GReAT User Manual

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1. Introduction

The GReAT tool suite has been designed for the rapid specification and implementation of model to model transformations. These transformations are required in many domains. A few use case scenarios of this tools suite are:

- Developing model interpreters that convert gme models (conforming to a metamodel) to XML files conforming to a given dtd/xsd.
- Developing model interpreters that convert gme models (conforming to a metamodel) to a set of secondary data structures. A visitor can then be written to convert the secondary models to text.
- Developing model interpreters that convert gme models (conforming to a metamodel) to gme models conforming to another metamodel.
- Developing transformers that convert xml files belonging to one dtd to xml files belonging to another dtd.
- Developing transformers that convert xml files belonging to a given dtd to gme models.

1.1. Installation Instructions

Download the latest GReAT install shield package, change log and readme from http://www.isis.vanderbilt.edu/projects/mobies/filedownloads.asp. The readme will have the updated list of required software and install instruction.

2. Package Contents

- Languages

1.	UML Model Transformer	The Graph Transformation Language
2.	MetaGME	A UDM compatible MetaGME
3.	UML	A UDM compatible UML
4.	GReAT Config	A paradigm to store configuration information (not directly used by the user)

- UML Model Transformer (UMT) Interpreters

GReAT Master Interpreter	It receives information of all the file locations and calls GenerateConfig, GenerateGR and Uml2XML. It can optionally call the Invoke Engine and Code Generator interpreter
Generate GR	Converts rewriting rules to internal format
Generate Config	Converts configuration information to GReAT Config
UML2XML	Converts the Meta information to UDM
Invoke Engine	Executes engine that performs transformations
Code Generator	Converts transformation rules to C++ code.
Library Update	Updates references from one class diagram package to another

- MetaGME interpreters

MetaGME2UML	Converts GME metamodels to a UDM compatible UML Class diagram.
MetaGME2UMT	Converts GME metamodels to a UML package and attaches it to the provided UMT file.

- UML interpreters

UML2XML	Converts UML class diagrams to UDM meta XML file

- Command Line Tools

1.	CG.exe	Command line version of the code generator
2.	GRE.exe	Command line version of the transformation engine
3.	GRD.exe	Debugging GUI for the transformations

3. Step by Step guide to using GReAT

The GReAT package can be used in various scenarios. This section will give a walk through of two typical scenarios.

3.1. Transforming models from one GME paradigm to another

This is a scenario where there exists two GME metamodels, source and target and the user wants to create a transformation to transform source models to equivalent target models.

1. Open the source metamodel and invoke the MetaGME2UMT interpreter. The interpreter prompts the user to provide the transformation file name. This can either be a pre-existing or a new transformation file. This transformation file will be referred to as <TF> subsequently. Then Run the MetaGME interpreter () on the source metamodel.
2. Open the target GME Metamodel and invoke the MetaGME2UMT interpreter () and specify the same <TF> file. Run the MetaGME interpreter on the target metamodel.
3. Open the transformation file <TF> in GME. Using the Browser, you will see your source and target GME Metamodels inserted under two packages in UML format. The name of these package folders (a.k.a. libraries) will have the following format:

   New<Paradigm Name><Unique ID>

   Decoration of paradigm names is important for the library update interpreter, i.e. the library updater can differentiate between the new and old paradigms using these names. The update process is described in step 6, here it is assumed, that you inserted the Metamodels the first time.

   Please remove the new and the ID part from the name. It is imperative that the name of the folder be the same as the paradigm name.
4. You can now start to create your transformation rules. Use the Browser to insert a Transformation folder and insert a Block model into that folder for the start rule. The start rule can contain any number of input and output ports. These ports represent the various inputs and outputs of the actual rule, or more precisely, the objects in the input and output models, which are received and passed by the rule. There should be at least one port per model file. For example, in this case there will be at least two ports, one for the root object in the input (or source) model and another for the root object in the output (or target) model, however it is not compulsory to pass root objects, you can specify any object.

   Note: *These top level ports need to be named uniquely for proper execution of the transformations. You should check all constraints on the transformation model before running the GReAT Master Interpreter.*

   Now you typically continue with creating subsequent blocks, test, rules, etc. in the root rule. The transformation steps can be specified in the rules; blocks, for-blocks, tests and cases control the sequence of the transformation steps by specifying hierarchical and conditional organization of the rules. (For more background information, please refer to the GReAT User Manual, Chapter 3. Semantics of the Transformation Language)

Addition of a rule into a block consists of three steps:

- Specify the pattern by creating a reference to those Metamodel classes which you want to participate in the pattern. Then create the pattern links between the pattern objects. Patterns are displayed in black.
- Specify a set of objects and links you want to create or delete, similarly. Then set the Action attribute to “CreateNew” or “Delete” of each object and link in the set. Optionally, specify Guard or AttributeMapping code for more sophisticated operation. Objects and links with action “CreateNew” are colored blue, with action “Delete” colored green automatically for visual separation from pattern objects and links.
- Specify the connection of the rule with its consisting block, first by creating ports in the rule, then by connecting these ports with the ports of the parent block. These directed connections represent clearly the flow of inputs and outputs between the rules.
- The minimal proper transformation consists of the root block containing one rule created as above. Later, as your transformation evolves, you want to add more rules, connect and organize them hierarchically.

5. After creating the transformations you need to create a configuration. This specifies how the transformations will be invoked by the various GR transformation tools (GR Engine, Debugger and the Code Generator). Minimal configuration requires the specification of
   - the start rule which will be invoked first,
   - the meta info; this configuration element is specified automatically by running the “Convert transformation rules to GR format” and the “UML 2 UDM/XML” interpreters, and
   - the input and output file types, which define the meta name, root folder and file mode of the participating files.

   Finally, the created configuration must be interpreted by the “GReAT Master Interpreter” interpreter. Please refer to Chapter 9.
6. If you update your Metamodel, you need to reflect those changes in your transformation.
   - Run the MetaGME2UMT interpreter again. This will create another package in <TF> with the name *New<Paradigm Name><Unique ID>*.
   - Run Library Update ( ) and specify the old library as <*ParadigmName*> and the new library as *New<Paradigm Name><Unique ID>*. The Library Update utility will transfer all references to the old library/package to the new library/package and change the old package name from <*ParadigmName*> to *Old<Paradigm Name><Unique ID>* and change new package name to <*ParadigmName*>
   - Delete *Old<Paradigm Name><Unique ID>* from <TF>
7. Different parts of the transformation model are converted into different internal file representations.

    - Transformation information in converted to GR format
    - UML Packages and cross links are converted to UDM meta format
    - Configuration is converted to GReATConfig format.

    The GReAT Master interpreter is used to convert the models to the required formats.
8. After all the files have been generated the transformation can be executed either through the GRE, InvokeEngine, GRD or through generating code from the transformations and compiling it.

3.2. Transforming GME models to text

This is a scenario where the user has a GME metamodel and wants to generate text in a particular format from the models of the metamodel.

The approach to solve this problem is to create a data structure that is close to the output text format. DOM is an example of such a data structure for the XML format. Then specify the transformations from the GME models to the data structure and specify the printing of the data structures to text.

1. Open the metamodel and invoke the MetaGME2UMT interpreter. The interpreter prompts the user to provide the transformation file name. This can either be a pre-existing or a new transformation file. This transformation file will be referred to as <TF> subsequently. Then Run the MetaGME interpreter () on the metamodel.
2. Open a new project in the UML paradigm of GME and specify the text data structure.
3. Open the transformation file <TF> in GME. You will see your GME Metamodel as a package in UML format. The name of this package folder (a.k.a. libraries) will have the following format:

   New<Paradigm Name><Unique ID>

   This decoration of paradigm names are important for the library update interpreter, i.e. the library updater can differentiate between the new and old paradigms using these names. The update process is described in step 6, here it is assumed, that you inserted the Metamodels the first time.
   Please remove the new and the ID part from the name. It is imperative that the name of the folder be the same as the paradigm name.
4. Attach the text data structure file as a library in the <TF> file.
5. You can now start to create your transformation rules. Use the Browser to insert a Transformation folder and insert a Block model into that folder for the start rule. The start rule can contain any number of input and output ports. These ports represent the various inputs and outputs of the actual rule, or more precisely, the objects in the input and output models, which are received and passed by the rule. There should be at least one port per model that will be manipulated. For example, in this case there will be at least two ports, one for the root object in the input (or source) model and another for the root object in the output (or target) model, however it is not compulsory to pass root objects, you can specify any type of objects.

Note: *These top level ports need to be named uniquely for proper execution of the transformations.*

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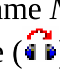
   - the input and output file types, which define the meta name, root folder and file mode of the participating files.

