflow.DEBIT )
        not AllocatedCashflow( account == $account, date < $date)
    then
        System.out.println("Debit: " + $date + " :: " + $amount);
        $account.setBalance($account.getBalance() - $amount);
        System.out.println("Account: " + $account.getAccountNo() +
                          " - new balance: " + $account.getBalance());
        retract($cashflow);
end
```

Although we have separate rules for credits and debits, but we do not specify a type when checking for earlier cashflows. This is so that all cashflows are applied in date order, regardless of the cashflow type. In the conditions we identify the account to work with, and in the consequences we update it with the cashflow amount.

Example 9.51. Banking Tutorial: Output of Example6.java

```
Loading file: Example6.drl
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=1,balance=0.0],date=Mon   Jan   01
 00:00:00 GMT 2007,type=Credit,amount=300.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=1,balance=0.0],date=Mon   Feb   05
 00:00:00 GMT 2007,type=Credit,amount=100.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=2,balance=0.0],date=Sun   Mar   11
 00:00:00 GMT 2007,type=Credit,amount=500.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=1,balance=0.0],date=Wed   Feb   07
 00:00:00 GMT 2007,type=Debit,amount=800.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=2,balance=0.0],date=Fri   Mar   02
 00:00:00 GMT 2007,type=Debit,amount=400.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=1,balance=0.0],date=Sun   Apr   01
 00:00:00 BST 2007,type=Credit,amount=200.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=1,balance=0.0],date=Thu   Apr   05
 00:00:00 BST 2007,type=Credit,amount=300.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=2,balance=0.0],date=Fri   May   11
 00:00:00 BST 2007,type=Credit,amount=700.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=1,balance=0.0],date=Mon   May   07
 00:00:00 BST 2007,type=Debit,amount=900.0]
Inserting                                                                fact:
   AllocatedCashflow[account=Account[accountNo=2,balance=0.0],date=Wed   May   02
 00:00:00 BST 2007,type=Debit,amount=100.0]
Debit: Fri Mar 02 00:00:00 GMT 2007 :: 400.0
Account: 2 - new balance: -400.0
Credit: Sun Mar 11 00:00:00 GMT 2007 :: 500.0
Account: 2 - new balance: 100.0
Debit: Wed May 02 00:00:00 BST 2007 :: 100.0
Account: 2 - new balance: 0.0
Credit: Fri May 11 00:00:00 BST 2007 :: 700.0
Account: 2 - new balance: 700.0
Credit: Mon Jan 01 00:00:00 GMT 2007 :: 300.0
Account: 1 - new balance: 300.0
```

```
Credit: Mon Feb 05 00:00:00 GMT 2007 :: 100.0
Account: 1 - new balance: 400.0
Debit: Wed Feb 07 00:00:00 GMT 2007 :: 800.0
Account: 1 - new balance: -400.0
Credit: Sun Apr 01 00:00:00 BST 2007 :: 200.0
Account: 1 - new balance: -200.0
Credit: Thu Apr 05 00:00:00 BST 2007 :: 300.0
Account: 1 - new balance: 100.0
Debit: Mon May 07 00:00:00 BST 2007 :: 900.0
Account: 1 - new balance: -800.0
```

9.6. Pricing Rule Decision Table Example

The Pricing Rule decision table demonstrates the use of a decision table in a spreadsheet, in Excel's XLS format, in calculating the retail cost of an insurance policy. The purpose of the provide set of rules is to calculate a base price and a discount for a car driver applying for a specific policy. The driver's age, history and the policy type all contribute to what the basic premium is, and an additional chunk of rules deals with refining this with a discount percentage.

```
Name: Example Policy Pricing
Main class: org.drools.examples.decisiontable.PricingRuleDTExample
Module: drools-examples
Type: Java application
Rules file: ExamplePolicyPricing.xls
Objective: demonstrate spreadsheet-based decision tables.
```

9.6.1. Executing the example

Open the file `PricingRuleDTExample.java` and execute it as a Java application. It should produce the following output in the Console window:

```
Cheapest possible
BASE PRICE IS: 120
DISCOUNT IS: 20
```

The code to execute the example follows the usual pattern. The rules are loaded, the facts inserted and a Stateless Session is created. What is different is how the rules are added.

```
DecisionTableConfiguration dtableconfiguration =
    KnowledgeBuilderFactory.newDecisionTableConfiguration();
        dtableconfiguration.setInputType( DecisionTableInputType.XLS );

      KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
```

```
        Resource xlsRes = ResourceFactory.newClassPathResource( "ExamplePolicyPricing.xls",
                                                                 getClass() );
        kbuilder.add( xlsRes,
                      ResourceType.DTABLE,
                      dtableconfiguration );
```

Note the use of the `DecisionTableConfiguration` object. Its input type is set to `DecisionTableInputType.XLS`. If you use the BRMS, all this is of course taken care of for you.

There are two fact types used in this example, `Driver` and `Policy`. Both are used with their default values. The `Driver` is 30 years old, has had no prior claims and currently has a risk profile of `LOW`. The `Policy` being applied for is `COMPREHENSIVE`, and it has not yet been approved.

9.6.2. The decision table

In this decision table, each row is a rule, and each column is a condition or an action.

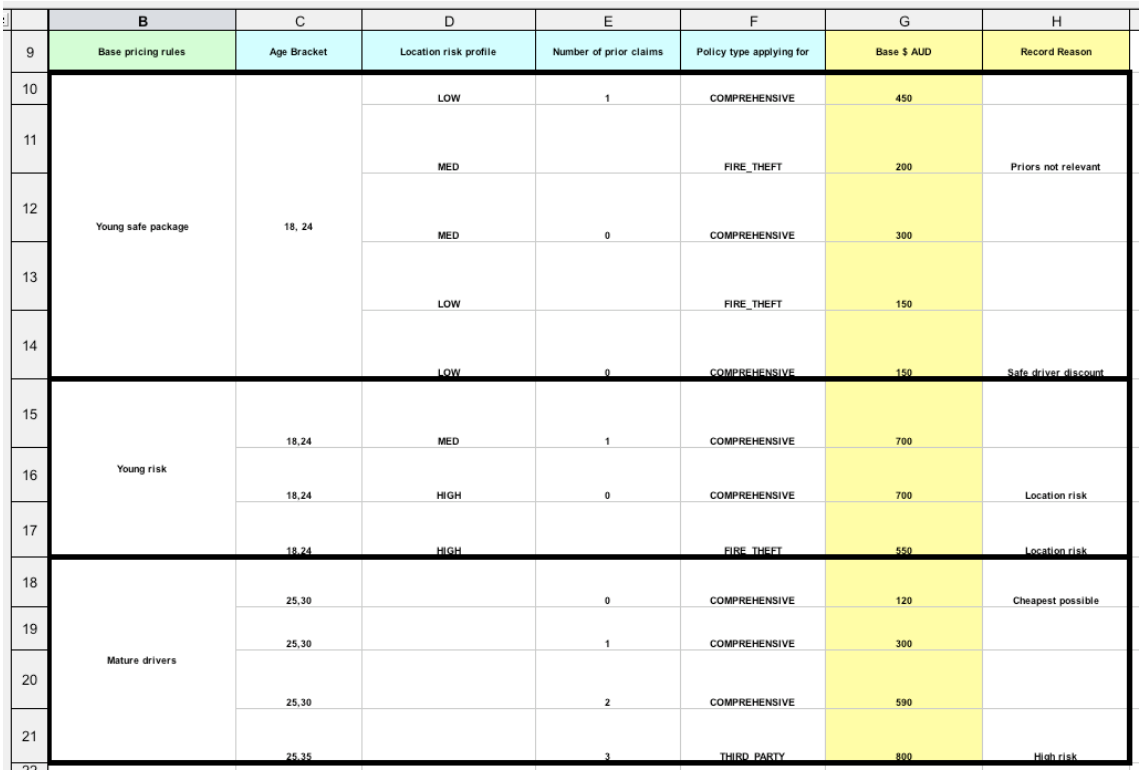
	C	D	E	F	G	H
	RuleSet	org.drools.examples.decisiontable				
	Notes	This decision table is for working out some basic prices and pretending actuaries don't exist				
	RuleTable Pricing bracket					
	CONDITION	CONDITION	CONDITION	CONDITION	ACTION	ACTION
	Driver			policy: Policy		
	age >= $1, age <= $2	locationRiskProfile	priorClaims	type	policy.setBasePrice($param);	System.out.println("$param");
	Age Bracket	Location risk profile	Number of prior claims	Policy type applying for	Base $ AUD	Record Reason

Figure 9.10. Decision table configuration

Referring to the spreadsheet show above, we have the `RuleSet` declaration, which provides the package name. There are also other optional items you can have here, such as `Variables` for global variables, and `Imports` for importing classes. In this case, the namespace of the rules is the same as the fact classes we are using, so we can omit it.

Moving further down, we can see the `RuleTable` declaration. The name after this (Pricing bracket) is used as the prefix for all the generated rules. Below that, we have "CONDITION or ACTION", indicating the purpose of the column, i.e., whether it forms part of the condition or the consequence of the rule that will be generated.

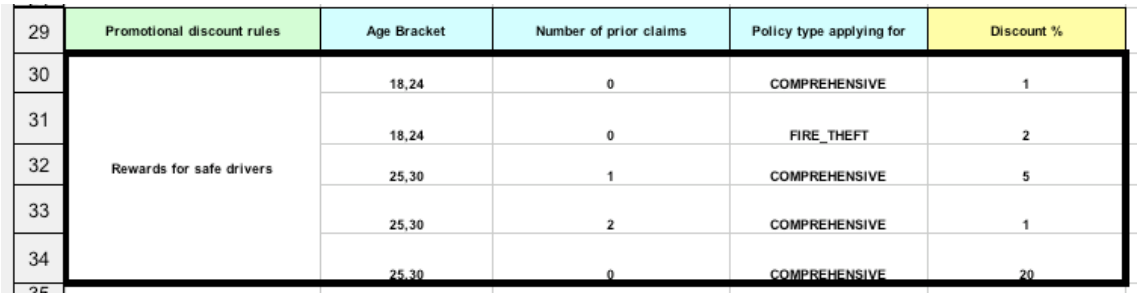
You can see that there is a driver, his data spanned across three cells, which means that the template expressions below it apply to that fact. We observe the driver's age range (which uses `$1` and `$2` with comma-separated values), `locationRiskProfile`, and `priorClaims` in the respective columns. In the action columns, we are set the policy base price and log a message.



	B	C	D	E	F	G	H
9	Base pricing rules	Age Bracket	Location risk profile	Number of prior claims	Policy type applying for	Base $ AUD	Record Reason
10	Young safe package	18, 24	LOW	1	COMPREHENSIVE	450	
11			MED		FIRE_THEFT	200	Priors not relevant
12			MED	0	COMPREHENSIVE	300	
13			LOW		FIRE_THEFT	150	
14			LOW	0	COMPREHENSIVE	150	Safe driver discount
15	Young risk	18,24	MED	1	COMPREHENSIVE	700	
16		18,24	HIGH	0	COMPREHENSIVE	700	Location risk
17		18,24	HIGH		FIRE_THEFT	550	Location risk
18	Mature drivers	25,30		0	COMPREHENSIVE	120	Cheapest possible
19		25,30		1	COMPREHENSIVE	300	
20		25,30		2	COMPREHENSIVE	590	
21		25,35		3	THIRD_PARTY	800	High risk

Figure 9.11. Base price calculation

In the preceding spreadsheet section, there are broad category brackets, indicated by the comment in the leftmost column. As we know the details of our drivers and their policies, we can tell (with a bit of thought) that they should match row number 18, as they have no prior accidents, and are 30 years old. This gives us a base price of 120.



29	Promotional discount rules	Age Bracket	Number of prior claims	Policy type applying for	Discount %
30	Rewards for safe drivers	18,24	0	COMPREHENSIVE	1
31		18,24	0	FIRE_THEFT	2
32		25,30	1	COMPREHENSIVE	5
33		25,30	2	COMPREHENSIVE	1
34		25,30	0	COMPREHENSIVE	20

Figure 9.12. Discount calculation

The above section contains the conditions for the discount we might grant our driver. The discount results from the `Age` bracket, the number of prior claims, and the policy type. In our case, the driver is 30, with no prior claims, and is applying for a `COMPREHENSIVE` policy, which means we can give a discount of 20%. Note that this is actually a separate table, but in the same worksheet, so that different templates apply.

It is important to note that decision tables generate rules. This means they aren't simply top-down logic, but more a means to capture data resulting in rules. This is a subtle difference that confuses

some people. The evaluation of the rules is not necessarily in the given order, since all the normal mechanics of the rule engine still apply.

9.7. Pet Store Example

```
Name: Pet Store
Main class: org.drools.examples.petstore.PetStoreExample
Module: drools-examples
Type: Java application
Rules file: PetStore.drl
Objective: Demonstrate use of Agenda Groups, Global Variables and integration
 with a GUI,
including callbacks from within the rules
```

The Pet Store example shows how to integrate Rules with a GUI, in this case a Swing based desktop application. Within the rules file, it demonstrates how to use Agenda groups and auto-focus to control which of a set of rules is allowed to fire at any given time. It also illustrates the mixing of the Java and MVEL dialects within the rules, the use of accumulate functions and the way of calling Java functions from within the ruleset.

All of the Java code is contained in one file, `PetStore.java`, defining the following principal classes (in addition to several classes to handle Swing Events):

- `Petstore` contains the `main()` method that we will look at shortly.
- `PetStoreUI` is responsible for creating and displaying the Swing based GUI. It contains several smaller classes, mainly for responding to various GUI events such as mouse button clicks.
- `TableModel` holds the table data. Think of it as a JavaBean that extends the Swing class `AbstractTableModel`.
- `CheckoutCallback` allows the GUI to interact with the Rules.
- `Ordershow` keeps the items that we wish to buy.
- `Purchase` stores details of the order and the products we are buying.
- `Product` is a JavaBean holding details of the product available for purchase, and its price.

Much of the Java code is either plain JavaBeans or Swing-based. Only a few Swing-related points will be discussed in this section, but a good tutorial about Swing components can be found at Sun's Swing website, in *http://java.sun.com/docs/books/tutorial/uiswing/* [???].

The pieces of Java code in `Petstore.java` that relate to rules and facts are shown below.

Example 9.52. Creating the PetStore RuleBase in PetStore.main

```
KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
```

```
kbuilder.add( ResourceFactory.newClassPathResource( "PetStore.drl",
                                                    PetStore.class ),
              ResourceType.DRL );
KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
kbase.addKnowledgePackages( kbuilder.getKnowledgePackages() );

// Create the stock.
Vector<Product> stock = new Vector<Product>();
stock.add( new Product( "Gold Fish", 5 ) );
stock.add( new Product( "Fish Tank", 25 ) );
stock.add( new Product( "Fish Food", 2 ) );

// A callback is responsible for populating the
// Working Memory and for firing all rules.
PetStoreUI ui = new PetStoreUI( stock,
                                new CheckoutCallback( kbase ) );
ui.createAndShowGUI();
```

The code shown above loads the rules from a DRL file on the classpath. Unlike other examples where the facts are asserted and fired straight away, this example defers this step to later. The way it does this is via the second last line where a `PetStoreUI` object is created using a constructor accepting the `Vector` object `stock` collecting our products, and an instance of the `CheckoutCallback` class containing the Rule Base that we have just loaded.

The Java code that fires the rules is within the `CheckoutCallBack.checkout()` method. This is triggered (eventually) when the Checkout button is pressed by the user.

Example 9.53. Firing the Rules - extract from CheckoutCallBack.checkout()

```
public String checkout(JFrame frame, List<Product> items) {
    Order order = new Order();

    // Iterate through list and add to cart
    for ( Product p: items ) {
        order.addItem( new Purchase( order, p ) );
    }

    // Add the JFrame to the ApplicationData to allow for user interaction

    StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();
    ksession.setGlobal( "frame", frame );
    ksession.setGlobal( "textArea", this.output );

    ksession.insert( new Product( "Gold Fish", 5 ) );
    ksession.insert( new Product( "Fish Tank", 25 ) );
    ksession.insert( new Product( "Fish Food", 2 ) );
```

```
    ksession.insert( new Product( "Fish Food Sample", 0 ) );

    ksession.insert( order );
    ksession.fireAllRules();

    // Return the state of the cart
    return order.toString();
}
```

Two items get passed into this method. One is the handle to the `JFrame` Swing component surrounding the output text frame, at the bottom of the GUI. The second is a list of order items; this comes from the `TableModel` storing the information from the "Table" area at the top right section of the GUI.

The for loop transforms the list of order items coming from the GUI into the `Order` JavaBean, also contained in the file `PetStore.java`. Note that it would be possible to refer to the Swing dataset directly within the rules, but it is better coding practice to do it this way, using simple Java objects. It means that we are not tied to Swing if we wanted to transform the sample into a Web application.

It is important to note that *all state in this example is stored in the Swing components, and that the rules are effectively stateless.* Each time the "Checkout" button is pressed, this code copies the contents of the Swing `TableModel` into the Session's Working Memory.

Within this code, there are nine calls to the Working Memory. The first of these creates a new Working Memory, as a Stateful Knowledge Session from the Knowledge Base. Remember that we passed in this Knowledge Base when we created the `CheckoutCallBack` class in the `main()` method. The next two calls pass in two objects that we will hold as global variables in the rules: the Swing text area and the Swing frame used for writing messages.

More inserts put information on products into the Working Memory, as well as the order list. The final call is the standard `fireAllRules()`. Next, we look at what this method causes to happen within the rules file.

Example 9.54. Package, Imports, Globals and Dialect: extract from PetStore.drl