   Finally, the created configuration must be interpreted by the “Generate Configuration file” interpreter. Please refer to Chapter 9
7. If you update your Metamodel, you need to reflect those changes in your transformation.
   - Run the MetaGME2UMT interpreter again. This will create another package in <TF> with the name *New<Paradigm Name><Unique ID>*.
   - Run Library Update () and specify the old library as <*ParadigmName*> and the new library as *New<Paradigm Name><Unique ID>*. The Library Update utility will transfer all references to the old library/package to the new

library/package and change the old package name from <*ParadigmName*> to *Old<Paradigm Name><Unique ID>* and change new package name to <*ParadigmName*>
   - Delete *Old<Paradigm Name><Unique ID>* from <TF>
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   - Transformation information in converted to GR format
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   - Configuration is converted to GReATConfig format.

   The GReAT Master interpreter is used to convert the models to the required formats.
9. After all the files have been generated the transformation can be executed either through the GRE, InvokeEngine, GRD or through generating code from the transformations and compiling it.
10. To generate data in a particular text format you extend the base visitor and implement a text dump.

4. The Tool Chain Overview

This section describes the different interpreter, their use and their dependencies.

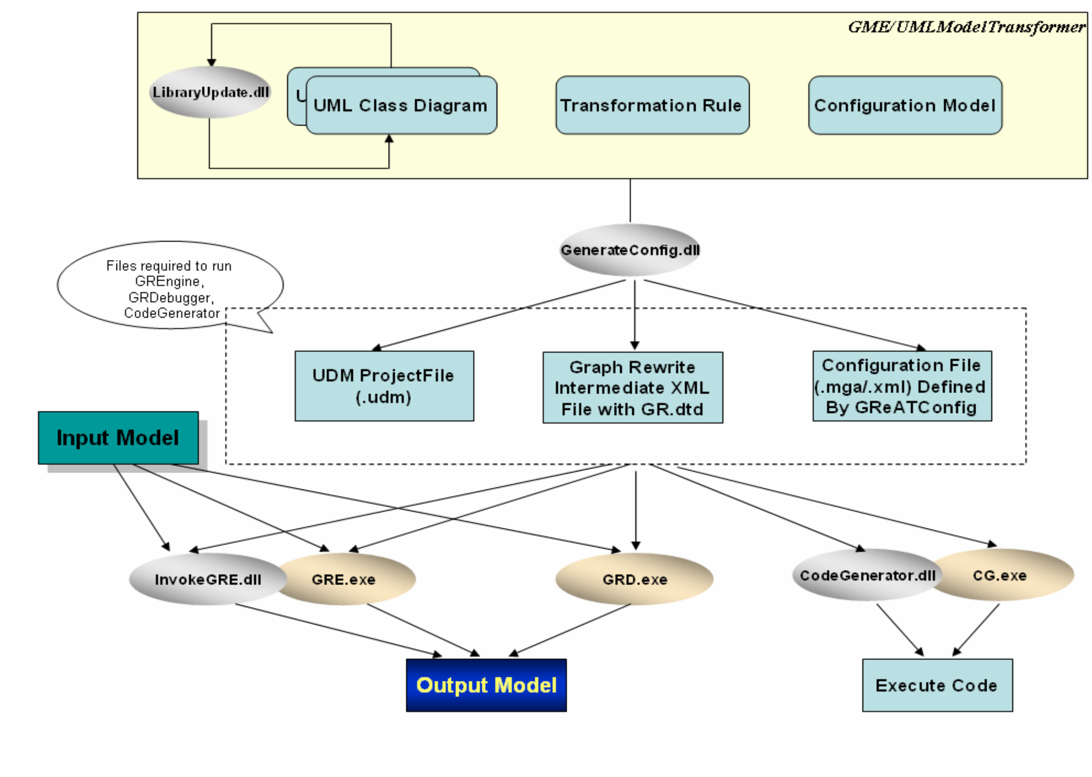


Figure 1 GReAT Tool Chain Overview

Interactions and steps between the tools are described as following:

Build Transformation model:

- Attach all UML class diagrams using either MetaGME2UMT or by attaching UML class diagrams as libraries. When you reattach a class diagram you can update the references using the LibraryUpdate interpreter (LibraryUpdate.dll);
- Build the transformation rules;
- Build configuration model, please refer to Section 9. GReAT Configuration.

Run Transformation model:

Phase I:

- Invoke GReAT Master interpreter interpreter (GReAT Master Interpreter.dll) to generate all the required files.

Phase II:

To successfully run Phase II and Phase III, Phase I should have been successfully executed.

- Run GR Engine to perform the transformation rules on input model. This package provides two usages of GR Engine, one is used as interpreter (InvokeGRE.dll), while it can also be used as Win32 application (GRE.exe). Please refer to Section 6. GR Engine.

- Run GR Debugger (GRD.exe) to locate bugs in a transformation rules. Please refer to 8. GR Debugger .

Phase III:

- Run Code Generator to generate C++ code from the transformation rules. This package provides two usages of Code Generator, one is used as interpreter (CodeGenerator.dll), while it can also be used as Win32 application (CG.exe). Please refer to Section 7. Code Generator.

4.1. The GReAT Master Interpreter

This is the main interpreter and it can call all other interpreters. When invoked, first a dialog box is displayed that asks for the file path and name for all the intermediate files (see Figure 2)

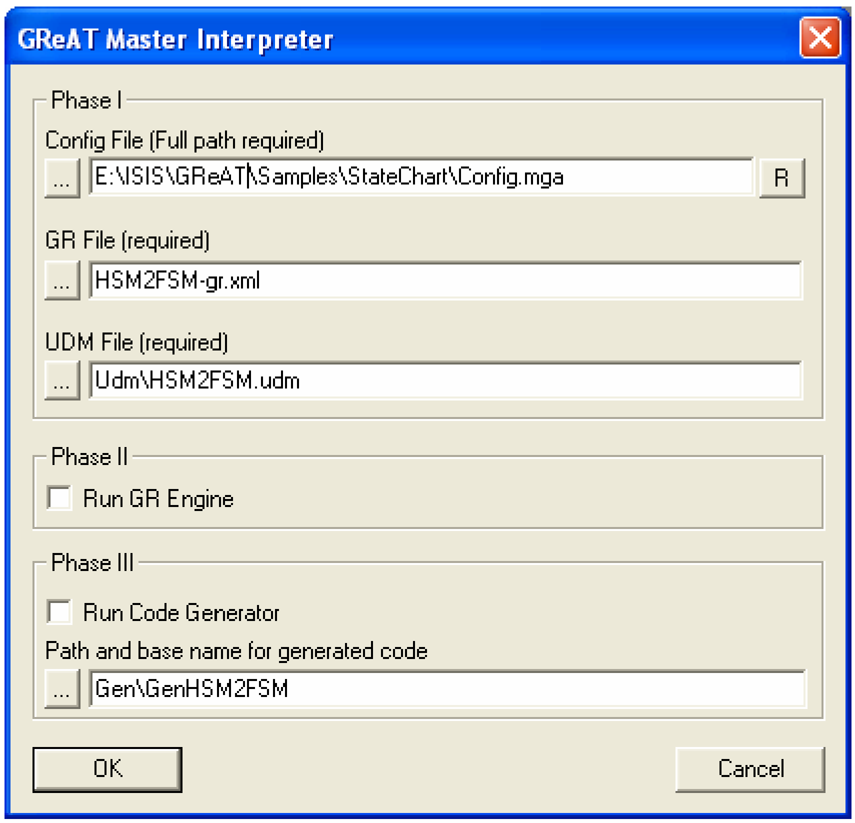


Figure 2 Sample of the GReAT Master Interpreter dialog box.

The first phase of the interpretation is the generation of the different files required by the GR Engine, GR Debugger and the Code Generator. These files are the configuration file, transformation file and the udm meta file. These files are produced from the distinct parts of the UMLModelTransformer language. Phase II, is optional and after the files are created the master interpreter can invoke the GR Engine. Phase III is also optional and can be used to invoke the Code generator.

4.2. The UML2XML Interpreter

 This interpreter works on both the UML paradigm in GME and the UmlModelTransformer paradigm. It converts the uml class diagram into and xml representation that is used by UDM.

If you have more that one uml package in you project it will create a file with .udm extension. The .udm file is essentially a zip fille that contains xml files for each package. For more information on this interpreter you can see the UDM documentation.

4.3. The GenerateGR Interpreter

This interpreter converts the transformation rules to the GR (Graph Rewrite) format. This format is used to decouple the high level language from the implementation of the transformation.

4.4. The GenerateConfig Interpreter

The Generate configuration Interpreter converts the configuration information into the GReAT config format. This is done to again decouple the configuration information form the UMT language. Details on this interpreter are provided in Section 9.

4.5. The Invoke GR Engine Interpreter

 This interpreter invokes the GR Engine that performs the transformations on given input and is explained in details in Section 6.2

4.6. The Code Generator Interpreter

 This interpreter generates C++ code that implements the transformation rules and is explained in Section 6.

4.7. The Library Update Utility

 The Library update utility is used to transfer references from one UML package to another. In UMT UML class diagrams are added as packages. If a packages change than you can add the new packages nd migrate all the references fro the old package to the new package. When invoked the interpreter asks for the name of the old and new library/uml package.

5. Semantics of the Transformation Language

The Transformation language called Universal Model Transformer (UMT) is described in this section. The theory and research issues of the language can be found in the technical document.

The language has a set of basic concepts. In Figure 3 we see the expression hierarchy of UMT. An expression is the base class for all rule definitions. Expressions are specialized to be, primitive rules, compound rules and tests. Primitive rules are elementary computational unit that specify a transformation. Primitives are realized by **Rule** and **Case.** **Test** is used to specify conditional execution of transformation. It is similar to a switch case statement in C, C++. A **Test** contains **Cases** and based on the success/failure of the cases different execution paths are chosen. Compound rules are used to modularize transformation sequences, control transversal schemes and to mitigate complexity. Compound rules are specialized to **Block** and **ForBlock**. Both Block and ForBlock can contain other compound rules, **Rules** and **Tests.** An expression can be considered as a function definition as well as the use of the function. In order to use a function in another context we use **ExpressionRef. ExpressionRef** is a call to a function previously defined. It can be used to define recursive structures as well as for the reuse of rules.

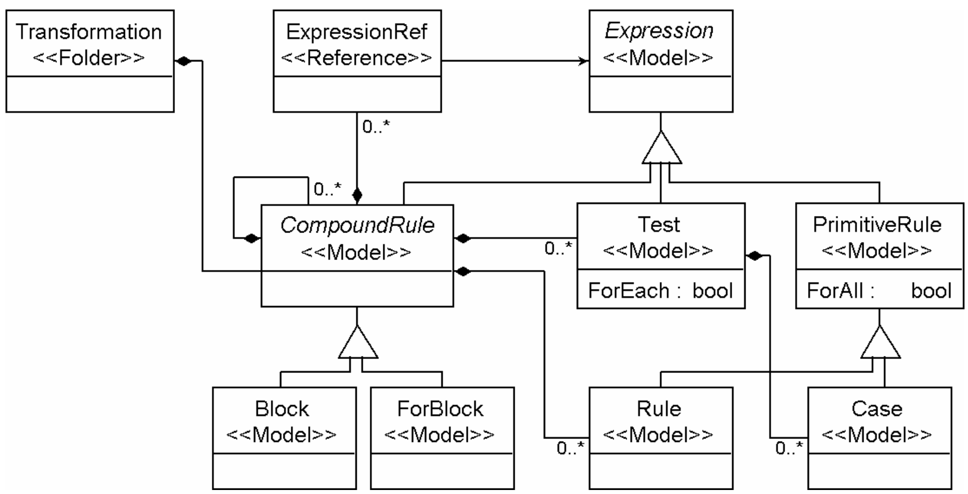


Figure 3 Expression Hierarchy of UMT

Before explaining the rules the concept of heterogeneous transformations needs to be introduced.

5.1. <u>Heterogeneous Graph Transformations</u>

UML classdiagrams are used in GreAT to capture the meta informaiton. As specified earlier GME metamodels can be converted to UML and attached with a transformaiton using the UML2XML interpreter. Alternatively a UML class diagram can either be directly create in the transformation paradigm, copied from another UML paradigm or attached as a library. These metamodels descrbe the input and output models.

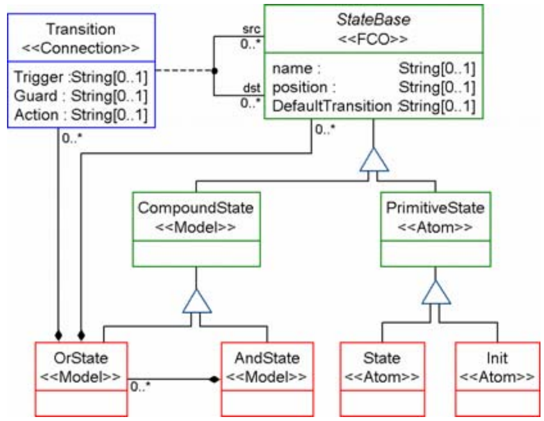


Figure 4 Metamodel of Hierarchical Concurrent State machine using UML class diagrams

Figure 5 shows a UML class diagram that represents the domain of Hierarchical Concurrent State Machines (HCSM) and Figure 5 shows the metamodel of a Finite State Machine (FSM).

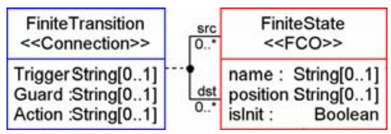


Figure 5 Metamodel of a simple finite state machine

There is problem: maintaining references between the different models/graphs. During the transformations it is usually required to maintain temporary information that may correspond to both paradigms. To illustrate the point let us consider a very simple transformation that needs to transform models conforming to one domain to another. For sake of simplicity we consider that the source domain has only one vertex type called V1 and one edge type called E1. The target domain has vertex type V2 and edge type E2. The transformation's aim is to create a vertex and edge in the target set for each vertex and edge in the source set.

A simple algorithm could first create a target vertex for each source vertex and then create the edges. To create a target edge e2 that corresponds to source edge e1 we need to find the vertices in the target that correspond to the source vertices e1 is incident upon. This information needs to be saved in the first phase of the transformation for use in the second phase, and can be considered as maintaining reference between two graphs. There are other examples where the referencing is not that easy, for example, in a transformation that determines the cross product of two sets of vertices to generate a new set of vertices. In this case each pair of source vertices should reference a single target vertex.

This problem is tackled in GReAT by using an additional domain to represent all the cross-domain links and temporary links. In GReAT users can create a *Package* for describing the cross-links. In the package the users can drag references to classes in other packages and create new association types. For example, Figure 6 shows a metamodel that defines associations/edges between HCSM and FSM. The *State* and *Transition* are classes from Figure 4 while the *FiniteState* and *FiniteTransition* are classes from Figure 5. This metamodel defines three types of edges. There is a *refersTo* edge type that can exist between *State* and *FiniteState* and between *Transition* and *FiniteTransition*. Another edge type *associatedWith* is defined and it can exist between *State* objects.

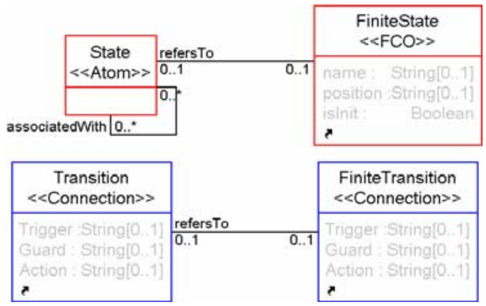


Figure 6 A metamodel that introduces cross-links

Cross-links can be defined not only between different domains but can also be used to extend a domain to provide some extra functionality required by the transformation. By using a different domain/package for cross-links we are able to specify a larger, heterogeneous domain that encompasses all the domains and cross-references.

During the transformation the users can create modify and delete instances of the cross-link types in the same manner as they deal with other vertex and edge types.

5.2. <u>Rule</u>

A rule in the transformation language is defined as a 9-tuple

R = (pattern, action, input interface, output interface, guard, attribute mapping, match condition)

Where,

Pattern	→	is a graph with pattern vertices and edges.
Action	→	is a mapping of pattern vertices and edges to {Bind, CreateNew, Delete} the set of actions
Input interface	→	is a set of distinct input ports that can receive graph objects from previous rules
Output interface	→	is a set of distinct output ports that will transfer graph objects of this rule to the next rule.
Guard	→	is an OCL expression that's evaluates on a match of the LHS pattern to return true or false. If this expression is true only then will the rule fire for that match otherwise the next match will be considered.
Attribute mapping	→	are arithmetic and string expressions that are evaluated for each valid match to generate the values of edge and vertex attributes.
Match	→	can be either "all matches" or "any match". If it is "all

condition matches” for each input packet the rule will find all the matches and for all the valid matches it will execute the effecter. If it is “any match” then for each packet the rule will find the first valid match and call the effecter for that match. The match chosen is non-deterministic.