```
package org.drools.examples

import org.drools.WorkingMemory
import org.drools.examples.petstore.PetStoreExample.Order
import org.drools.examples.petstore.PetStoreExample.Purchase
import org.drools.examples.petstore.PetStoreExample.Product
import java.util.ArrayList
import javax.swing.JOptionPane;
```

```
import javax.swing.JFrame

global JFrame frame
global javax.swing.JTextArea textArea
```

The first part of file `PetStore.drl` contains the standard package and import statements to make various Java classes available to the rules. New to us are the two globals `frame` and `textArea`. They hold references to the Swing components `JFrame` and `JTextArea` components that were previously passed on by the Java code calling the `setGlobal()` method. Unlike variables in rules, which expire as soon as the rule has fired, global variables retain their value for the lifetime of the Session.

The next extract from the file `PetStore.drl` contains two functions that are referenced by the rules that we will look at shortly.

Example 9.55. Java Functions in the Rules: extract from PetStore.drl

```
function void doCheckout(JFrame frame, WorkingMemory workingMemory) {
    Object[] options = {"Yes",
                        "No"};

    int n = JOptionPane.showOptionDialog(frame,
        "Would you like to checkout?",
        "",
        JOptionPane.YES_NO_OPTION,
        JOptionPane.QUESTION_MESSAGE,
        null,
        options,
        options[0]);

    if (n == 0) {
        workingMemory.setFocus( "checkout" );
    }
}

function boolean requireTank(JFrame frame, WorkingMemory workingMemory, Order order, Product fi
    Object[] options = {"Yes",
                        "No"};

    int n = JOptionPane.showOptionDialog(frame,
        "Would you like to buy a tank for your " + total + " fish?",
        "Purchase Suggestion",
        JOptionPane.YES_NO_OPTION,
        JOptionPane.QUESTION_MESSAGE,
        null,
        options,
        options[0]);
```

```
    System.out.print( "SUGGESTION: Would you like to buy a tank for your "
                      + total + " fish? - " );

    if (n == 0) {
        Purchase purchase = new Purchase( order, fishTank );
        workingMemory.insert( purchase );
        order.addItem( purchase );
        System.out.println( "Yes" );
    } else {
        System.out.println( "No" );
    }
    return true;
}
```

Having these functions in the rules file just makes the Pet Store example more compact. In real life you probably have the functions in a file of their own, within the same rules package, or as a static method on a standard Java class, and import them, using `import function my.package.Foo.hello`.

The purpose of these two functions is:

- `doCheckout()` displays a dialog asking users whether they wish to checkout. If they do, focus is set to the `checkOut` agenda-group, allowing rules in that group to (potentially) fire.
- `requireTank()` displays a dialog asking users whether they wish to buy a tank. If so, a new fish tank `Product` is added to the order list in Working Memory.

We'll see the rules that call these functions later on. The next set of examples are from the Pet Store rules themselves. The first extract is the one that happens to fire first, partly because it has the `auto-focus` attribute set to true.

Example 9.56. Putting items into working memory: extract from PetStore.drl

```
// Insert each item in the shopping cart into the Working Memory
// Insert each item in the shopping cart into the Working Memory
rule "Explode Cart"
    agenda-group "init"
    auto-focus true
    salience 10
    dialect "java"
when
    $order : Order( grossTotal == -1 )
    $item : Purchase() from $order.items
then
    insert( $item );
```

```
            kcontext.getKnowledgeRuntime().getAgenda().getAgendaGroup(   "show
 items" ).setFocus();

 kcontext.getKnowledgeRuntime().getAgenda().getAgendaGroup( "evaluate" ).setFocus();
end
```

This rule matches against all orders that do not yet have their `grossTotal` calculated . It loops for each purchase item in that order. Some parts of the "Explode Cart" rule should be familiar: the rule name, the salience (suggesting the order for the rules being fired) and the dialect set to `"java"`. There are three new features:

- `agenda-group "init"` defines the name of the agenda group. In this case, there is only one rule in the group. However, neither the Java code nor a rule consequence sets the focus to this group, and therefore it relies on the next attribute for its chance to fire.
- `auto-focus true` ensures that this rule, while being the only rule in the agenda group, gets a chance to fire when `fireAllRules()` is called from the Java code.
- `kcontext....setFocus()` sets the focus to the `"show items"` and `"evaluate"` agenda groups in turn, permitting their rules to fire. In practice, we loop through all items on the order, inserting them into memory, then firing the other rules after each insert.

The next two listings show the rules within the `"show items"` and `evaluate` agenda groups. We look at them in the order that they are called.

Example 9.57. Show Items in the GUI - extract from PetStore.drl

```
rule "Show Items"
    agenda-group "show items"
    dialect "mvel"
when
    $order : Order( )
    $p : Purchase( order == $order )
then
   textArea.append( $p.product + "\n");
end
```

The `"show items"` agenda-group has only one rule, called "Show Items" (note the difference in case). For each purchase on the order currently in the Working Memory (or Session), it logs details to the text area at the bottom of the GUI. The `textArea` variable used to do this is one of the global variables we looked at earlier.

The `evaluate` Agenda group also gains focus from the `"Explode Cart"` rule listed previously. This Agenda group has two rules, `"Free Fish Food Sample"` and `"Suggest Tank"`, shown below.

Example 9.58. Evaluate Agenda Group: extract from PetStore.drl

```
// Free Fish Food sample when we buy a Gold Fish if we haven't already bought
// Fish Food and don't already have a Fish Food Sample
rule "Free Fish Food Sample"
    agenda-group "evaluate"
    dialect "mvel"
when
    $order : Order()
   not ( $p : Product( name == "Fish Food") &amp;&amp; Purchase( product == $p ) )
    not ( $p : Product( name == "Fish Food Sample") &amp;&amp; Purchase( product
 == $p ) )
     exists ( $p : Product( name == "Gold Fish") &amp;&amp; Purchase( product
 == $p ) )
    $fishFoodSample : Product( name == "Fish Food Sample" );
then
    System.out.println( "Adding free Fish Food Sample to cart" );
    purchase = new Purchase($order, $fishFoodSample);
    insert( purchase );
    $order.addItem( purchase );
end

// Suggest a tank if we have bought more than 5 gold fish and don't already
 have one
rule "Suggest Tank"
    agenda-group "evaluate"
    dialect "java"
when
    $order : Order()
   not ( $p : Product( name == "Fish Tank") &amp;&amp; Purchase( product == $p ) )
     ArrayList( $total : size &gt; 5 ) from collect( Purchase( product.name ==
 "Gold Fish" ) )
    $fishTank : Product( name == "Fish Tank" )
then
    requireTank(frame, drools.getWorkingMemory(), $order, $fishTank, $total);
end
```

The rule `"Free Fish Food Sample"` will only fire if

- we *don't* already have any fish food, *and*
- we *don't* already have a free fish food sample, *and*
- we *do* have a Gold Fish in our order.

If the rule does fire, it creates a new product (Fish Food Sample), and adds it to the order in Working Memory.

The rule `"Suggest Tank"` will only fire if

- we *don't* already have a Fish Tank in our order, *and*
- we *do* have more than 5 Gold Fish Products in our order.

If the rule does fire, it calls the `requireTank()` function that we looked at earlier (showing a Dialog to the user, and adding a Tank to the order / working memory if confirmed). When calling the *requireTank*() function the rule passes the global *frame* variable so that the function has a handle to the Swing GUI.

The next rule we look at is `"do checkout"`.

Example 9.59. Doing the Checkout - extract (6) from PetStore.drl

```
rule "do checkout"
    dialect "java"
    when
    then
        doCheckout(frame, drools.getWorkingMemory());
end
```

The rule `"do checkout"` has **no agenda group set and no auto-focus attribute**. As such, is is deemed part of the default (MAIN) agenda group. This group gets focus by default when all the rules in agenda-groups that explicity had focus set to them have run their course.

There is no LHS to the rule, so the RHS will always call the `doCheckout()` function. When calling the `doCheckout()` function, the rule passes the global `frame` variable to give the function a handle to the Swing GUI. As we saw earlier, the `doCheckout()` function shows a confirmation dialog to the user. If confirmed, the function sets the focus to the *checkout* agenda-group, allowing the next lot of rules to fire.

Example 9.60. Checkout Rules: extract from PetStore.drl

```
rule "Gross Total"
    agenda-group "checkout"
    dialect "mvel"
when
   $order : Order( grossTotal == -1)
   Number( total : doubleValue )
       from accumulate( Purchase( $price : product.price ), sum( $price ) )
then
    modify( $order ) { grossTotal = total };
    textArea.append( "\ngross total=" + total + "\n" );
```

```
end

rule "Apply 5% Discount"
    agenda-group "checkout"
dialect "mvel"
when
   $order : Order( grossTotal &gt;= 10 &amp;&amp; &lt; 20 )
then
   $order.discountedTotal = $order.grossTotal * 0.95;
   textArea.append( "discountedTotal total=" + $order.discountedTotal + "\n" );
end


rule "Apply 10% Discount"
    agenda-group "checkout"
    dialect "mvel"
when
   $order : Order( grossTotal &gt;= 20 )
then
   $order.discountedTotal = $order.grossTotal * 0.90;
   textArea.append( "discountedTotal total=" + $order.discountedTotal + "\n" );
end
```

There are three rules in the *checkout* agenda-group:

- If we haven't already calculated the gross total, `Gross Total` accumulates the product prices into a total, puts this total into Working Memory, and displays it via the Swing `JTextArea`, using the `textArea` global variable yet again.
- If our gross total is between 10 and 20, `"Apply 5% Discount"` calculates the discounted total and adds it to the Working Memory and displays it in the text area.
- If our gross total is not less than 20, `"Apply 10% Discount"` calculates the discounted total and adds it to the Working Memory and displays it in the text area.

Now that we've run through what happens in the code, let's have a look at what happens when we actually run the code. The file `PetStore.java` contains a `main()` method, so that it can be run as a standard Java application, either from the command line or via the IDE. This assumes you have your classpath set correctly. (See the start of the examples section for more information.)

The first screen that we see is the Pet Store Demo. It has a list of available products (top left), an empty list of selected products (top right), checkout and reset buttons (middle) and an empty system messages area (bottom).

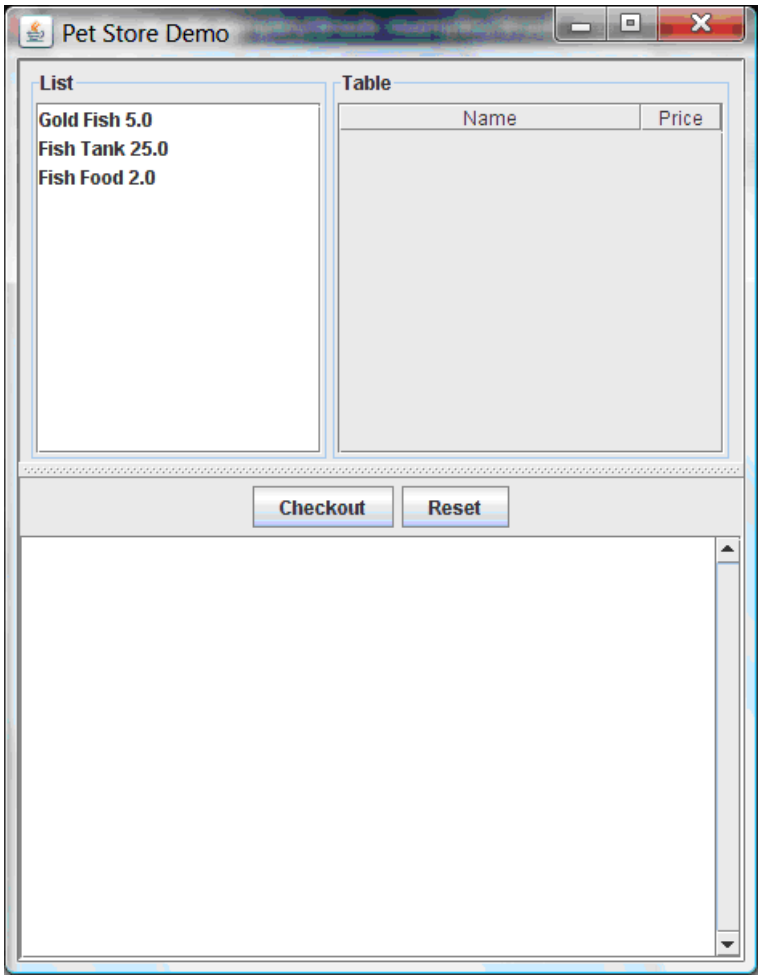


Figure 9.13. PetStore Demo just after Launch

To get to this point, the following things have happened:

1. The `main()` method has run and loaded the Rule Base *but not yet fired the rules*. So far, this is the only code in connection with rules that has been run.

2. A new `PetStoreUI` object has been created and given a handle to the Rule Base, for later use.

3. Various Swing components do their stuff, and the above screen is shown and *waits for user input*.

Clicking on various products from the list might give you a screen similar to the one below.

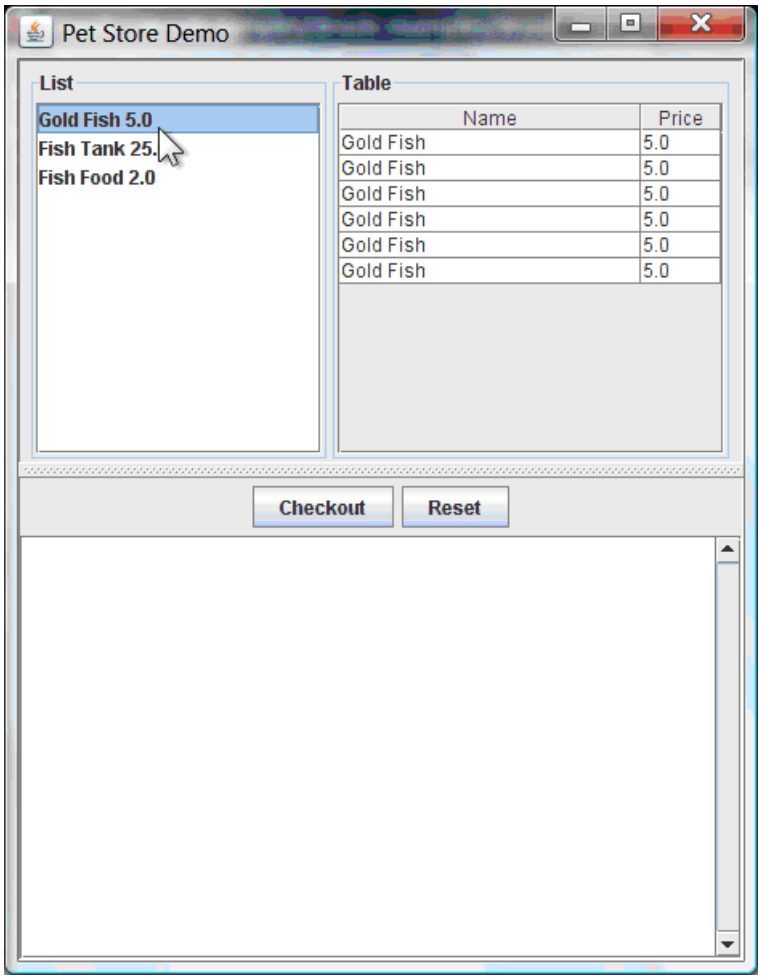


Figure 9.14. PetStore Demo with Products Selected

Note that *no rules code has been fired here*. This is only Swing code, listening for mouse click events, and adding some selected product to the `TableModel` object for display in the top right hand section. (As an aside, note that this is a classic use of the Model View Controller design pattern).

It is only when we press the "Checkout" button that we fire our business rules, in roughly the same order that we walked through the code earlier.

1. Method `CheckOutCallBack.checkout()` is called (eventually) by the Swing class waiting for the click on the "Checkout" button. This inserts the data from the `TableModel` object (top right hand side of the GUI), and inserts it into the Session's Working Memory. It then fires the rules.

2. The `"Explode Cart"` rule is the first to fire, given that it has `auto-focus` set to true. It loops through all the products in the cart, ensures that the products are in the Working Memory, and then gives the `"Show Items"` and `Evaluation` agenda groups a chance to fire. The rules in these groups add the contents of the cart to the text area (at the bottom of the window), decide whether or not to give us free fish food, and to ask us whether we want to buy a fish tank. This is shown in the figure below.

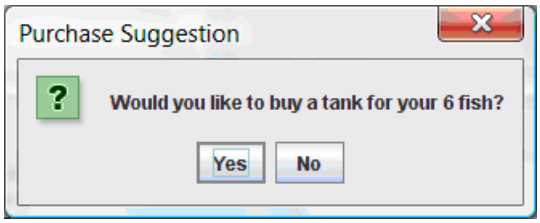


Figure 9.15. Do we want to buy a fish tank?

1. The *Do Checkout* rule is the next to fire as it (a) No other agenda group currently has focus and (b) it is part of the default (MAIN) agenda group. It always calls the *doCheckout() function* which displays a 'Would you like to Checkout?' Dialog Box.

2. The `doCheckout()` function sets the focus to the `checkout` agenda-group, giving the rules in that group the option to fire.

3. The rules in the the `checkout` agenda-group display the contents of the cart and apply the appropriate discount.

4. *Swing then waits for user input* to either checkout more products (and to cause the rules to fire again), or to close the GUI - see the figure below.

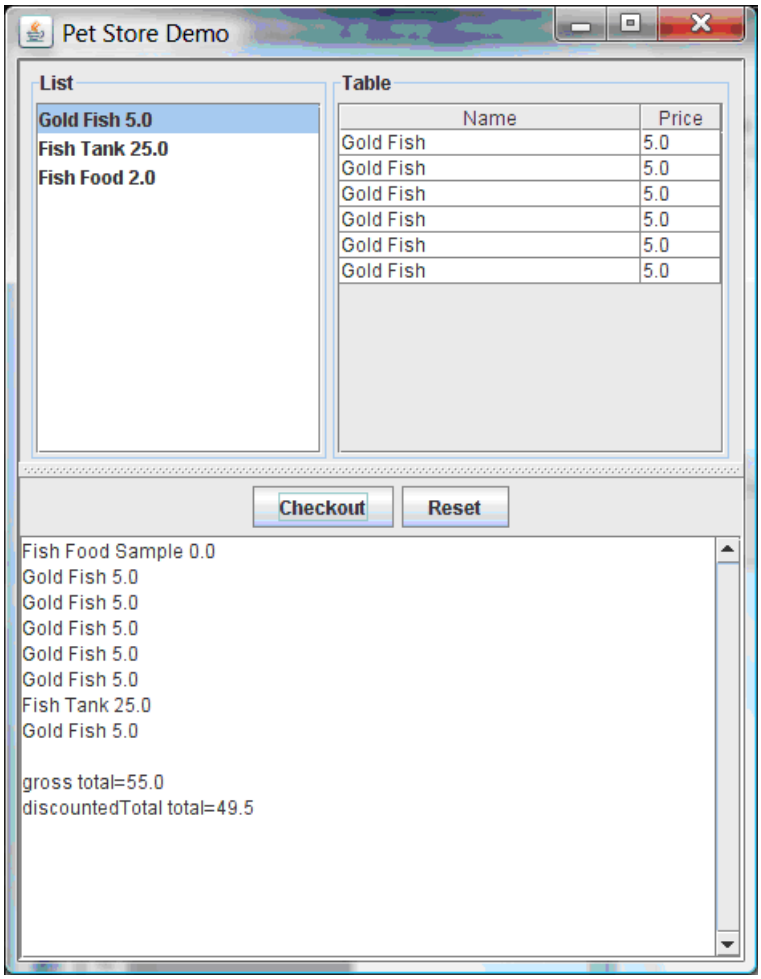


Figure 9.16. Petstore Demo after all rules have fired.

We could add more System.out calls to demonstrate this flow of events. The output, as it currently appears in the Console window, is given in the listing below.

Example 9.61. Console (System.out) from running the PetStore GUI