Figure 7 shows an example rule. The rule contains a pattern graph, a Guard and an AttributeMapping. Each object in the pattern graph refers to a class in the heterogeneous metamodel. The semantic meaning of the reference is that the pattern object should match with a graph object that is an instance of the class represented by the metamodel entity. The default action of the pattern objects is *Bind*. The *New* action is denoted by a tick mark on the pattern vertex (see the vertex StateNew in figure). *Delete* is represented using a cross mark (not shown in figure). The *In* and *Out* icons in the figure are used for passing graph objects between rules and will be discussed in detail in the next section.

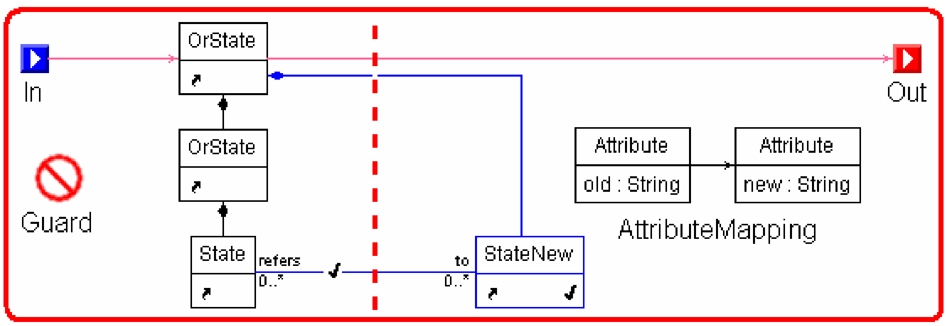


Figure 7 An example rule with patterns, guards and attribute mapping

GReAT relies on UML metamodels for defining patterns. Furthermore, the patterns are also specified in (a superset of the) UML syntax and since the modeler uses UML for metamodeling, as it was more intuitive to describe the rules also in UML. By making the user reference each pattern object we can enforce the consistency of the patterns and thus the consistency of the transformations.

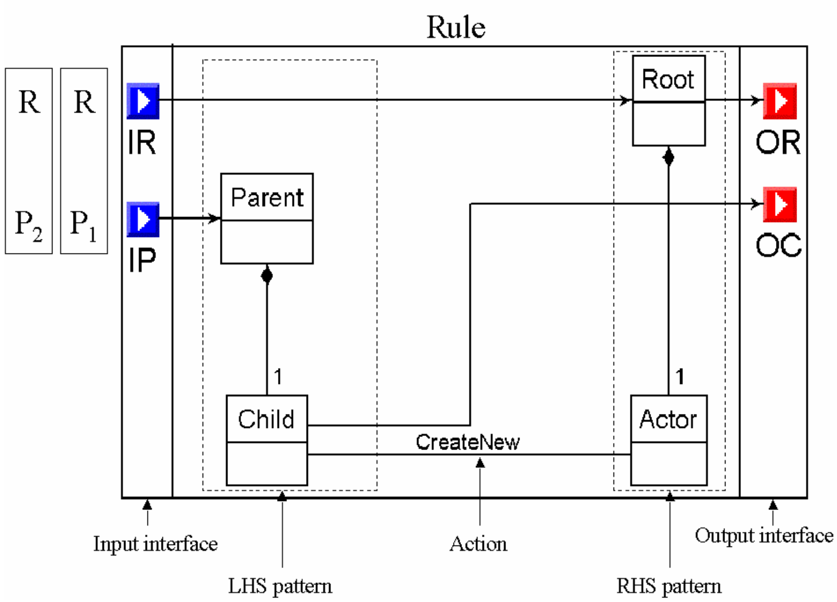


Figure 8 Start of a rule fire sequence with 2 input packets

Figure 8 till Figure 12 shows the execution of a rule. In Figure 8 we have two incoming packets to the rule. The execution of the rule will start with the first packet. The first packet will be used to produce matches for the pattern. Figure 9 shows the production of two matches from the first packet. Each match is tested wit the guard expression and only the matches that have the guard evaluate to true are kept. Then for each match new objects are created and matched objects deleted according to the rule specification. After the creation and deletion of the objects the attribute mapping is invoked that add and modifies values of attributes. The pattern objects connected to the output port are then used to create output packets base on the matched and/or created graph objects as shown in Figure 10. The same process is repeated with the second packet.

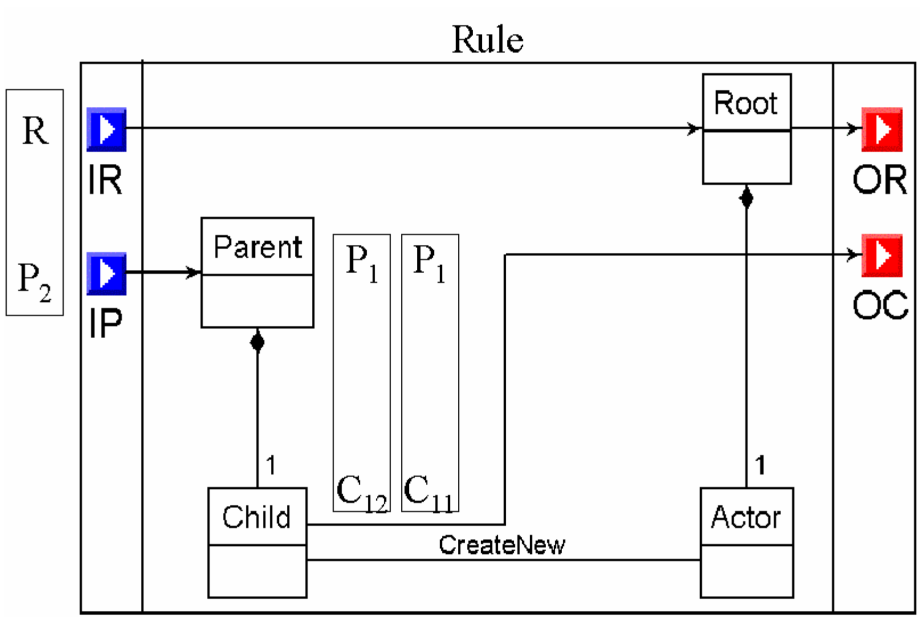


Figure 9 Rule has a set of matches for first input packet

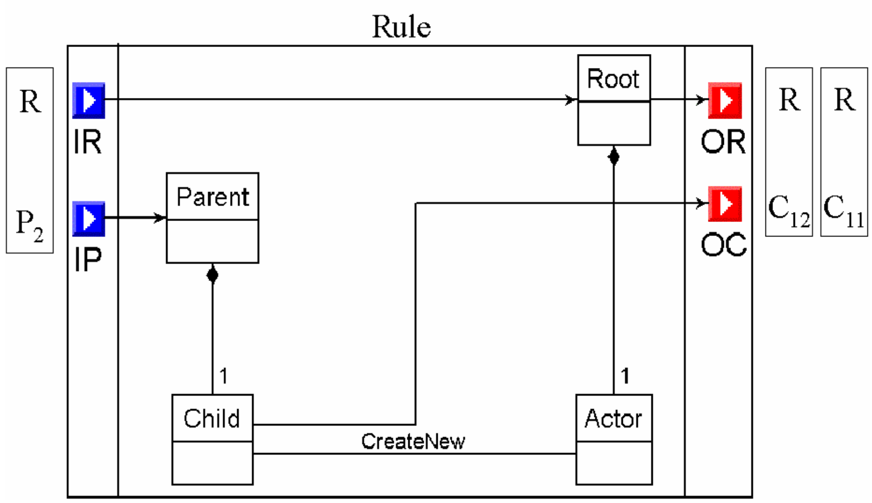


Figure 10 a set of output packets generated for each match

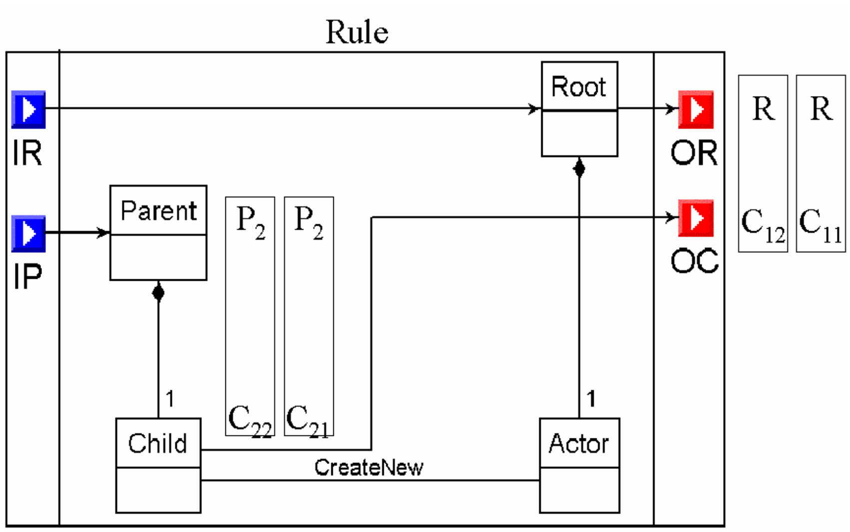


Figure 11 matches for the second input packet

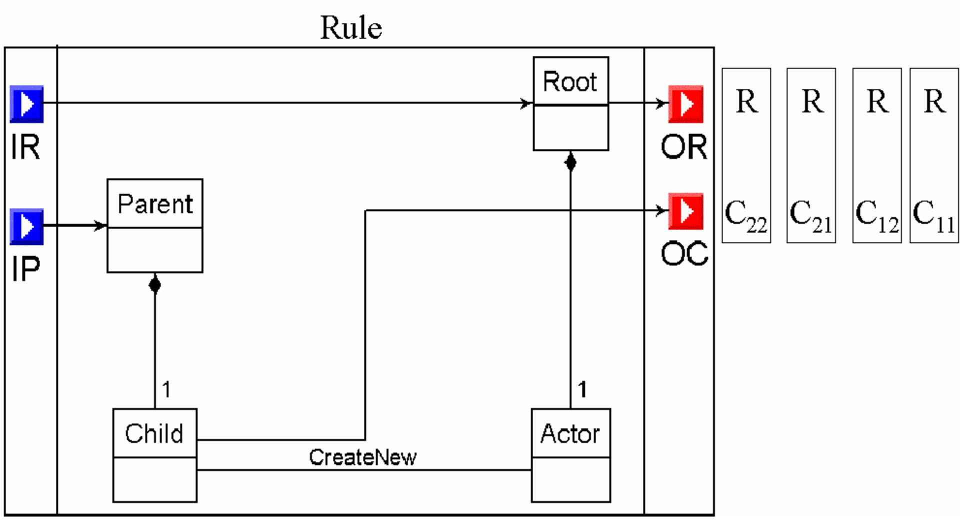
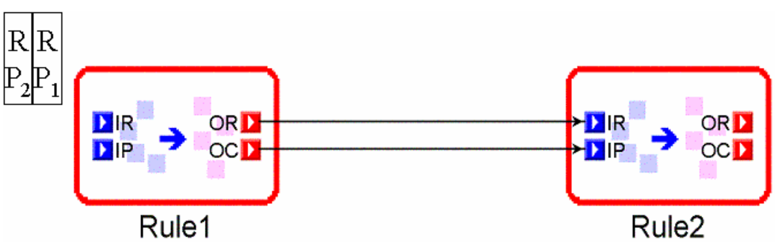


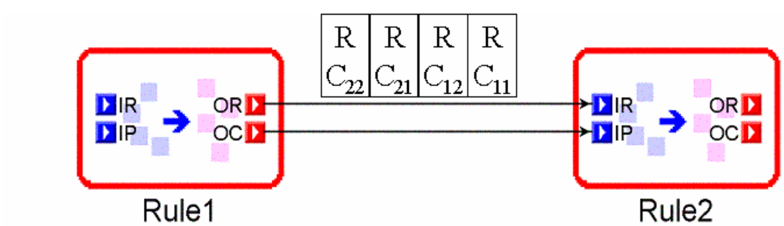
Figure 12 final state after the execution of the rule

5.3. <u>Sequence of Rules</u>

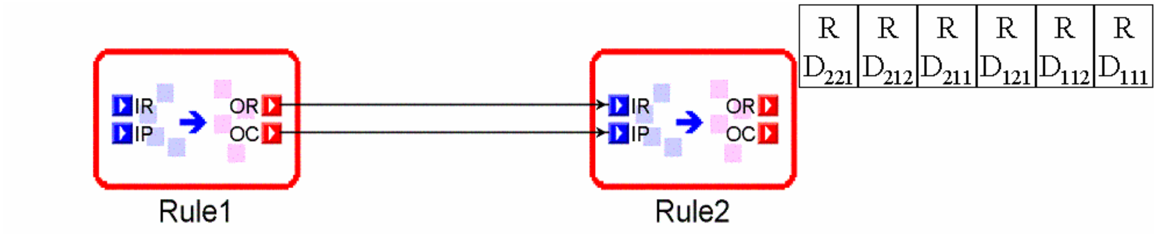
After having a clear idea of the execution of a single rule we can think about the execution of a series of rules. In the transformation language execution is mainly sequential. Thus if a rule is coupled to another rule they will execute sequentially. Thus, in Figure 13 rule 1 will fire first to consume all its tokens and produce a number of output tokens. Then rule 2 will fire to consume all its input tokens to produce a number of output tokens.



(a)



(b)



(c)

Figure 13 Firing of a sequence of 2 rules

5.4. <u>Hierarchical Rules</u>

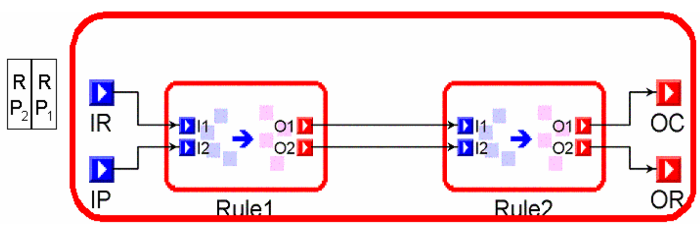
There are two types of hierarchical rules.

- Block
- For Block

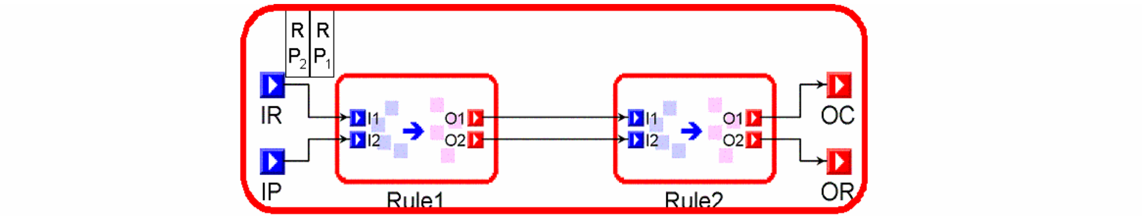
Both the hierarchical rules have the same semantics with respect to rules connected to and from it. Thus if in Figure 13 the rules 1 and 2 were hierarchical even then they would have has the same action as described there. The semantics within a hierarchical rule differs.

A block is a container that encapsulates a number of rules. The block has the semantics that it will push all its incoming packets through to the first internal rule. So it is very similar to the regular rule semantics.

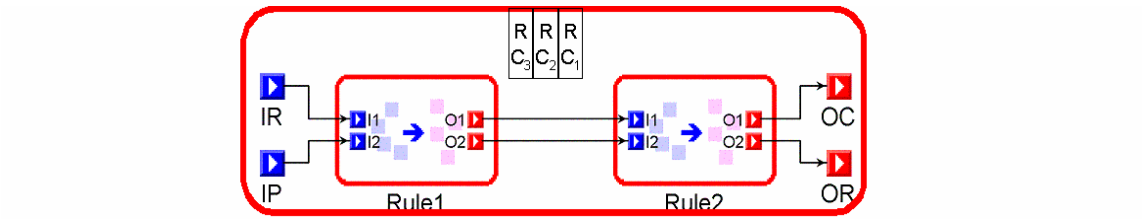
The output interface of the block can be attached to the output interface of any internal block or the input interface of the block. In other words the block can send output packets from any internal rule or pass its input packets as output. However, the output interface of a block must be attached to exactly one interface and it cannot be attached to two different interfaces. Figure 144 shown the execution of rules within a block.