```
Adding free Fish Food Sample to cart
SUGGESTION: Would you like to buy a tank for your 6 fish? - Yes
```

9.8. Honest Politician Example

```
Name: Honest Politician
Main class: org.drools.examples.honestpolitician.HonestPoliticianExample
Module: drools-examples
Type: Java application
Rules file: HonestPoliticianExample.drl
```

```
Objective: Illustrate the concept of "truth maintenance" based on the logical
 insertion of facts
```

The Honest Politician example demonstrates truth maintenance with logical assertions. The basic premise is that an object can only exist while a statement is true. A rule's consequence can logically insert an object with the `insertLogical()` method. This means the object will only remain in the Working Memory as long as the rule that logically inserted it remains true. When the rule is no longer true the object is automatically retracted.

In this example there is the class `Politician`, with a name and a boolean value for being honest. Four politicians with honest state set to true are inserted.

Example 9.62. Class Politician

```
public class Politician {
    private String name;
    private boolean honest;
    ...
}
```

Example 9.63. Honest Politician: Execution

```
Politician blair = new Politician("blair", true);
Politician bush = new Politician("bush", true);
Politician chirac = new Politician("chirac", true);
Politician schroder = new Politician("schroder", true);

ksession.insert( blair );
ksession.insert( bush );
ksession.insert( chirac );
ksession.insert( schroder );

ksession.fireAllRules();
```

The Console window output shows that, while there is at least one honest politician, democracy lives. However, as each politician is in turn corrupted by an evil corporation, so that all politicians become dishonest, democracy is dead.

Example 9.64. Honest Politician: Console Output

```
Hurrah!!! Democracy Lives
I'm an evil corporation and I have corrupted schroder
I'm an evil corporation and I have corrupted chirac
```

```
I'm an evil corporation and I have corrupted bush
I'm an evil corporation and I have corrupted blair
We are all Doomed!!! Democracy is Dead
```

As soon as there is at least one honest politician in the Working Memory a new `Hope` object is logically asserted. This object will only exist while there is at least one honest politician. As soon as all politicians are dishonest, the `Hope` object will be automatically retracted. This rule is given a salience of 10 to ensure that it fires before any other rule, as at this stage the "Hope is Dead" rule is actually true.

Example 9.65. Honest Politician: Rule "We have an honest politician"

```
rule "We have an honest Politician"
    salience 10
    when
        exists( Politician( honest == true ) )
    then
        insertLogical( new Hope() );
end
```

As soon as a `Hope` object exists the "Hope Lives" rule matches and fires. It has a salience of 10 so that it takes priority over "Corrupt the Honest".

Example 9.66. Honest Politician: Rule "Hope Lives"

```
rule "Hope Lives"
    salience 10
        when
            exists( Hope() )
        then
            System.out.println("Hurrah!!! Democracy Lives");
end
```

Now that there is hope and we have, at the start, four honest politicians, we have four activations for this rule, all in conflict. They will fire in turn, corrupting each politician so that they are no longer honest. When all four politicians have been corrupted we have no politicians with the property `honest == true`. Thus, the rule "We have an honest Politician" is no longer true and the object it logical inserted (due to the last execution of `new Hope()`) is automatically retracted.

Example 9.67. Honest Politician: Rule "Corrupt the Honest"

```
rule "Corrupt the Honest"
    when
```

```
        politician : Politician( honest == true )
        exists( Hope() )
    then
          System.out.println( "I'm an evil corporation and I have corrupted "
 + politician.getName() );
        modify ( politician ) { honest = false };
end
```

With the `Hope` object being automatically retracted, via the truth maintenance system, the conditional element `not` applied to `Hope` is no longer true so that the following rule will match and fire.

Example 9.68. Honest Politician: Rule "Hope is Dead"

```
rule "Hope is Dead"
    when
        not( Hope() )
    then
        System.out.println( "We are all Doomed!!! Democracy is Dead" );
end
```

Let's take a look at the Audit trail for this application:

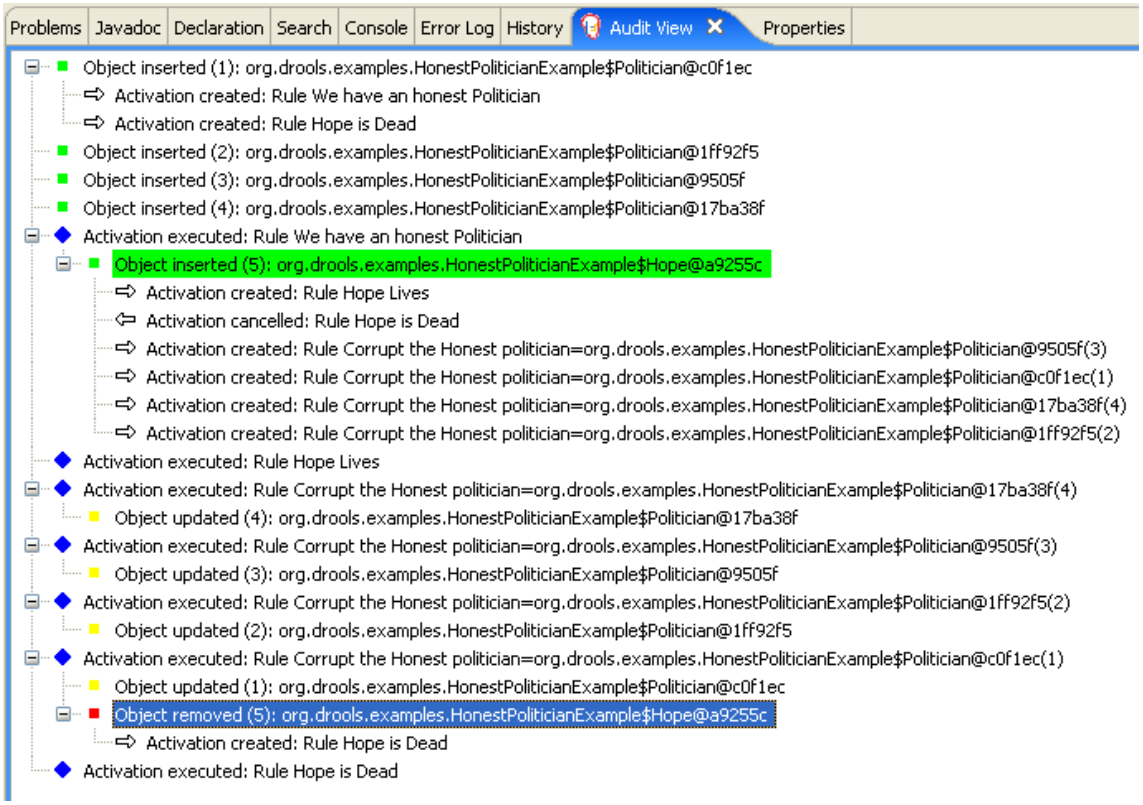


Figure 9.17. Honest Politician Example Audit View

The moment we insert the first politician we have two activations. The rule "We have an honest Politician" is activated only once for the first inserted politician because it uses an `exists` conditional element, which matches once for any number. The rule "Hope is Dead" is also activated at this stage, because we have not yet inserted the `Hope` object. Rule "We have an honest Politician" fires first, as it has a higher salience than "Hope is Dead", which inserts the `Hope` object. (That action is highlighted green.) The insertion of the `Hope` object activates "Hope Lives" and de-activates "Hope is Dead"; it also activates "Corrupt the Honest" for each inserted honest politician. Rule "Hope Lives" executes, printing "Hurrah!!! Democracy Lives". Then, for each politician, rule "Corrupt the Honest" fires, printing "I'm an evil corporation and I have corrupted X", where X is the name of the politician, and modifies the politician's honest value to false. When the last honest politician is corrupted, `Hope` is automatically retracted, by the truth maintenance system, as shown by the blue highlighted area. The green highlighted area shows the origin of the currently selected blue highlighted area. Once the `Hope` fact is retracted, "Hope is dead" activates and fires printing "We are all Doomed!!! Democracy is Dead".

9.9. Sudoku Example

```
Name: Sudoku
Main class: org.drools.examples.sudoku.SudokuExample
Type: Java application
Rules file: sudoku.drl, validate.drl
```

```
Objective: Demonstrates the solving of logic problems, and complex pattern
 matching.
```

This example demonstrates how Drools can be used to find a solution in a large potential solution space based on a number of constraints. We use the popular puzzle of Sudoku. This example also shows how Drools can be integrated into a graphical interface and how callbacks can be used to interact with a running Drools rules engine in order to update the graphical interface based on changes in the Working Memory at runtime.

9.9.1. Sudoku Overview

Sudoku is a logic-based number placement puzzle. The objective is to fill a 9x9 grid so that each column, each row, and each of the nine 3x3 zones contains the digits from 1 to 9, once, and only once.

The puzzle setter provides a partially completed grid and the puzzle solver's task is to complete the grid with these constraints.

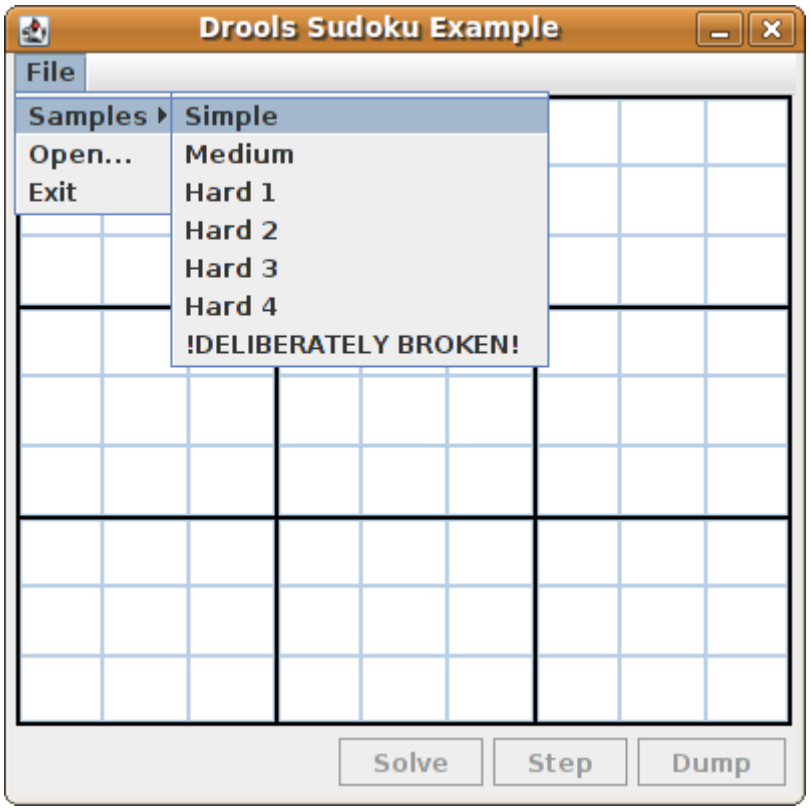
The general strategy to solve the problem is to ensure that when you insert a new number it should be unique in its particular 3x3 zone, row and column.

See *Wikipedia* [http://en.wikipedia.org/wiki/Sudoku] for a more detailed description.

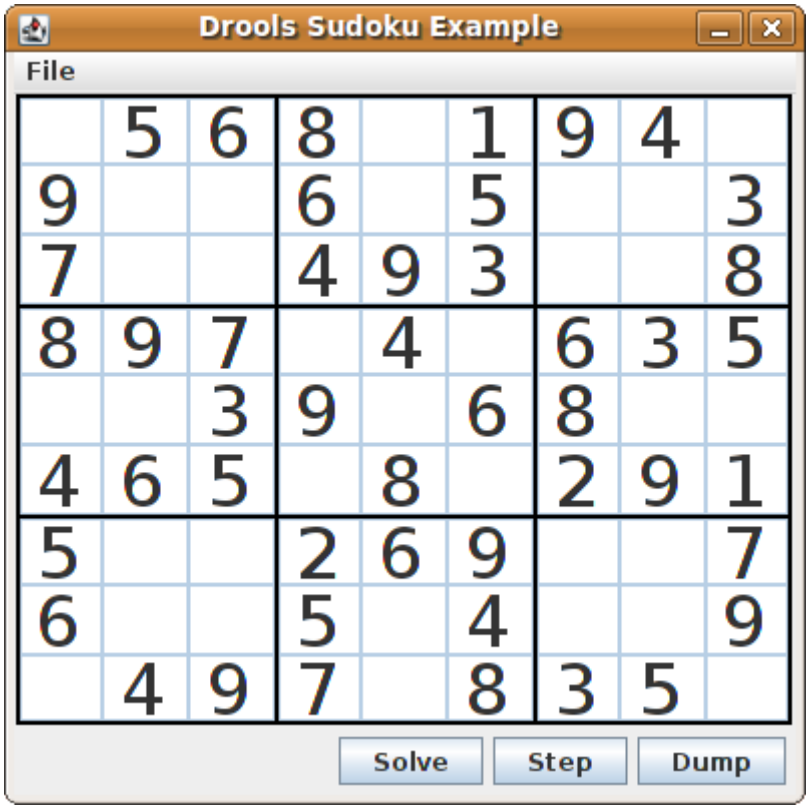
9.9.2. Running the Example

Download and install drools-examples as described above and then execute `java org.drools.examples.DroolsExamplesApp` and click on "SudokuExample".

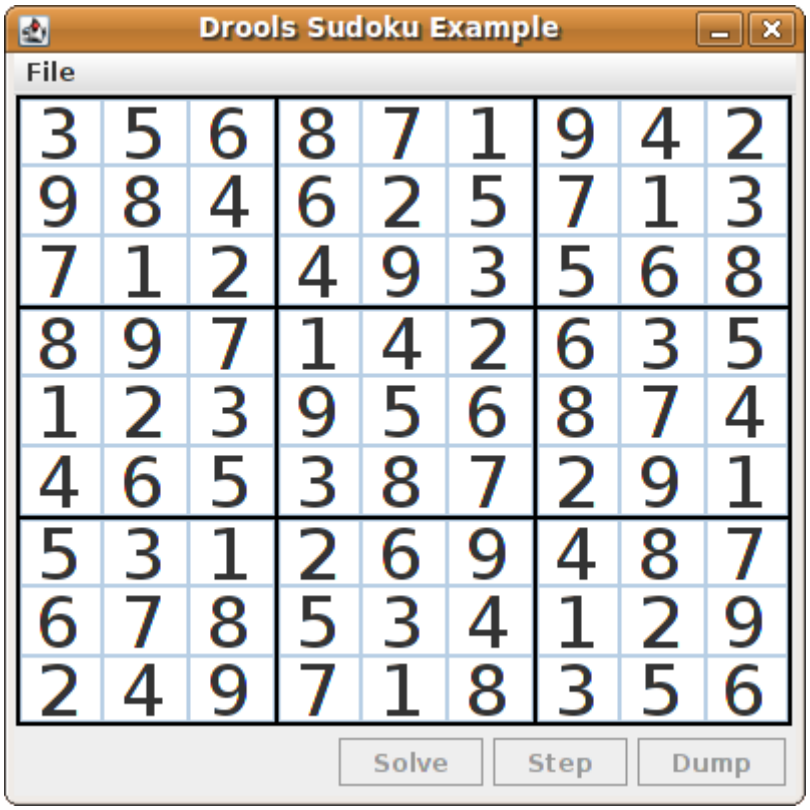
The window contains an empty grid, but the program comes with a number of grids stored internally which can be loaded and solved. Click on "File", then "Samples" and select "Simple" to load one of the examples. Note that all buttons are disabled until a grid is loaded.



Loading the "Simple" example fills the grid according to the puzzle's initial state.



Click on the "Solve" button and the Drools-based engine will fill out the remaining values, and the buttons are inactive once more.



Alternatively, you may click on the "Step" button to see the next digit found by the rule set. The Console window will display detailed information about the rules which are executing to solve the step in a human readable form. Some examples of these messages are presented below.

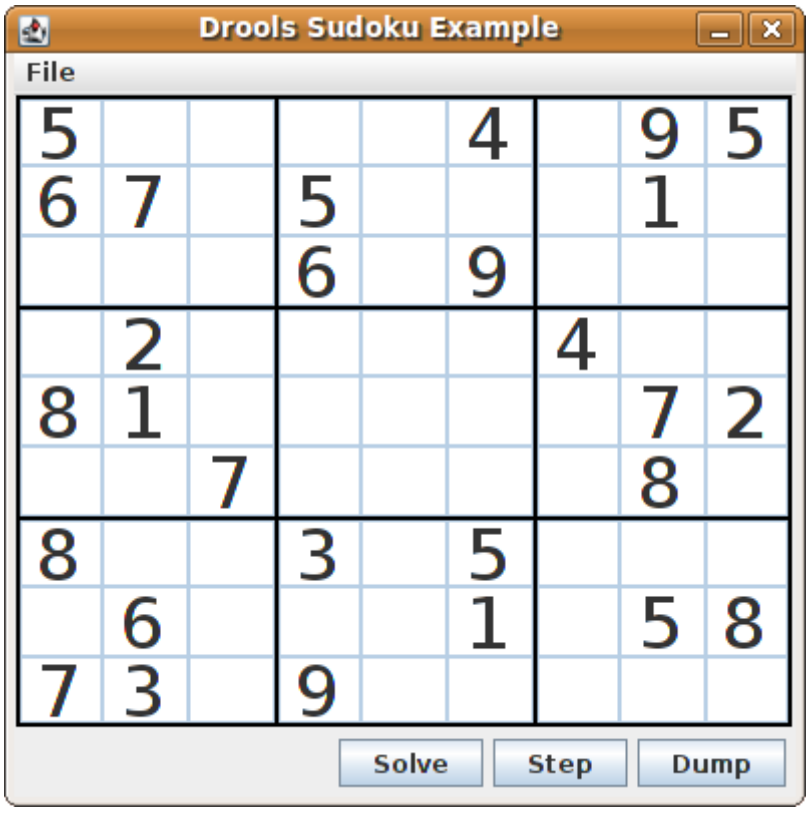
```
single 8 at [0,1]
column elimination due to [1,2]: remove 9 from [4,2]
hidden single 9 at [1,2]
row elimination due to [2,8]: remove 7 from [2,4]
remove 6 from [3,8] due to naked pair at [3,2] and [3,7]
hidden pair in row at [4,6] and [4,4]
```

Click on the "Dump" button to see the state of the grid, with cells showing either the established value or the remaining possibilitiescandidates.