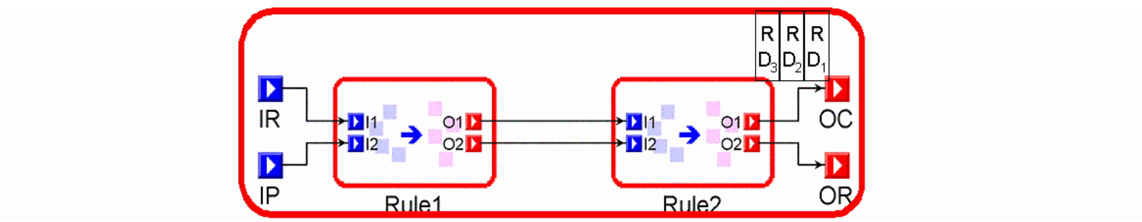
(a)



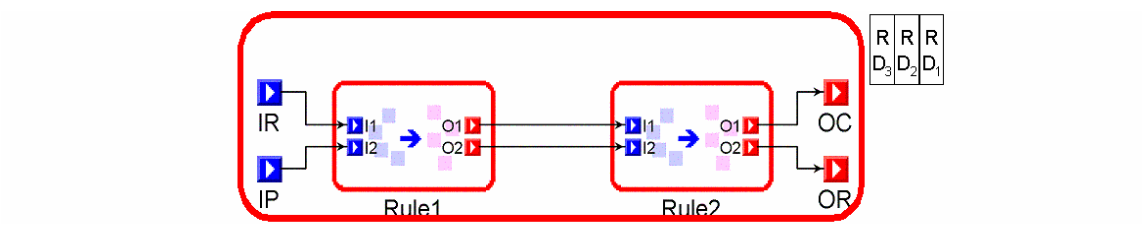
(b)



(c)



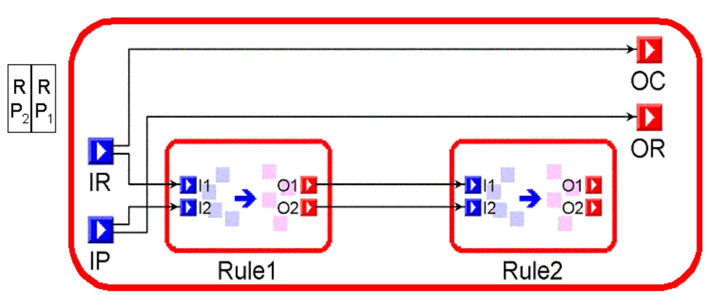
(d)



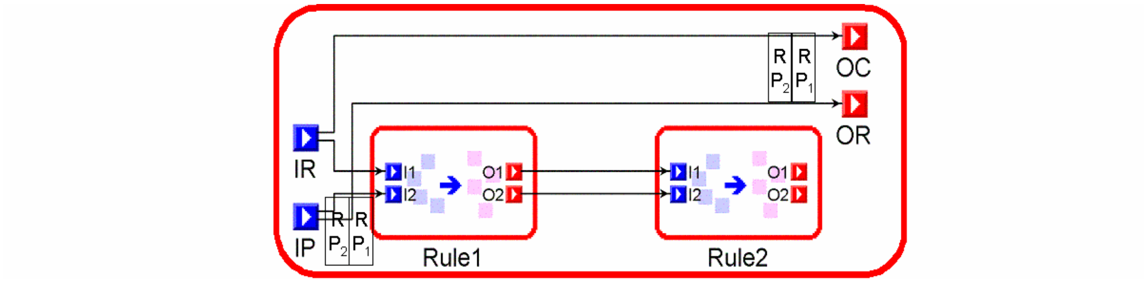
(e)

Figure 14 Rule execution of a Block

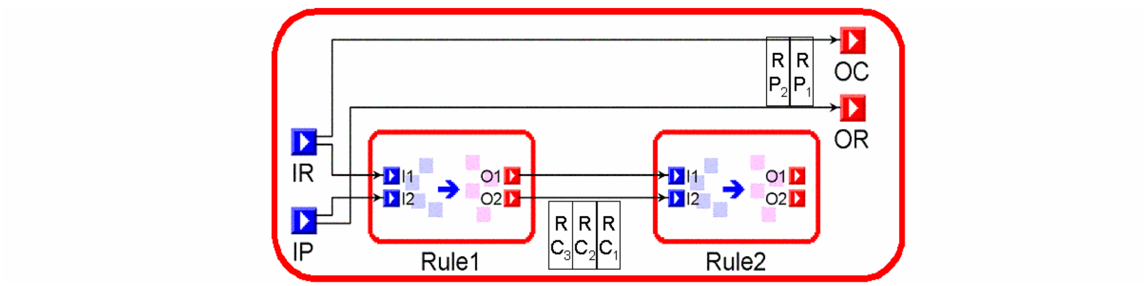
Figure 15 illustrates the case when the output interface of a block is connected to the input interface of the same block.



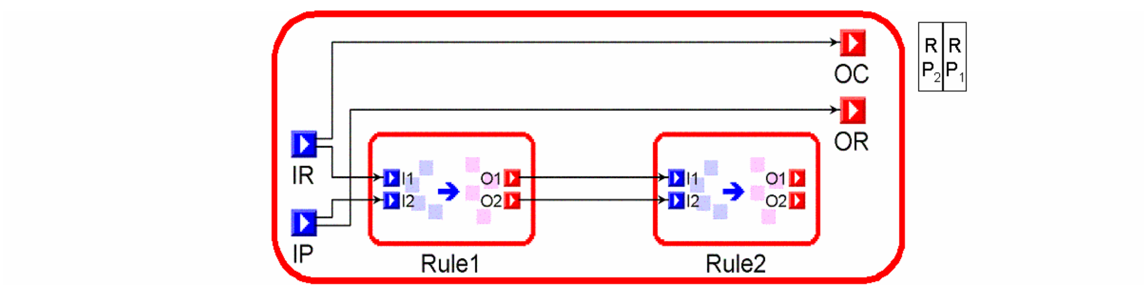
(a)



(b)



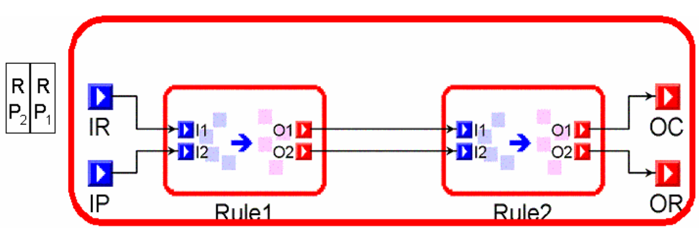
(c)



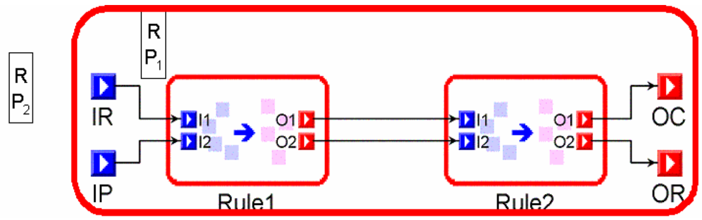
(d)

Figure 15 Sequence of execution within a block

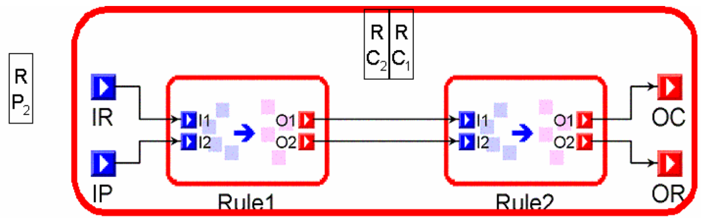
The “for block” has different semantics within. If we have n incoming packets in a “for block” then the first packet will be pushed through thru all its internal rules to produce output packets and then the next packet will be taken. The semantics are illustrated with the help of an example in Figure 16.



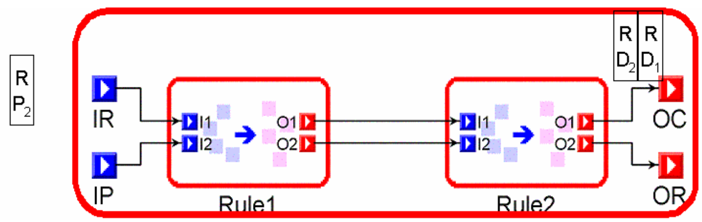
(a)


R P_2
R P_1
IR
IP
I1
I2
O1
O2
Rule1
Rule2
OC
OR

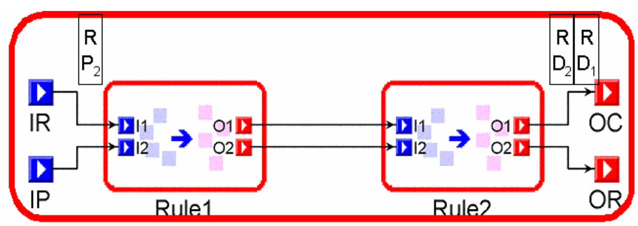
(b)


R P_2
R C_2
R C_1
IR
IP
I1
I2
O1
O2
Rule1
Rule2
OC
OR

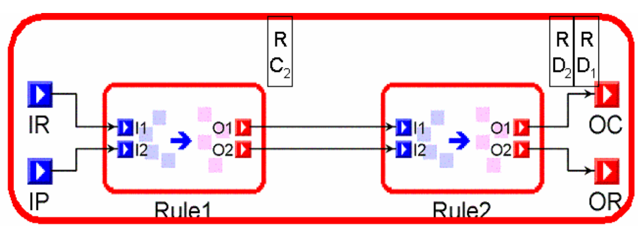
(c)


R P_2
R D_2
R D_1
IR
IP
I1
I2
O1
O2
Rule1
Rule2
OC
OR

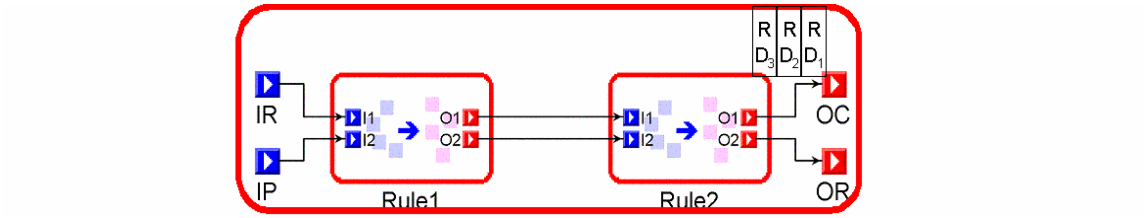
(d)


R P_2
R D_2
R D_1
IR
IP
I1
I2
O1
O2
Rule1
Rule2
OC
OR

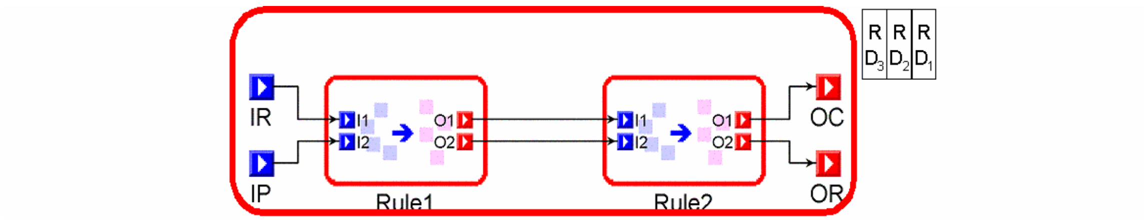
(e)


R C_2
R D_2
R D_1
IR
IP
I1
I2
O1
O2
Rule1
Rule2
OC
OR

(f)



(g)



(h)

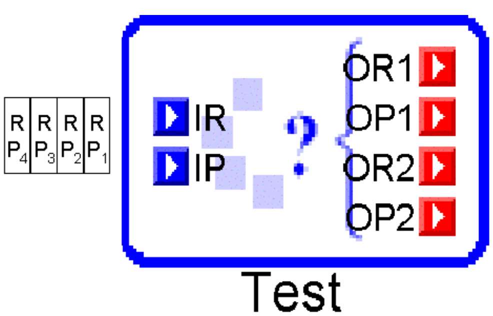
Figure 16 Rule execution sequence of a "for block"

Similar to the block the output interface of the “for block” can also be associated with the input interface of any internal rule or the input interface of itself.

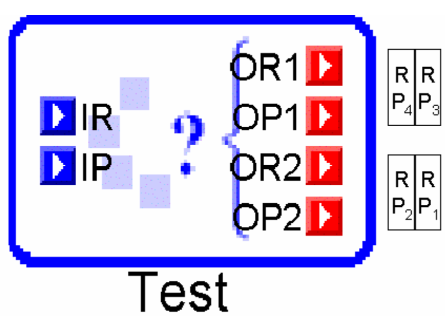
5.5. Branching using test case

There are many scenarios where the transformation to be applied is conditional and a branching construct is required. Thus the branching construct supported by us is a test case.

The external semantics of a test case is similar to any other rule. When fired or executed it consumes all its input packets to produce some output packets. In Figure 17 a test is shown that has two cases. The Test has one input interface and two output interfaces ({OR1, OP1} and {OR2, OP2}). When the test is fired each incoming packet is tested and placed in the corresponding output interface.



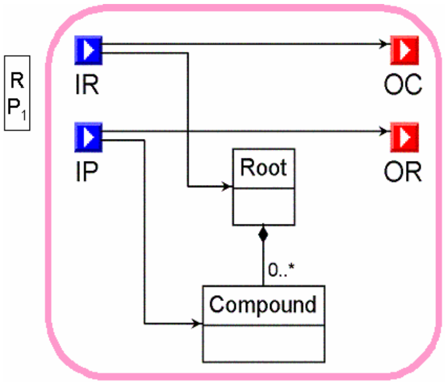
(a)



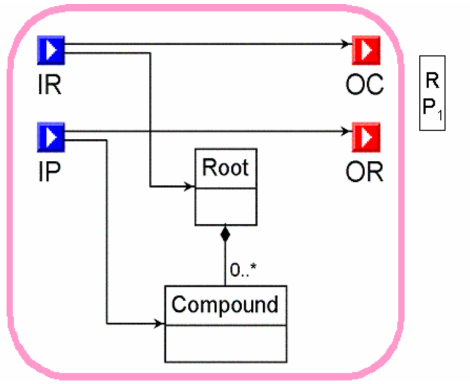
(b)

Figure 17 Execution of a test case construct

The test can have 1..* cases. Each case is a rule with no output pattern and no actions. It contains an LHS pattern a guard condition and an input and output interface. If the LHS pattern has a match the case succeeds and the input packet to the case is passed along. If the pattern has no matches then the test fails. Alternatively if the match doesn't satisfy the guard condition even then the case fails. Figure 18 shows a case with a successful execution. The input packet has a valid match and so the packet it allowed to go forward.



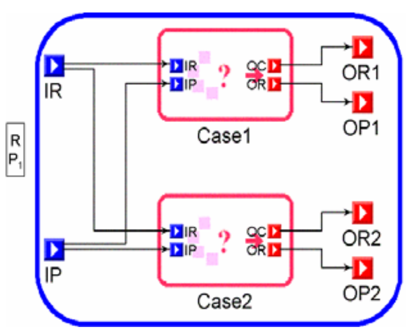
(a)



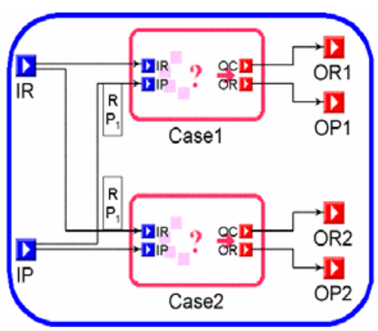
(b)

Figure 18 Execution of a case

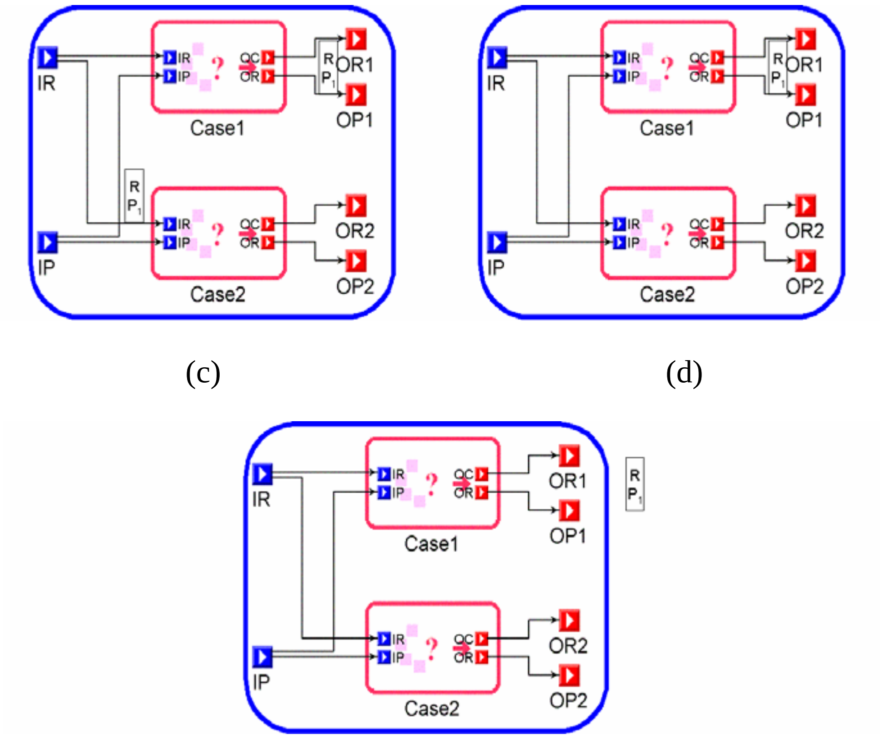
When a test has many cases then each input packet is checked with each case to see which cases are satisfied for the particular packet and the packet is placed in the output interface of each satisfied case. The order of testing cases is derived from the physical placement of the case within the test. The cases are evaluated from top to bottom. If there is a tie in the y co-ordinate then the x co-ordinate is used from left to right. There fore the comparison is made ascending order of y and if two y are same then in ascending order of x. The case also has another attribute called the cut. When enabled it means that if the case succeeds for a given packet then the packet should not be tested with the other cases.