```
       Col: 0     Col: 1     Col: 2     Col: 3     Col: 4     Col: 5
 Col: 6     Col: 7     Col: 8
Row 0:   2 4  7 9   2 456        4567 9   23 56  9  --- 5 ---  --- 1 ---
 3  67 9  --- 8 ---     4 67
Row 1:  12    7 9  --- 8 ---  1    67 9   23  6  9  --- 4 ---   23  67    1
 3  67 9    3  67 9  --- 5 ---
```

```
Row 2:  1  4  7 9  1  456     --- 3 ---      56 89      5 78       5678
 --- 2 ---     4 67 9  1  4 67
Row 3:  1234       12345      1  45      12  5  8   --- 6 ---   2  5 78
  5 78      45 7    --- 9 ---
Row 4:  --- 6 ---  --- 7 ---      5      --- 4 ---   2  5  8   --- 9 ---
  5  8   --- 1 ---  --- 3 ---
Row 5:  --- 8 ---  12 45      1  45   9  12  5      --- 3 ---   2  5 7
  567       4567     2 4 67
Row 6:  1 3   7    1 3  6     --- 2 ---    3 56 8       5  8     3 56 8
 --- 4 ---    3 567 9  1    678
Row 7:  --- 5 ---  1 34 6     1  4 678     3  6 8   --- 9 ---    34 6 8   1
 3  678   --- 2 ---  1    678
Row 8:    34       --- 9 ---     4 6 8   --- 7 ---  --- 1 ---   23456 8
 3 56 8     3 56          6 8
```

Now, let us load a Sudoku grid that is deliberately invalid. Click on "File", "Samples" and "! DELIBERATELY BROKEN!". Note that this grid starts with some issues, for example the value 5 appears twice in the first row.

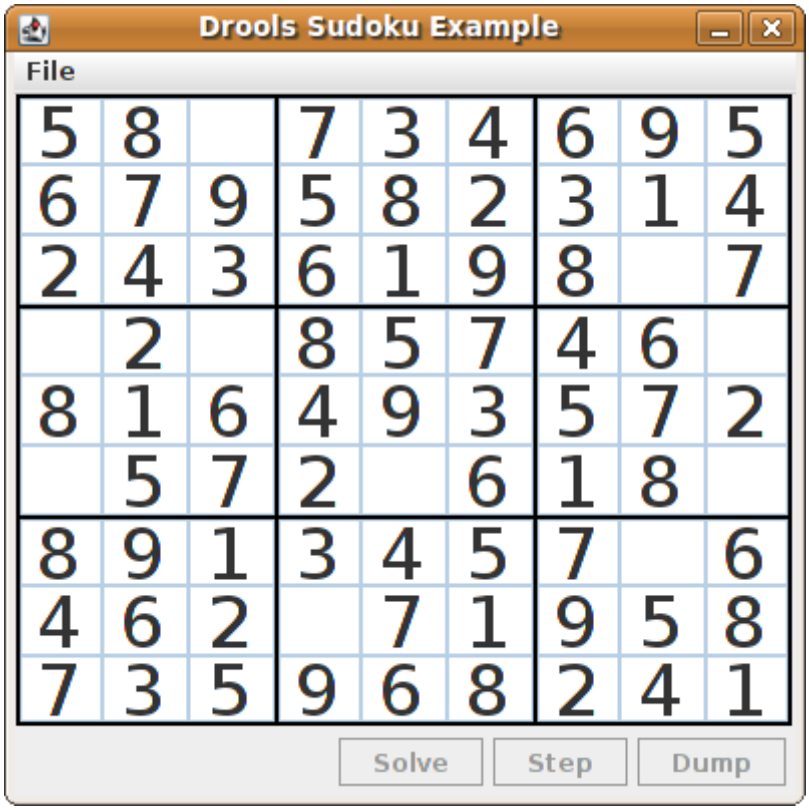


A few simple rules perform a sanity check, right after loading a grid. In this case, the following messages are printed on standard output:

```
cell [0,8]: 5 has a duplicate in row 0
cell [0,0]: 5 has a duplicate in row 0
cell [6,0]: 8 has a duplicate in col 0
```

```
cell [4,0]: 8 has a duplicate in col 0
Validation complete.
```

Nevertheless, click on the "Solve" button to apply the solving rules to this invalid grid. This will not complete; some cells remain empty.



The solving functionality has been achieved by the use of rules that implement standard solving techniques. They are based on the sets of values that are still candidates for a cell. If, for instance, such a set contains a single value, then this is the value for the cell. A little less obvious is the single occurrence of a value in one of the groups of nine cells. The rules detecting these situations insert a fact of type Setting with the solution value for some specific cell. This fact causes the elimination of this value from all other cells in any of the groups the cell belongs to. Finally, it is retracted.

Other rules merely reduce the permissible values for some cells. Rules "naked pair", "hidden pair in row", "hidden pair in column" and "hidden pair in square" merely eliminate possibilities but do not establish solutions. More sophisticated eliminations are done by "X-wings in rows", "X-wings in columns", "intersection removal row" and "intersection removal column".

9.9.3. Java Source and Rules Overview

The Java source code can be found in the /src/main/java/org/drools/examples/sudoku directory, with the two DRL files defining the rules located in the /src/main/rules/org/drools/examples/sudoku directory.

The package `org.drools.examples.sudoku.swing` contains a set of classes which implement a framework for Sudoku puzzles. Note that this package does not have any dependencies on

the Drools libraries. `SudokuGridModel` defines an interface which can be implemented to store a Sudoku puzzle as a 9x9 grid of `Cell` objects. `SudokuGridView` is a Swing component which can visualize any implementation of `SudokuGridModel`. `SudokuGridEvent` and `SudokuGridListener` are used to communicate state changes between the model and the view: events are fired when a cell's value is resolved or changed. If you are familiar with the model-view-controller patterns in other Swing components such as `JTable` then this pattern should be familiar. `SudokuGridSamples` provides a number of partially filled Sudoku puzzles for demonstration purposes.

Package `org.drools.examples.sudoku.rules` contains a utility class with a method for compiling DRL files.

The package `org.drools.examples.sudoku` contains a set of classes implementing the elementary `Cell` object and its various aggregations: the `CellFile` subtypes `CellRow` and `CellCol` as well as `CellSqr`, all of which are subtypes of `CellGroup`. It's interesting to note that `Cell` and `CellGroup` are subclasses of `SetOfNine`, which provides a property `free` with the type `Set<Integer>`. For a `Cell` it represents the individual candidate set; for a `CellGroup` the set is the union of all candidate sets of its cells, or, simply, the set of digits that still need to be allocated.

With 81 `Cell` and 27 `CellGroup` objects and the linkage provided by the `Cell` properties `cellRow`, `cellCol` and `cellSqr` and the `CellGroup` property `cells`, a list of `Cell` objects, it is possible to write rules that detect the specific sitations that permit the allocation of a value to a cell or the elimination of a value from some candidate set.

An object of class `Setting` is used for triggering the operations that accompany the allocation of a value: its removal from the candidata sets of sibling cells and associated cell groups. Moreover, the presence of a `Setting` fact is used in all rules that should detect a new situation; this is to avoid reactions to inconsistent intermediary states.

An object of class `Stepping` is used in a low priority rule to execute an emergency halt when a "Step" does not terminate regularly. This indicates that the puzzle cannot be solved by the program.

The class `org.drools.examples.sudoku.SudokuExample` implements a Java application combining the components desribed.

9.9.4. Sudoku Validator Rules (validate.drl)

Validation rules detect duplicate numbers in cell groups. They are combined in an agenda group which enables us to activate them, explicitly, after loading a puzzle.

The three rules "duplicate in cell..." are very similar. The first pattern locates a cell with an allocated value. The second pattern pulls in any of the three cell groups the cell belongs to. The final pattern would find a cell (other than the first one) with the same value as the first cell and in the same row, column or square, respectively.

Rule "terminate group" fires last. It prints a message and calls halt.

9.9.5. Sudoku Solving Rules (sudoku.drl)

There are three types of rules in this file: one group handles the allocation of a number to a cell, another group detects feasible allocations, and the third group eliminates values from candidate sets.

Rules "set a value", "eliminate a value from Cell" and "retract setting" depend on the presence of a `Setting` object. The first rule handles the assignment to the cell and the operations for removing the value from the "free" sets of the cell's three groups. Also, it decrements a counter that, when zero, returns control to the Java application that has called `fireUntilHalt()`. The purpose of rule "eliminate a value from Cell" is to reduce the candidate lists of all cells that are related to the newly assigned cell. Finally, when all eliminations have been made, rule "retract setting" retracts the triggering `Setting` fact.

There are just two rules that detect a situation where an allocation of a number to a cell is possible. Rule "single" fires for a `Cell` with a candidate set containing a single number. Rule "hidden single" fires when there is no cell with a single candidate but when there is a cell containing a candidate but this candidate is absent from all other cells in one of the three groups the cell belongs to. Both rules create and insert a `Setting` fact.

Rules from the largest group of rules implement, singly or in groups of two or three, various solving techniques, as they are employed when solving Sudoku puzzles manually.

Rule "naked pair" detects identical candidate sets of size 2 in two cells of a group; these two values may be removed from all other candidate sets of that group.

A similar idea motivates the three rules "hidden pair in..."; here, the rules look for a subset of two numbers in exactly two cells of a group, with neither value occurring in any of the other cells of this group. This, then, means that all other candidates can be eliminated from the two cells harbouring the hidden pair.

A pair of rules deals with "X-wings" in rows and columns. When there are only two possible cells for a value in each of two different rows (or columns) and these candidates lie also in the same columns (or rows), then all other candidates for this value in the columns (or rows) can be eliminated. If you follow the pattern sequence in one of these rules, you will see how the conditions that are conveniently expressed by words such as "same" or "only" result in patterns with suitable constraints or prefixed with "not".

The rule pair "intersection removal..." is based on the restricted occurrence of some number within one square, either in a single row or in a single column. This means that this number must be in one of those two or three cells of the row or column; hence it can be removed from the candidate sets of all other cells of the group. The pattern establishes the restricted occurrence and then fires for each cell outside the square and within the same cell file.

These rules are sufficient for many but certainly not for all Sudoku puzzles. To solve very difficult grids, the rule set would need to be extended with more complex rules. (Ultimately, there are puzzles that cannot be solved except by trial and error.)

9.10. Number Guess

```
Name: Number Guess
Main class: org.drools.examples.numberguess.NumberGuessExample
Module: droolsjbpm-integration-examples (Note: this is in a different download,
 the droolsjbpm-integration download.)
Type: Java application
Rules file: NumberGuess.drl
Objective: Demonstrate use of Rule Flow to organise Rules
```

The "Number Guess" example shows the use of Rule Flow, a way of controlling the order in which rules are fired. It uses widely understood workflow diagrams for defining the order in which groups of rules will be executed.

Example 9.69. Creating the Number Guess RuleBase: NumberGuessExample.main() - part 1

```
final KnowledgeBuilder kbuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kbuilder.add( ResourceFactory.newClassPathResource( "NumberGuess.drl",
                                                    ShoppingExample.class ),
              ResourceType.DRL );
kbuilder.add( ResourceFactory.newClassPathResource( "NumberGuess.rf",
                                                    ShoppingExample.class ),
              ResourceType.DRF );

final KnowledgeBase kbase = KnowledgeBaseFactory.newKnowledgeBase();
kbase.addKnowledgePackages( kbuilder.getKnowledgePackages() );
```

The creation of the package and the loading of the rules (using the `add()` method) is the same as the previous examples. There is an additional line to add the Rule Flow (`NumberGuess.rf`), which provides the option of specifying different rule flows for the same Knowledge Base. Otherwise, the Knowledge Base is created in the same manner as before.

Example 9.70. Starting the RuleFlow: NumberGuessExample.main() - part 2

```
final StatefulKnowledgeSession ksession = kbase.newStatefulKnowledgeSession();

KnowledgeRuntimeLogger logger =
  KnowledgeRuntimeLoggerFactory.newFileLogger(ksession, "log/numberguess");

ksession.insert( new GameRules( 100, 5 ) );
ksession.insert( new RandomNumber() );
ksession.insert( new Game() );
```

```
ksession.startProcess( "Number Guess" );
ksession.fireAllRules();

logger.close();

ksession.dispose();
```

Once we have a Knowledge Base, we can use it to obtain a Stateful Session. Into our session we insert our facts, i.e., standard Java objects. (For simplicity, in this sample, these classes are all contained within our `NumberGuessExample.java` file. Class `GameRules` provides the maximum range and the number of guesses allowed. Class `RandomNumber` automatically generates a number between 0 and 100 and makes it available to our rules, by insertion via the `getValue()` method. Class `Game` keeps track of the guesses we have made before, and their number.

Note that before we call the standard `fireAllRules()` method, we also start the process that we loaded earlier, via the `startProcess()` method. We'll learn where to obtain the parameter we pass ("Number Guess", i.e., the identifier of the rule flow) when we talk about the rule flow file and the graphical Rule Flow Editor below.

Before we finish the discussion of our Java code, we note that in some real-life application we would examine the final state of the objects. (Here, we could retrieve the number of guesses, to add it to a high score table.) For this example we are content to ensure that the Working Memory session is cleared by calling the `dispose()` method.

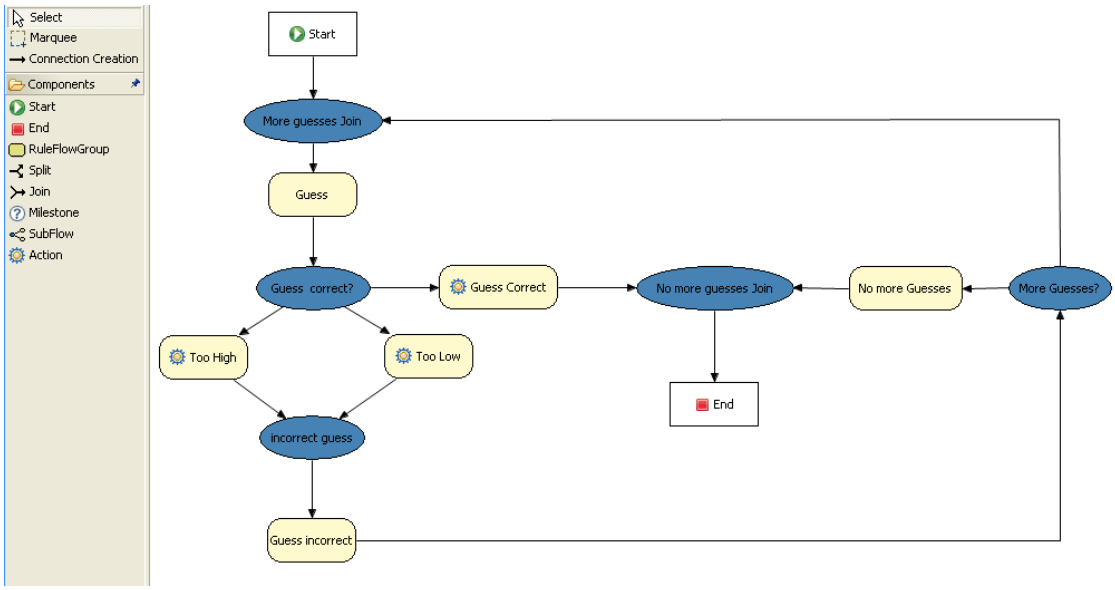


Figure 9.18. RuleFlow for the NumberGuess Example

If you open the `NumberGuess.rf` file in the Drools IDE (provided you have the JBoss Rules extensions installed correctly in Eclipse) you should see the above diagram, similar to a standard flowchart. Its icons are similar (but not exactly the same) as in the JBoss jBPM workflow product.

Should you wish to edit the diagram, a menu of available components should be available to the left of the diagram in the IDE, which is called the *palette*. This diagram is saved in XML, an (almost) human readable format, using XStream.

If it is not already open, ensure that the Properties View is visible in the IDE. It can be opened by clicking "Window", then "Show View" and "Other", where you can select the "Properties" view. If you do this *before* you select any item on the rule flow (or click on the blank space in the rule flow) you should be presented with the following set of properties.

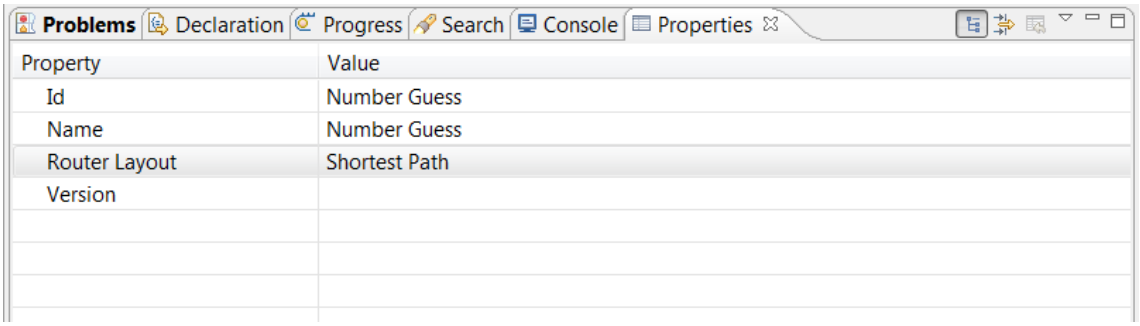


Figure 9.19. Properties for the Number Guess Rule Flow

Keep an eye on the Properties View as we progress through the example's rule flow, as it presents valuable information. In this case, it provides us with the identification of the Rule Flow Process that we used in our earlier code snippet, when we called `session.startProcess()`.

In the "Number Guess" Rule Flow we encounter several node types, many of them identified by an icon.

- The Start node (white arrow in a green circle) and the End node (red box) mark beginning and end of the rule flow.
- A Rule Flow Group box (yellow, without an icon) represents a Rule Flow Groups defined in our rules (DRL) file that we will look at later. For example, when the flow reaches the Rule Flow Group "Too High", only those rules marked with an attribute of `ruleflow-group "Too High"` can potentially fire.
- Action nodes (yellow, cog-shaped icon) perform standard Java method calls. Most action nodes in this example call `System.out.println()`, indicating the program's progress to the user.
- Split and Join Nodes (blue ovals, no icon) such as "Guess Correct?" and "More guesses Join" mark places where the flow of control can split, according to various conditions, and rejoin, respectively
- Arrows indicate the flow between the various nodes.

The various nodes in combination with the rules make the Number Guess game work. For example, the "Guess" Rule Flow Group allows only the rule "Get user Guess" to fire, because only that rule has a matching attribute of `ruleflow-group "Guess"`.

Example 9.71. A Rule firing only at a specific point in the Rule Flow: NumberGuess.drl

```
rule "Get user Guess"
    ruleflow-group "Guess"
    no-loop
    when
        $r : RandomNumber()
        rules : GameRules( allowed : allowedGuesses )
        game : Game( guessCount < allowed )
        not ( Guess() )
    then
     System.out.println( "You have " + ( rules.allowedGuesses - game.guessCount )
                           + " out of " + rules.allowedGuesses
                        + " guesses left.\nPlease enter your guess from 0 to "
                           + rules.maxRange );
        br = new BufferedReader( new InputStreamReader( System.in ) );
        i = br.readLine();
        modify ( game ) { guessCount = game.guessCount + 1 }
        insert( new Guess( i ) );
end
```

The rest of this rule is fairly standard. The LHS section (after `when`) of the rule states that it will be activated for each `RandomNumber` object inserted into the Working Memory where `guessCount` is less than `allowedGuesses` from the `GameRules` object and where the user has not guessed the correct number.

The RHS section (or consequence, after `then`) prints a message to the user and then awaits user input from `System.in`. After obtaining this input (the `readLine()` method call blocks until the return key is pressed) it modifies the guess count and inserts the new guess, making both available to the Working Memory.

The rest of the rules file is fairly standard: the package declares the dialect as MVEL, and various Java classes are imported. In total, there are five rules in this file:

1. Get User Guess, the Rule we examined above.
2. A Rule to record the highest guess.
3. A Rule to record the lowest guess.
4. A Rule to inspect the guess and retract it from memory if incorrect.
5. A Rule that notifies the user that all guesses have been used up.

One point of integration between the standard Rules and the RuleFlow is via the `ruleflow-group` attribute on the rules, as dicussed above. A *second point of integration between the rules (.drl) file*

and the Rules Flow .rf files is that the Split Nodes (the blue ovals) can use values in the Working Memory (as updated by the rules) to decide which flow of action to take. To see how this works, click on the "Guess Correct Node"; then within the Properties View, open the Constraints Editor by clicking the button at the right that appears once you click on the "Constraints" property line. You should see something similar to the diagram below.

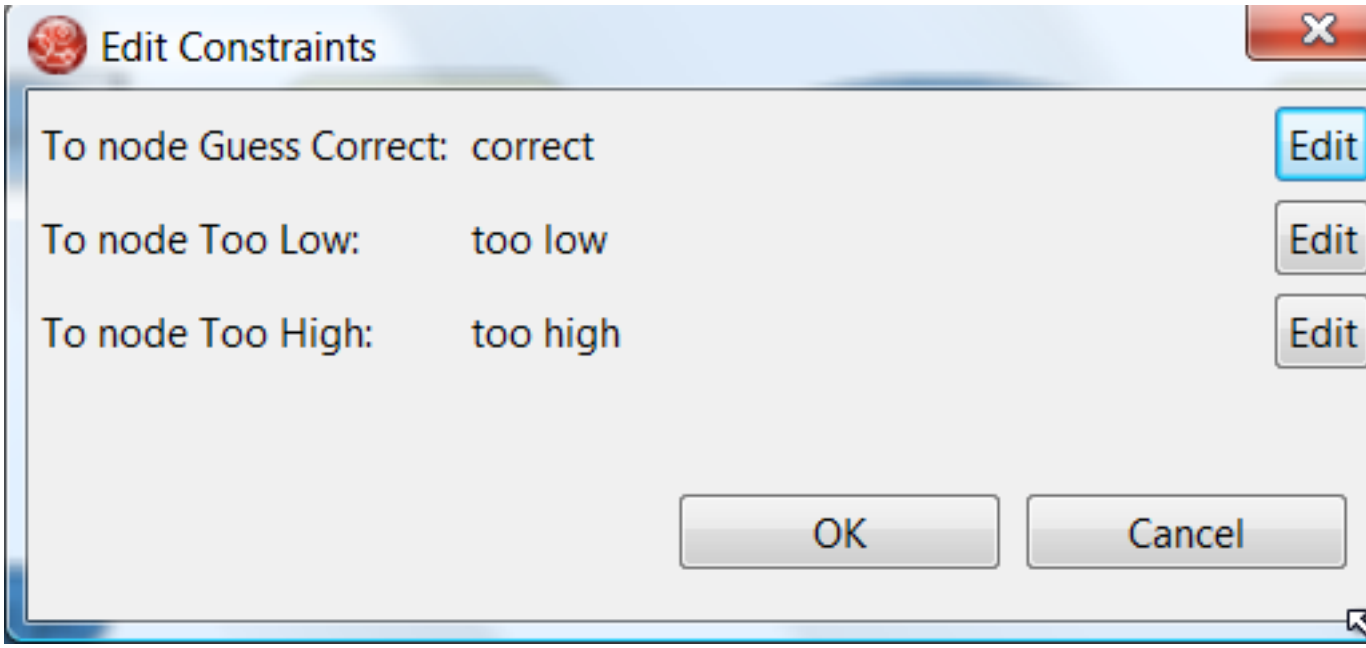


Figure 9.20. Edit Constraints for the "Guess Correct" Node

Click on the "Edit" button beside "To node Too High" and you'll see a dialog like the one below. The values in the "Textual Editor" window follow the standard rule format for the LHS and can refer to objects in Working Memory. The consequence (RHS) is that the flow of control follows this node (i.e., "To node Too High") if the LHS expression evaluates to true.

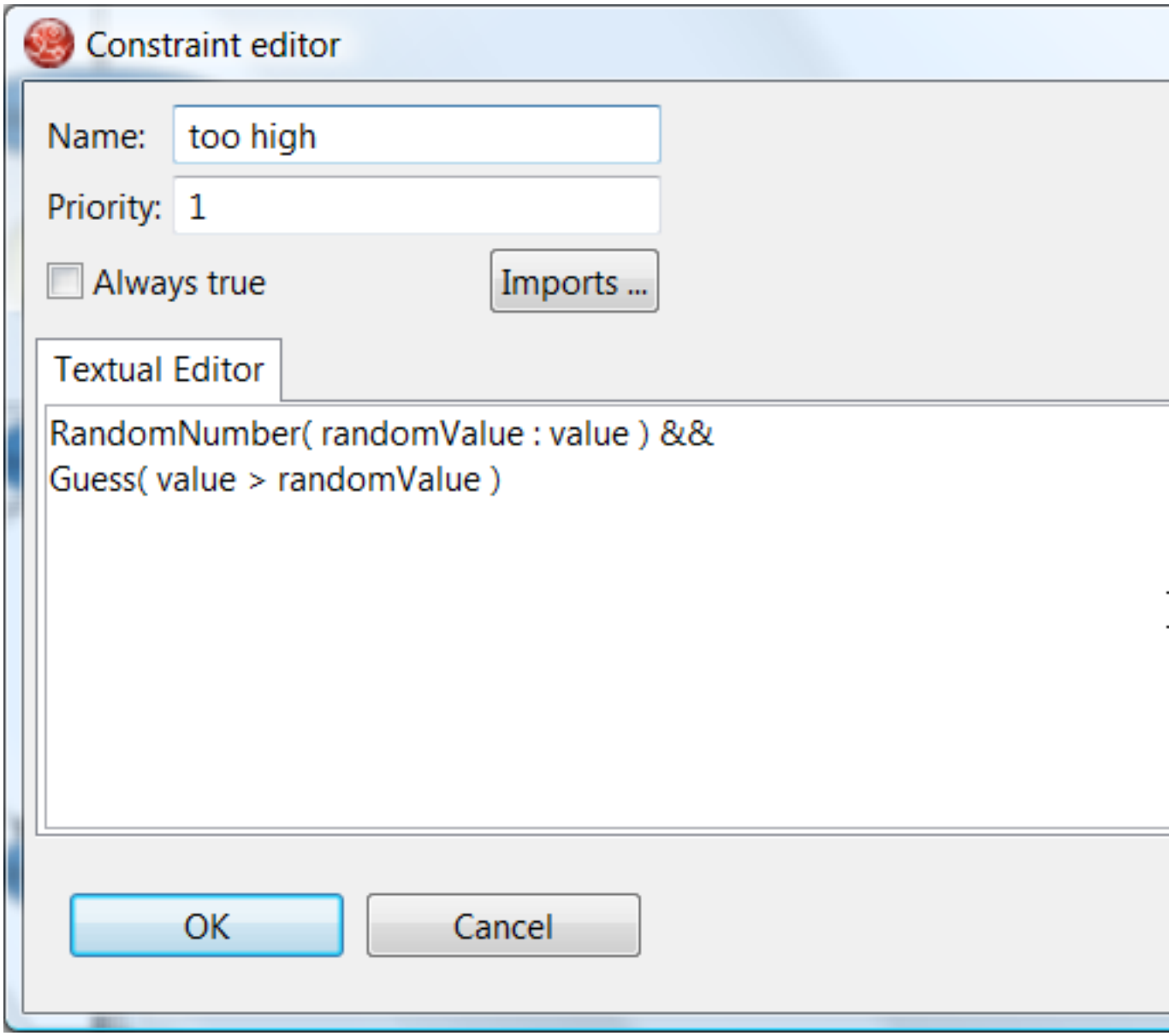


Figure 9.21. Constraint Editor for the "Guess Correct" Node: value too high

Since the file `NumberGuess.java` contains a `main()` method, it can be run as a standard Java application, either from the command line or via the IDE. A typical game might result in the interaction below. The numbers in bold are typed in by the user.

Example 9.72. Example Console output where the Number Guess Example beat the human!

```
You have 5 out of 5 guesses left.
Please enter your guess from 0 to 100
50
Your guess was too high
```

```
You have 4 out of 5 guesses left.
Please enter your guess from 0 to 100
25
Your guess was too low
You have 3 out of 5 guesses left.
Please enter your guess from 0 to 100
37
Your guess was too low
You have 2 out of 5 guesses left.
Please enter your guess from 0 to 100
44
Your guess was too low
You have 1 out of 5 guesses left.
Please enter your guess from 0 to 100
47
Your guess was too low
You have no more guesses
The correct guess was 48
```

A summary of what is happening in this sample is:

1. The `main()` method of `NumberGuessExample.java` loads a Rule Base, creates a Stateful Session and inserts `Game`, `GameRules` and `RandomNumber` (containing the target number) objects into it. The method also sets the process flow we are going to use, and fires all rules. Control passes to the Rule Flow.

2. File `NumberGuess.rf`, the Rule Flow, begins at the "Start" node.

3. Control passes (via the "More guesses" join node) to the Guess node.

4. At the Guess node, the appropriate Rule Flow Group ("Get user Guess") is enabled. In this case the Rule "Guess" (in the `NumberGuess.drl` file) is triggered. This rule displays a message to the user, takes the response, and puts it into Working Memory. Flow passes to the next Rule Flow Node.

5. At the next node, "Guess Correct", constraints inspect the current session and decide which path to take.

   If the guess in step 4 was too high or too low, flow proceeds along a path which has an action node with normal Java code printing a suitable message and a Rule Flow Group causing a highest guess or lowest guess rule to be triggered. Flow passes from these nodes to step 6.

   If the guess in step 4 was right, we proceed along the path towards the end of the Rule Flow. Before we get there, an action node with normal Java code prints a statement "you guessed correctly". There is a join node here (just before the Rule Flow end) so that our no-more-guesses path (step 7) can also terminate the Rule Flow.

6. Control passes as per the Rule Flow via a join node, a guess incorrect Rule Flow Group (triggering a rule to retract a guess from Working Memory) onto the "More guesses" decision node.

7. The "More guesses" decision node (on the right hand side of the rule flow) uses constraints, again looking at values that the rules have put into the working memory, to decide if we have more guesses and if so, goto step 3. If not, we proceed to the end of the rule flow, via a Rule Flow Group that triggers a rule stating "you have no more guesses".

8. The loop over steps 3 to 7 continues until the number is guessed correctly, or we run out of guesses.

9.11. Miss Manners and Benchmarking

```
Name: Miss Manners
Main class: org.drools.benchmark.manners.MannersBenchmark
Module: drools-examples
Type: Java application
Rules file: manners.drl
Objective: Advanced walkthrough on the Manners benchmark, covers Depth conflict
 resolution in depth.
```

9.11.1. Introduction

Miss Manners is throwing a party and, being a good host, she wants to arrange good seating. Her initial design arranges everyone in male-female pairs, but then she worries about people have things to talk about. What is a good host to do? She decides to note the hobby of each guest so she can then arrange guests not only pairing them according to alternating sex but also ensuring that a guest has someone with a common hobby, at least on one side.

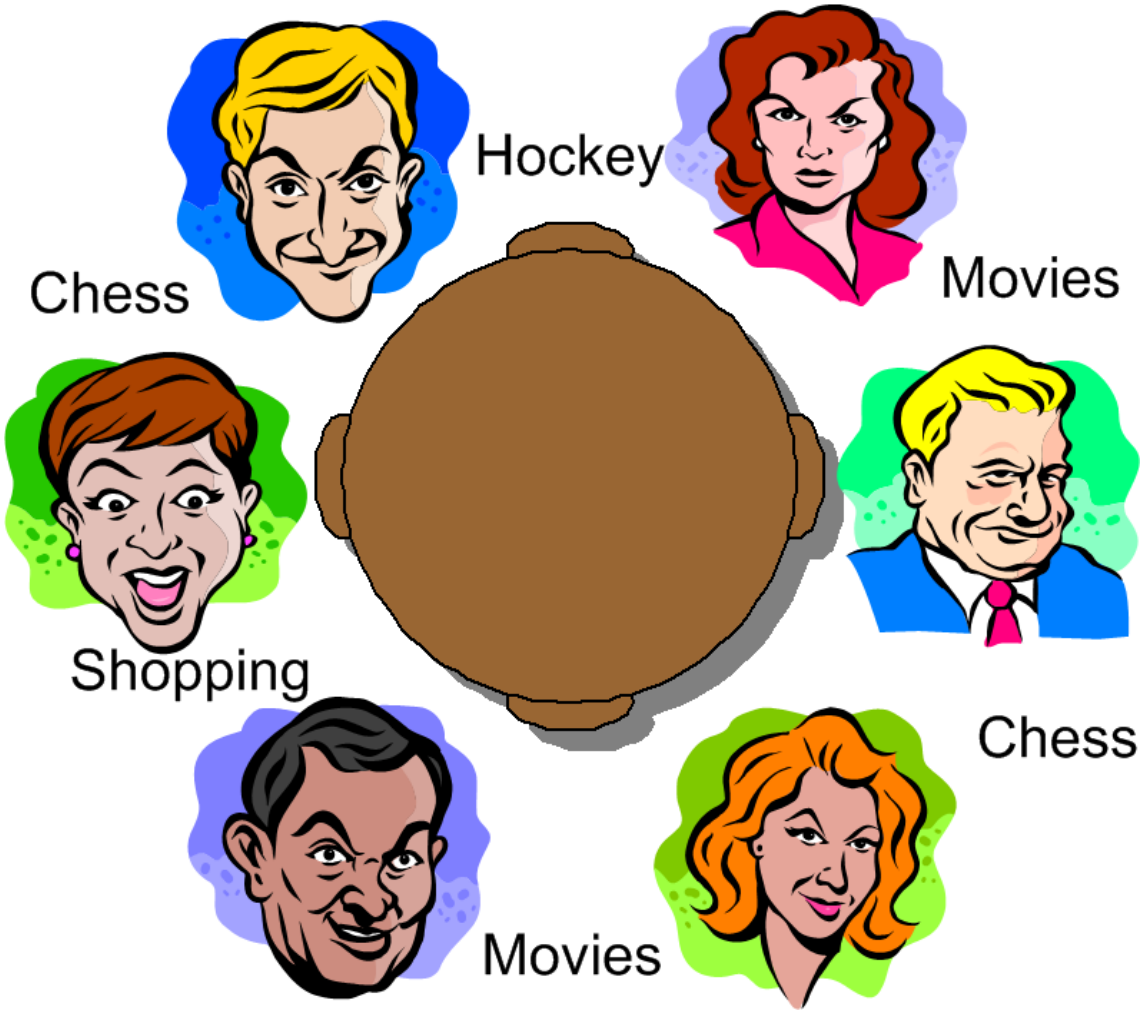


Figure 9.22. Miss Manners' Guests

9.11.1.1. BenchMarking

Five benchmarks were established in the 1991 paper "Effects of Database Size on Rule System Performance: Five Case Studies" by David Brant, Timothy Grose, Bernie Lofaso and Daniel P. Miranker:

- **Manners** uses a depth-first search approach to determine the seating arrangements alternating women and men and ensuring one common hobby for neighbors.
- **Waltz** establishes a three-dimensional interpretation of a line drawing by line labeling by constraint propagation.
- **WaltzDB** is a more general version of Waltz, supporting junctions of more than three lines and using a database.
- **ARP** is a route planner for a robotic air vehicle using the A* search algorithm to achieve minimal cost.
- **Weaver** VLSI router for channels and boxes using a black-board technique.

Manners has become the de facto rule engine benchmark. Its behavior, however, is now well known and many engines optimize for this, thus negating its usefulness as a benchmark which is why Waltz is becoming more favorable. These five benchmarks are also published at the University of Texas *http://www.cs.utexas.edu/ftp/pub/ops5-benchmark-suite/*.

9.11.1.2. Miss Manners Execution Flow

After the first seating arrangement has been assigned, a depth-first recursion occurs which repeatedly assigns correct seating arrangements until the last seat is assigned. Manners uses a `Context` instance to control execution flow. The activity diagram is partitioned to show the relation of the rule execution to the current `Context` state.

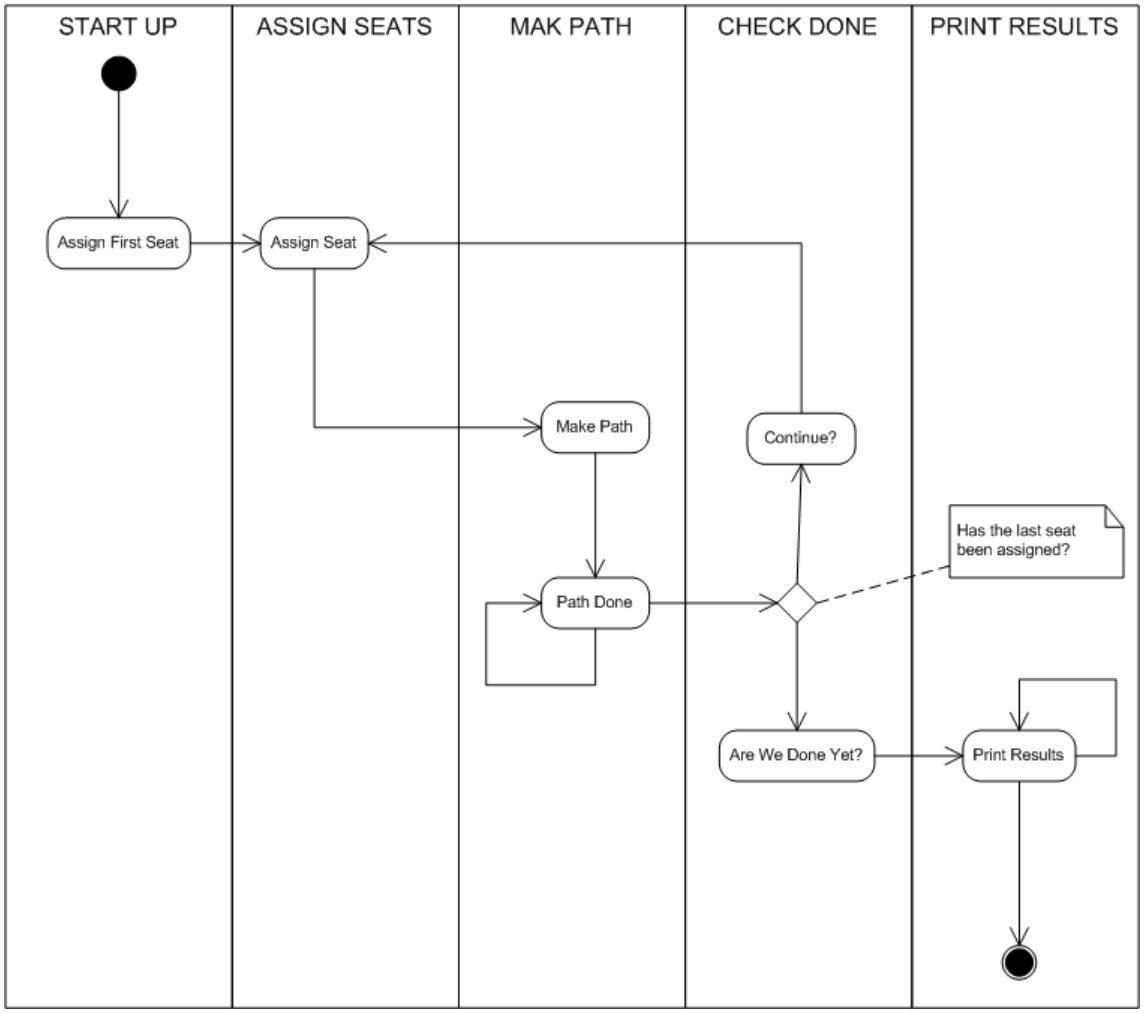


Figure 9.23. Manners Activity Diagram

9.11.1.3. The Data and Results

Before going deeper into the rules, let's first take a look at the asserted data and the resulting seating arrangement. The data is a simple set of five guests who should be arranged so that sexes alternate and neighbors have a common hobby.

The Data

The data is given in OPS5 syntax, with a parenthesized list of name and value pairs for each attribute. Each person has only one hobby.

```
(guest (name n1) (sex m) (hobby  h1)  )
(guest (name n2) (sex f) (hobby  h1)  )
(guest (name n2) (sex f) (hobby  h3)  )
(guest (name n3) (sex m) (hobby  h3)  )
(guest (name n4) (sex m) (hobby  h1)  )
(guest (name n4) (sex f) (hobby  h2)  )
(guest (name n4) (sex f) (hobby  h3)  )
(guest (name n5) (sex f) (hobby  h2)  )
(guest (name n5) (sex f) (hobby  h1)  )
(last_seat (seat 5)  )
```

The Results

Each line of the results list is printed per execution of the "Assign Seat" rule. They key bit to notice is that each line has a "pid" value one greater than the last. (The significance of this will be explained in the discussion of the rule "Assign Seating".) The "ls", "rs", "ln" and "rn" refer to the left and right seat and neighbor's name, respectively. The actual implementation uses longer attribute names (e.g., `leftGuestName`, but here we'll stick to the notation from the original implementation.

```
[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[Seating id=2, pid=1, done=false, ls=1, ln=n5, rs=2, rn=n4]
[Seating id=3, pid=2, done=false, ls=2, ln=n4, rs=3, rn=n3]
[Seating id=4, pid=3, done=false, ls=3, rn=n3, rs=4, rn=n2]
[Seating id=5, pid=4, done=false, ls=4, ln=n2, rs=5, rn=n1]
```

9.11.2. Indepth Discussion

9.11.2.1. Cheating

Manners has been designed to exercise cross product joins and Agenda activities. Many people not understanding this tweak the example to achieve better performance, making their port of the Manners benchmark pointless. Known cheats or porting errors for Miss Manners are:

- Using arrays for a guests hobbies, instead of asserting each one as a single fact massively reduces the cross products.
- Altering the sequence of data can also reduce the amount of matching, increasing execution speed.
- It's possible to change the `not` Conditional Element so that the test algorithm only uses the "first-best-match", which is, basically, transforming the test algorithm to backward chaining. The results are only comparable to other backward chaining rule engines or ports of Manners.

- Removing the context so the rule engine matches the guests and seats prematurely. A proper port will prevent facts from matching using the context start.
- It's possible to prevent the rule engine from performing combinatorial pattern matching.
- If no facts are retracted in the reasoning cycle, as a result of the `not` CE, the port is incorrect.

9.11.2.2. Conflict Resolution

The Manners benchmark was written for OPS5 which has two conflict resolution strategies, LEX and MEA. LEX is a chain of several strategies including salience, recency and complexity. The recency part of the strategy drives the depth first (LIFO) firing order. The CLIPS manual documents the Recency strategy as follows:

> Every fact and instance is marked internally with a "time tag" to indicate its relative recency with respect to every other fact and instance in the system. The pattern entities associated with each rule activation are sorted in descending order for determining placement. An activation with a more recent pattern entity is placed before activations with less recent pattern entities. To determine the placement order of two activations, compare the sorted time tags of the two activations one by one starting with the largest time tags. The comparison should continue until one activation’s time tag is greater than the other activation’s corresponding time tag. The activation with the greater time tag is placed before the other activation on the agenda. If one activation has more pattern entities than the other activation and the compared time tags are all identical, then the activation with more time tags is placed before the other activation on the agenda.
>
> —CLIPS Reference Manual

However Jess and CLIPS both use the Depth strategy, which is simpler and lighter, which Drools also adopted. The CLIPS manual documents the Depth strategy as:

> Newly activated rules are placed above all rules of the same salience. For example, given that fact-a activates rule-1 and rule-2 and fact-b activates rule-3 and rule-4, then if fact-a is asserted before fact-b, rule-3 and rule-4 will be above rule-1 and rule-2 on the agenda. However, the position of rule-1 relative to rule-2 and rule-3 relative to rule-4 will be arbitrary.
>
> —CLIPS Reference Manual

The initial Drools implementation for the Depth strategy would not work for Manners without the use of salience on the "make_path" rule. The CLIPS support team had this to say:

> The default conflict resolution strategy for CLIPS, Depth, is different than the default conflict resolution strategy used by OPS5. Therefore if you directly translate an OPS5 program to CLIPS, but use the default depth conflict resolution strategy, you're only likely to get the correct behavior by coincidence. The LEX and MEA conflict resolution strategies are provided in CLIPS to allow you to quickly convert and correctly run an OPS5 program in CLIPS.
>
> —Clips Support Forum

Investigation into the CLIPS code reveals there is undocumented functionality in the Depth strategy. There is an accumulated time tag used in this strategy; it's not an extensively fact by fact comparison as in the recency strategy, it simply adds the total of all the time tags for each activation and compares.

9.11.2.3. Rule "assignFirstSeat"

Once the context is changed to `START_UP`, activations are created for all asserted guest. Because all activations are created as the result of a single Working Memory action, they all have the same Activation time tag. The last asserted `Guest` object would have a higher fact time tag, and its Activation would fire because it has the highest accumulated fact time tag. The execution order in this rule has little importance, but has a big impact in the rule "Assign Seat". The activation fires and asserts the first `Seating` arrangement and a `Path`, and then sets the `Context` attribute `state` to create an activation for rule `findSeating`.

```
rule assignFirstSeat
    when
        context : Context( state == Context.START_UP )
        guest : Guest()
        count : Count()
    then
        String guestName = guest.getName();

        Seating seating =
          new Seating( count.getValue(), 1, true, 1, guestName, 1, guestName);
        insert( seating );

        Path path = new Path( count.getValue(), 1, guestName );
        insert( path );

        modify( count ) { setValue ( count.getValue() + 1 )  }

    System.out.println( "assign first seat :  " + seating + " : " + path );

        modify( context ) {
            setState( Context.ASSIGN_SEATS )
        }
end
```

9.11.2.4. Rule "findSeating"

This rule determines each of the `Seating` arrangements. The rule creates cross product solutions for *all* asserted `Seating` arrangements against *all* the asserted guests except against itself or any already assigned chosen solutions.

```
rule findSeating
```

```
    when
        context : Context( state == Context.ASSIGN_SEATS )
        $s      : Seating( pathDone == true )
        $g1     : Guest( name == $s.rightGuestName )
        $g2     : Guest( sex != $g1.sex, hobby == $g1.hobby )

        count   : Count()

        not ( Path( id == $s.id, guestName == $g2.name) )
        not ( Chosen( id == $s.id, guestName == $g2.name, hobby == $g1.hobby) )
    then
        int rightSeat = $s.getRightSeat();
        int seatId = $s.getId();
        int countValue = count.getValue();

        Seating seating =
          new Seating( countValue, seatId, false, rightSeat,
                       $s.getRightGuestName(), rightSeat + 1, $g2.getName() );
        insert( seating );

        Path path = new Path( countValue, rightSeat + 1, $g2.getName()  );
        insert( path );

        Chosen chosen = new Chosen( seatId, $g2.getName(), $g1.getHobby() );
        insert( chosen  );

        System.err.println( "find seating : " + seating + " : " + path +
                            " : " + chosen);

        modify( count ) {setValue(  countValue + 1 )}
        modify( context ) {setState( Context.MAKE_PATH )}
end
```

However, as can be seen from the printed results shown earlier, it is essential that only the `Seating` with the highest `pid` cross product be chosen. How can this be possible if we have activations, of the same time tag, for nearly all existing `Seating` and `Guest` objects? For example, on the third iteration of `findDeating` the produced activations will be as shown below. Remember, this is from a very small data set, and with larger data sets there would be many more possible activated `Seating` solutions, with multiple solutions per `pid`:

```
=>[ActivationCreated(35): rule=findSeating
[fid:19:33]:[Seating id=3, pid=2, done=true, ls=2, ln=n4, rs=3, rn=n3]
[fid:4:4]:[Guest name=n3, sex=m, hobbies=h3]
[fid:3:3]:[Guest name=n2, sex=f, hobbies=h3]

=>[ActivationCreated(35): rule=findSeating
[fid:15:23]:[Seating id=2, pid=1, done=true, ls=1, ln=n5, rs=2, rn=n4]
```

```
[fid:5:5]:[Guest name=n4, sex=m, hobbies=h1]
[fid:2:2]:[Guest name=n2, sex=f, hobbies=h1]

=>[ActivationCreated(35): rule=findSeating
[fid:13:13]:[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[fid:9:9]:[Guest name=n5, sex=f, hobbies=h1]
[fid:1:1]:[Guest name=n1, sex=m, hobbies=h1]
```

The creation of all these redundant activations might seem pointless, but it must be remembered that Manners is not about good rule design; it's purposefully designed as a bad ruleset to fully stress-test the cross product matching process and the Agenda, which this clearly does. Notice that each activation has the same time tag of 35, as they were all activated by the change in the `Context` object to `ASSIGN_SEATS`. With OPS5 and LEX it would correctly fire the activation with the `Seating` asserted last. With Depth, the accumulated fact time tag ensures that the activation with the last asserted `Seating` fires.

9.11.2.5. Rules "makePath" and "pathDone"

Rule `makePath` must always fire before `pathDone`. A `Path` object is asserted for each `Seating` arrangement, up to the last asserted `Seating`. Notice that the conditions in `pathDone` are a subset of those in `makePath` - so how do we ensure that `makePath` fires first?

```
rule makePath
    when
        Context( state == Context.MAKE_PATH )
        Seating( seatingId:id, seatingPid:pid, pathDone == false )
        Path( id == seatingPid, pathGuestName:guestName, pathSeat:seat )
        not Path( id == seatingId, guestName == pathGuestName )
    then
        insert( new Path( seatingId, pathSeat, pathGuestName ) );
end
```

```
rule pathDone
    when
        context : Context( state == Context.MAKE_PATH )
        seating : Seating( pathDone == false )
    then
        modify( seating ) {setPathDone( true )}

    modify( context ) {setState( Context.CHECK_DONE)}
end
```

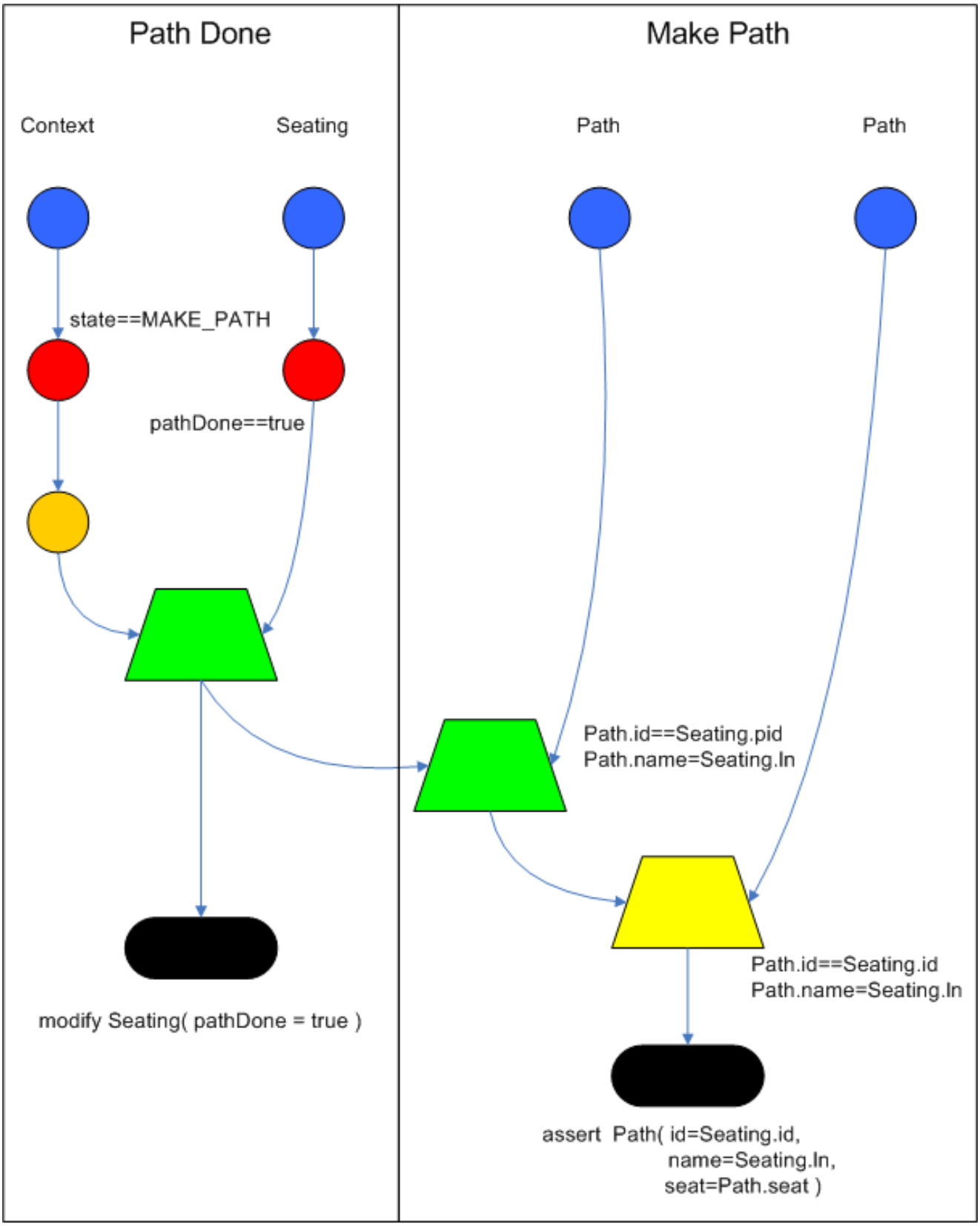


Figure 9.24. Rete Diagram

Both rules end up on the Agenda in conflict and with identical activation time tags. However, the accumulate fact time tag is greater for "Make Path" so it gets priority.

9.11.2.6. Rules "continue" and "areWeDone"

Rule `areWeDone` only activates when the last seat is assigned, at which point both rules will be activated. For the same reason that `makePath` always wins over `path Done`, `areWeDone` will take priority over rule `continue`.

```
rule areWeDone
    when
        context : Context( state == Context.CHECK_DONE )
        LastSeat( lastSeat: seat )
        Seating( rightSeat == lastSeat )
    then
        modify( context ) {setState(Context.PRINT_RESULTS )}
end
```

```
rule continue
    when
        context : Context( state == Context.CHECK_DONE )
    then
        modify( context ) {setState( Context.ASSIGN_SEATS )}
end
```

9.11.3. Output Summary

Assign First seat
=>[fid:13:13]:[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
=>[fid:14:14]:[Path id=1, seat=1, guest=n5]

==>[ActivationCreated(16): rule=findSeating
[fid:13:13]:[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[fid:9:9]:[Guest name=n5, sex=f, hobbies=h1]
[fid:1:1]:[Guest name=n1, sex=m, hobbies=h1]

==>[ActivationCreated(16): rule=findSeating
[fid:13:13]:[Seating id=1 , pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[fid:9:9]:[Guest name=n5, sex=f, hobbies=h1]
[fid:5:5]:[Guest name=n4, sex=m, hobbies=h1]*

Assign Seating
=>[fid:15:17] :[Seating id=2 , pid=1 , done=false, ls=1, lg=n5, rs=2, rn=n4]

```
=>[fid:16:18]:[Path id=2, seat=2, guest=n4]
=>[fid:17:19]:[Chosen id=1, name=n4, hobbies=h1]

=>[ActivationCreated(21): rule=makePath
[fid:15:17] : [Seating id=2, pid=1, done=false, ls=1, ln=n5, rs=2, rn=n4]
[fid:14:14] : [Path id=1, seat=1, guest=n5]*

==>[ActivationCreated(21): rule=pathDone
[Seating id=2, pid=1, done=false, ls=1, ln=n5, rs=2, rn=n4]*

Make Path
=>[fid:18:22:[Path id=2, seat=1, guest=n5]]

Path Done

Continue Process
=>[ActivationCreated(25): rule=findSeating
[fid:15:23]:[Seating id=2, pid=1, done=true, ls=1, ln=n5, rs=2, rn=n4]
[fid:7:7]:[Guest name=n4, sex=f, hobbies=h3]
[fid:4:4] : [Guest name=n3, sex=m, hobbies=h3]*

=>[ActivationCreated(25): rule=findSeating
[fid:15:23]:[Seating id=2, pid=1, done=true, ls=1, ln=n5, rs=2, rn=n4]
[fid:5:5]:[Guest name=n4, sex=m, hobbies=h1]
[fid:2:2]:[Guest name=n2, sex=f, hobbies=h1], [fid:12:20] : [Count value=3]

=>[ActivationCreated(25): rule=findSeating
[fid:13:13]:[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[fid:9:9]:[Guest name=n5, sex=f, hobbies=h1]
[fid:1:1]:[Guest name=n1, sex=m, hobbies=h1]

Assign Seating
=>[fid:19:26]:[Seating id=3, pid=2, done=false, ls=2, lnn4, rs=3, rn=n3]]
=>[fid:20:27]:[Path id=3, seat=3, guest=n3]]
=>[fid:21:28]:[Chosen id=2, name=n3, hobbies=h3}]

=>[ActivationCreated(30): rule=makePath
[fid:19:26]:[Seating id=3, pid=2, done=false, ls=2, ln=n4, rs=3, rn=n3]
[fid:18:22]:[Path id=2, seat=1, guest=n5]*

=>[ActivationCreated(30): rule=makePath
[fid:19:26]:[Seating id=3, pid=2, done=false, ls=2, ln=n4, rs=3, rn=n3]
[fid:16:18]:[Path id=2, seat=2, guest=n4]*
```

=>[ActivationCreated(30): rule=done
[fid:19:26]:[Seating id=3, pid=2, done=false, ls=2, ln=n4, rs=3, rn=n3]*

Make Path
=>[fid:22:31]:[Path id=3, seat=1, guest=n5]

Make Path
=>[fid:23:32] [Path id=3, seat=2, guest=n4]

Path Done

Continue Processing
=>[ActivationCreated(35): rule=findSeating
[fid:19:33]:[Seating id=3, pid=2, done=true, ls=2, ln=n4, rs=3, rn=n3]
[fid:4:4]:[Guest name=n3, sex=m, hobbies=h3]
[fid:3:3]:[Guest name=n2, sex=f, hobbies=h3], [fid:12:29]*

=>[ActivationCreated(35): rule=findSeating
[fid:15:23]:[Seating id=2, pid=1, done=true, ls=1, ln=n5, rs=2, rn=n4]
[fid:5:5]:[Guest name=n4, sex=m, hobbies=h1]
[fid:2:2]:[Guest name=n2, sex=f, hobbies=h1]

=>[ActivationCreated(35): rule=findSeating
[fid:13:13]:[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[fid:9:9]:[Guest name=n5, sex=f, hobbies=h1], [fid:1:1] : [Guest name=n1, sex=m,
hobbies=h1]

Assign Seating
=>[fid:24:36]:[Seating id=4, pid=3, done=false, ls=3, ln=n3, rs=4, rn=n2]]
=>[fid:25:37]:[Path id=4, seat=4, guest=n2]]
=>[fid:26:38]:[Chosen id=3, name=n2, hobbies=h3]

==>[ActivationCreated(40): rule=makePath
[fid:24:36]:[Seating id=4, pid=3, done=false, ls=3, ln=n3, rs=4, rn=n2]
[fid:23:32]:[Path id=3, seat=2, guest=n4]*

==>[ActivationCreated(40): rule=makePath
[fid:24:36]:[Seating id=4, pid=3, done=false, ls=3, ln=n3, rs=4, rn=n2]
[fid:20:27]:[Path id=3, seat=3, guest=n3]*

=>[ActivationCreated(40): rule=makePath
[fid:24:36]:[Seating id=4, pid=3, done=false, ls=3, ln=n3, rs=4, rn=n2]
[fid:22:31]:[Path id=3, seat=1, guest=n5]*

=>[ActivationCreated(40): rule=done
[fid:24:36]:[Seating id=4, pid=3, done=false, ls=3, ln=n3, rs=4, rn=n2]*

Make Path
=>fid:27:41:[Path id=4, seat=2, guest=n4]

Make Path
=>fid:28:42]:[Path id=4, seat=1, guest=n5]]

Make Path
=>fid:29:43]:[Path id=4, seat=3, guest=n3]]

Path Done

Continue Processing
=>[ActivationCreated(46): rule=findSeating
[fid:15:23]:[Seating id=2, pid=1, done=true, ls=1, ln=n5, rs=2, rn=n4]
[fid:5:5]:[Guest name=n4, sex=m, hobbies=h1], [fid:2:2]
[Guest name=n2, sex=f, hobbies=h1]

=>[ActivationCreated(46): rule=findSeating
[fid:24:44]:[Seating id=4, pid=3, done=true, ls=3, ln=n3, rs=4, rn=n2]
[fid:2:2]:[Guest name=n2, sex=f, hobbies=h1]
[fid:1:1]:[Guest name=n1, sex=m, hobbies=h1]*

=>[ActivationCreated(46): rule=findSeating
[fid:13:13]:[Seating id=1, pid=0, done=true, ls=1, ln=n5, rs=1, rn=n5]
[fid:9:9]:[Guest name=n5, sex=f, hobbies=h1]
[fid:1:1]:[Guest name=n1, sex=m, hobbies=h1]

Assign Seating
=>[fid:30:47]:[Seating id=5, pid=4, done=false, ls=4, ln=n2, rs=5, rn=n1]
=>[fid:31:48]:[Path id=5, seat=5, guest=n1]
=>[fid:32:49]:[Chosen id=4, name=n1, hobbies=h1]

9.12. Conway's Game Of Life

Name: Conway's Game Of Life
Main class: org.drools.examples.conway.ConwayAgendaGroupRun
org.drools.examples.conway.ConwayRuleFlowGroupRun
Module: droolsjbpm-integration-examples (Note: this is in a different download, the droolsjbpm-integration download.)
Type: Java application
Rules file: conway-ruleflow.drl conway-agendagroup.drl

```
Objective: Demonstrates 'accumulate', 'collect' and 'from'
```

Conway's Game Of Life, described in *http://en.wikipedia.org/wiki/Conway's_Game_of_Life* and in *http://www.math.com/students/wonders/life/life.html*, is a famous cellular automaton conceived in the early 1970's by the mathematician John Conway. While the system is well known as "Conway's Game Of Life", it really isn't a game at all. Conway's system is more like a simulation of a form of life. Don't be intimidated. The system is terribly simple and terribly interesting. Math and Computer Science students alike have marvelled over Conway's system for more than 30 years now. The application presented here is a Swing-based implementation of Conway's Game of Life. The rules that govern the system are implemented as business rules using Drools. This document will explain the rules that drive the simulation and discuss the Drools parts of the implementation.

We'll first introduce the grid view, shown below, designed for the visualisation of the game, showing the "arena" where the life simuation takes place. Initially the grid is empty, meaning that there are no live cells in the system. Each cell is either alive or dead, with live cells showing a green ball. Preselected patterns of live cells can be chosen from the "Pattern" drop-down list. Alternatively, individual cells can be doubled-clicked to toggle them between live and dead. It's important to understand that each cell is related to its neighboring cells, which is fundamental for the game's rules. Neighbors include not only cells to the left, right, top and bottom but also cells that are connected diagonally, so that each cell has a total of 8 neighbors. Exceptions are the four corner cells which have only three neighbors, and the cells along the four border, with five neighbors each.

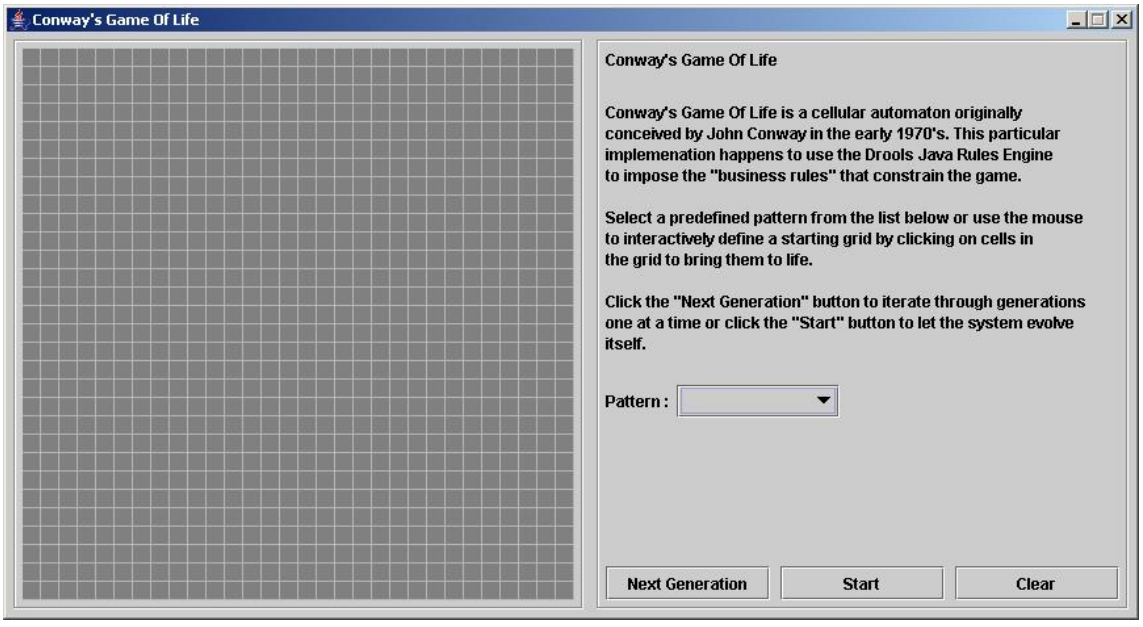


Figure 9.25. Conway's Game of Life: Starting a new game

So what are the basic rules that govern this game? Its goal is to show the development of a population, generation by generation. Each generation results from the preceding one, based on the simultaneous evaluation of all cells. This is the simple set of rules that govern what the next generation will look like:

- If a live cell has fewer than 2 live neighbors, it dies of loneliness.
- If a live cell has more than 3 live neighbors, it dies from overcrowding.
- If a dead cell has exactly 3 live neighbors, it comes to life.

That is all there is to it. Any cell that doesn't meet any of those criteria is left as is for the next generation. With those simple rules in mind, go back and play with the system a little bit more and step through some generations, one at a time, and notice these rules taking their effect.

The screenshot below shows an example generation, with a number of live cells. Don't worry about matching the exact patterns represented in the screen shot. Just get some groups of cells added to the grid. Once you have groups of live cells in the grid, or select a pre-designed pattern, click the "Next Generation" button and notice what happens. Some of the live cells are killed (the green ball disappears) and some dead cells come to life (a green ball appears). Step through several generations and see if you notice any patterns. If you click on the "Start" button, the system will evolve itself so you don't need to click the "Next Generation" button over and over. Play with the system a little and then come back here for more details of how the application works.

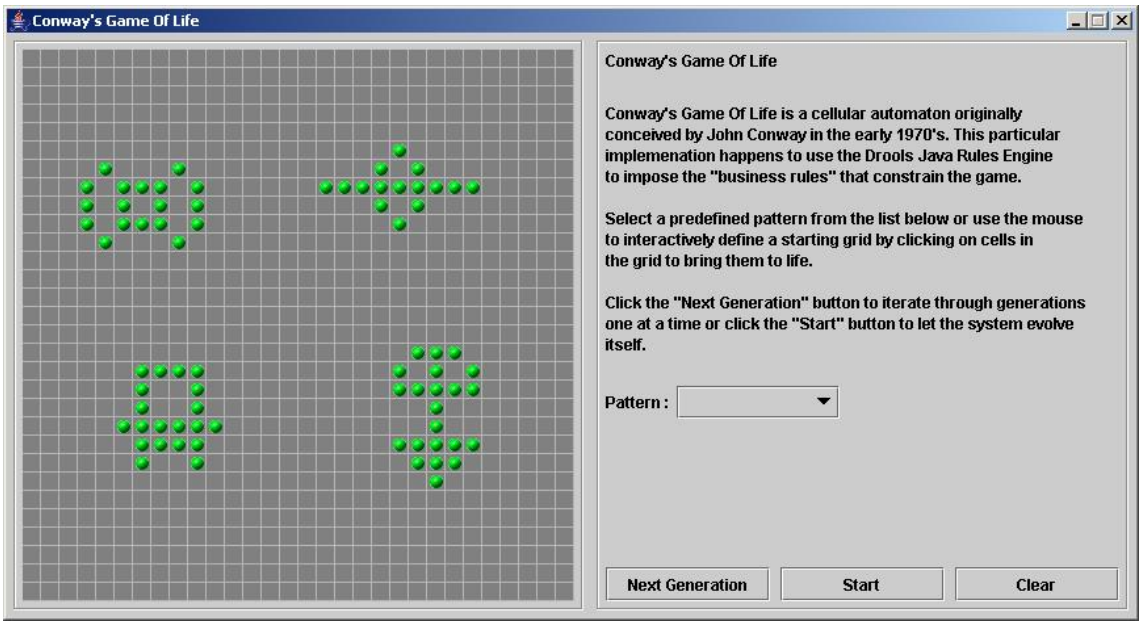


Figure 9.26. Conway's Game of Life: A running game

Now lets delve into the code. As this is an advanced example we'll assume that by now you know your way around the Drools framework and are able to connect the presented highlight, so that we'll just focus at a high level overview. The example has two ways to execute, one way uses Agenda Groups to manage execution flow, and the other one uses Rule Flow Groups to manage execution flow. These two versions are implemented in `ConwayAgendaGroupRun` and `ConwayRuleFlowGroupRun`, respectively. Here, we'll discuss the Rule Flow version, as it's what most people will use.

All the `Cell` objects are inserted into the Session and the rules in the `ruleflow-group` "register neighbor" are allowed to execute by the Rule Flow process. This group of four rules creates

`Neighbor` relations between some cell and its northeastern, northern, northwestern and western neighbors. This relation is bidirectional, which takes care of the other four directions. Border cells don't need any special treatment - they simply won't be paired with neighboring cells where there isn't any. By the time all activations have fired for these rules, all cells are related to all their neighboring cells.

Example 9.73. Conway's Game of Life: Register Cell Neighbour relations

```
rule "register north east"
    ruleflow-group "register neighbor"
when
    $cell: Cell( $row : row, $col : col )
    $northEast : Cell( row  == ($row - 1), col == ( $col + 1 ) )
then
    insert( new Neighbor( $cell, $northEast ) );
    insert( new Neighbor( $northEast, $cell ) );
end

rule "register north"
    ruleflow-group "register neighbor"
when
    $cell: Cell( $row : row, $col : col )
    $north : Cell( row  == ($row - 1), col == $col )
then
    insert( new Neighbor( $cell, $north ) );
    insert( new Neighbor( $north, $cell ) );
end

rule "register north west"
    ruleflow-group "register neighbor"
when
    $cell: Cell( $row : row, $col : col )
   $northWest : Cell( row  == ($row - 1), col == ( $col - 1 ) )
then
    insert( new Neighbor( $cell, $northWest ) );
    insert( new Neighbor( $northWest, $cell ) );
end

rule "register west"
    ruleflow-group "register neighbor"
when
    $cell: Cell( $row : row, $col : col )
    $west : Cell( row  == $row, col == ( $col - 1 ) )
then
    insert( new Neighbor( $cell, $west ) );
    insert( new Neighbor( $west, $cell ) );
end
```

Once all the cells are inserted, some Java code applies the pattern to the grid, setting certain cells to Live. Then, when the user clicks "Start" or "Next Generation", it executes the "Generation" ruleflow. This ruleflow is responsible for the management of all changes of cells in each generation cycle.

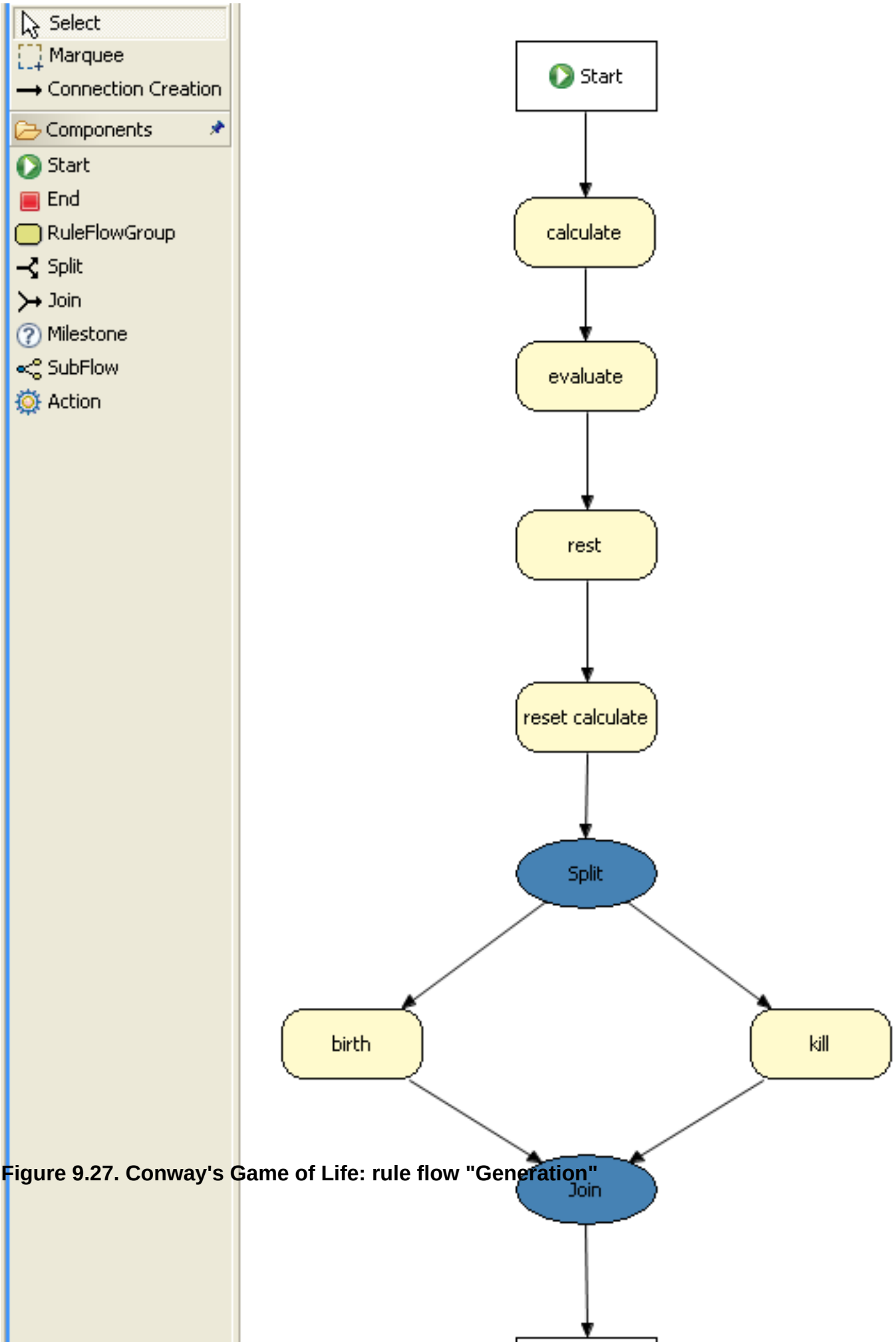


Figure 9.27. Conway's Game of Life: rule flow "Generation"

The rule flow process first enters the "evaluate" group, which means that any active rule in the group can fire. The rules in this group apply the Game-of-Life rules discussed in the beginning of the example, determining the cells to be killed and the ones to be given life. We use the "phase" attribute to drive the reasoning of the Cell by specific groups of rules; typically the phase is tied to a Rule Flow Group in the Rule Flow process definition. Notice that it doesn't actually change the state of any `Cell` objectss at this point; this is because it's evaluating the grid in turn and it must complete the full evaluation until those changes can be applied. To achieve this, it sets the cell to a "phase" which is either `Phase.KILL` or `Phase.BIRTH`, used later to control actions applied to the `Cell` object.

Example 9.74. Conway's Game of Life: Evaluate Cells with state changes

```
rule "Kill The Lonely"
    ruleflow-group "evaluate"
    no-loop
when
#   A live cell has fewer than 2 live neighbors
    theCell: Cell( liveNeighbors < 2, cellState == CellState.LIVE,
                   phase == Phase.EVALUATE )
then
    modify( theCell ){
        setPhase( Phase.KILL );
    }
end

rule "Kill The Overcrowded"
    ruleflow-group "evaluate"
    no-loop
when
#   A live cell has more than 3 live neighbors
    theCell: Cell( liveNeighbors > 3, cellState == CellState.LIVE,
                   phase == Phase.EVALUATE )
then
    modify( theCell ){
        setPhase( Phase.KILL );
    }
end

rule "Give Birth"
    ruleflow-group "evaluate"
    no-loop
when
#   A dead cell has 3 live neighbors
    theCell: Cell( liveNeighbors == 3, cellState == CellState.DEAD,
                   phase == Phase.EVALUATE )
then
    modify( theCell ){
```

```
        theCell.setPhase( Phase.BIRTH );
    }
end
```

Once all `Cell` objects in the grid have been evaluated, we first clear any calculation activations that occured from any previous data changes. This is done via the "reset calculate" rule, which clears any activations in the "calculate" group. We then enter a split in the rule flow which allows any activations in both the "kill" and the "birth" group to fire. These rules are responsible for applying the state change.

Example 9.75. Conway's Game of Life: Apply the state changes

```
rule "reset calculate"
    ruleflow-group "reset calculate"
when
then
    WorkingMemory wm = drools.getWorkingMemory();
    wm.clearRuleFlowGroup( "calculate" );
end

rule "kill"
    ruleflow-group "kill"
    no-loop
when
    theCell: Cell( phase == Phase.KILL )
then
    modify( theCell ){
        setCellState( CellState.DEAD ),
        setPhase( Phase.DONE );
    }
end

rule "birth"
    ruleflow-group "birth"
    no-loop
when
    theCell: Cell( phase == Phase.BIRTH )
then
    modify( theCell ){
        setCellState( CellState.LIVE ),
        setPhase( Phase.DONE );
    }
end
```

At this stage, a number of `Cell` objects have been modified with the state changed to either `LIVE` or `DEAD`. Now we get to see the power of the `Neighbor` facts defining the cell relations. When

a cell becomes live or dead, we use the `Neighbor` relation to iterate over all surrounding cells, increasing or decreasing the `liveNeighbor` count. Any cell that has its count changed is also set to to the `EVALUATE` phase, to make sure it is included in the reasoning during the evaluation stage of the Rule Flow Process. Notice that we don't have to do any iteration ourselves; simply by applying the relations in the rules we make the rule engine do all the hard work for us, with a minimal amount of code. Once the live count has been determined and set for all cells, the Rule Flow Process comes to and end. If the user has initially clicked the "Start" button, the engine will restart the rule flow; otherwise the user may request another generation.

Example 9.76. Conway's Game of Life: Evaluate cells with state changes

```
rule "Calculate Live"
    ruleflow-group "calculate"
    lock-on-active
when
    theCell: Cell( cellState == CellState.LIVE )
    Neighbor( cell == theCell, $neighbor : neighbor )
then
    modify( $neighbor ){
        setLiveNeighbors( $neighbor.getLiveNeighbors() + 1 ),
        setPhase( Phase.EVALUATE );
    }
end

rule "Calculate Dead"
    ruleflow-group "calculate"
    lock-on-active
when
    theCell: Cell( cellState == CellState.DEAD )
    Neighbor( cell == theCell, $neighbor : neighbor )
then
    modify( $neighbor ){
        setLiveNeighbors( $neighbor.getLiveNeighbors() - 1 ),
        setPhase( Phase.EVALUATE );
    }
end
```

Index

B

BeanShell, 6

C

Collection, 140, 140

D

Domain Specific Languages, 183
DSL, 183

I

Inference Engine, 2

L

Leaps, 2
Logical Object, 35

P

Pattern Matching, 2
Predicate, 143
Production Memory, 2

R

regular expression, 139
Rete, 2, 2

W

WorkingMemory, 2

X

XML, 192
XML Rule, 193