(a)



(b)



(c) (d)

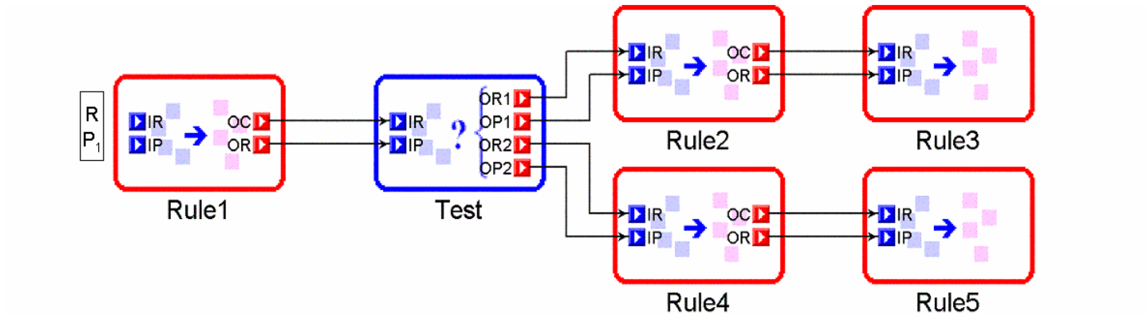
(e)

Figure 19 Execution of a test condition

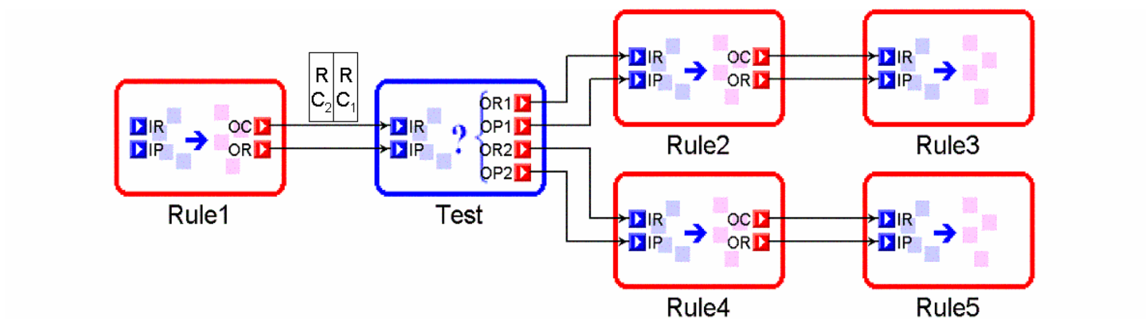
In Figure 19 the execution of a test is shown. An input packet is replicated for each case. Then the input packet is tried with the first case, it succeeds and is copied to the output of the case. Then the packet is tried with the second case, this time it fails and the packet is removed. Finally after all input packets have been consumed the output interfaces have the respective packets.

5.6. <u>Parallel Execution</u>

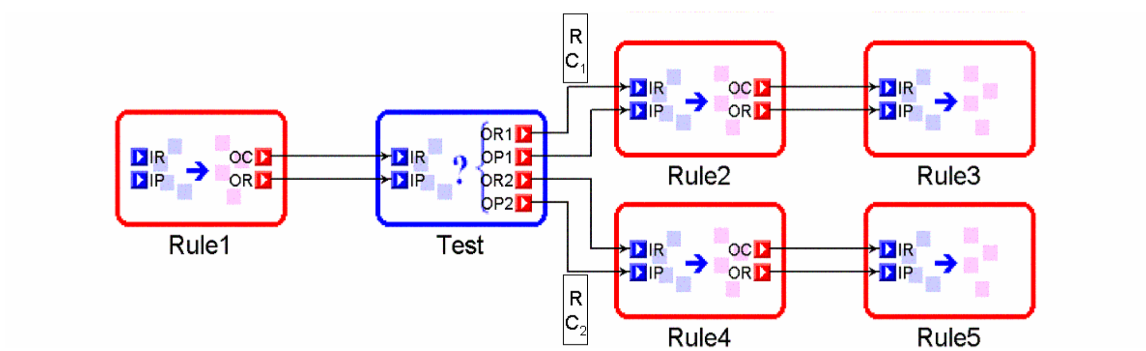
When a rule is connected to more than one rule or when there is a test condition with more than one path then it is called as the parallel execution. The parallel execution semantics is defined such that the different parallel paths can execute exclusive to each other and thus the order of execution of these paths are not defined. If executed on a sequential machine a particular path will be chosen and executed completely before the next path is chosen.


R
P1
IR
IP
OC
OR
Rule1
IR
IP
?
OR1
OP1
OR2
OP2
Test
IR
IP
OC
OR
Rule2
IR
IP
Rule3
IR
IP
OC
OR
Rule4
IR
IP
Rule5

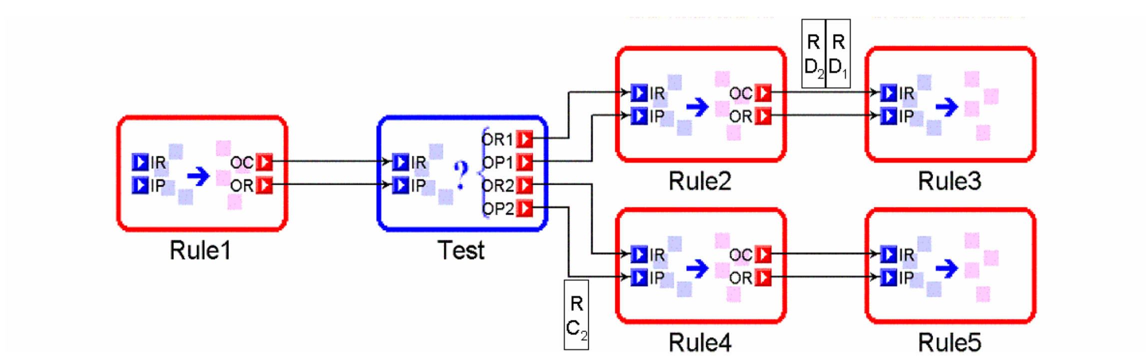
(a)


IR
IP
OC
OR
Rule1
R
C2
R
C1
IR
IP
?
OR1
OP1
OR2
OP2
Test
IR
IP
OC
OR
Rule2
IR
IP
Rule3
IR
IP
OC
OR
Rule4
IR
IP
Rule5

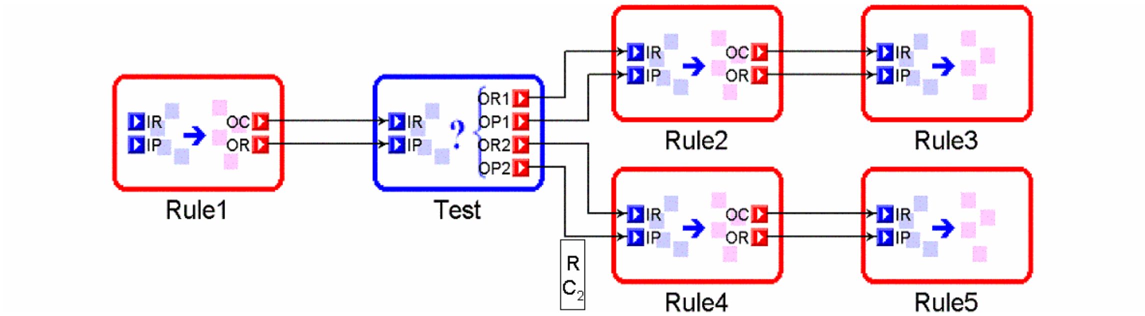
(b)


IR
IP
OC
OR
Rule1
IR
IP
?
OR1
OP1
OR2
OP2
Test
R
C1
IR
IP
OC
OR
Rule2
IR
IP
Rule3
R
C2
IR
IP
OC
OR
Rule4
IR
IP
Rule5

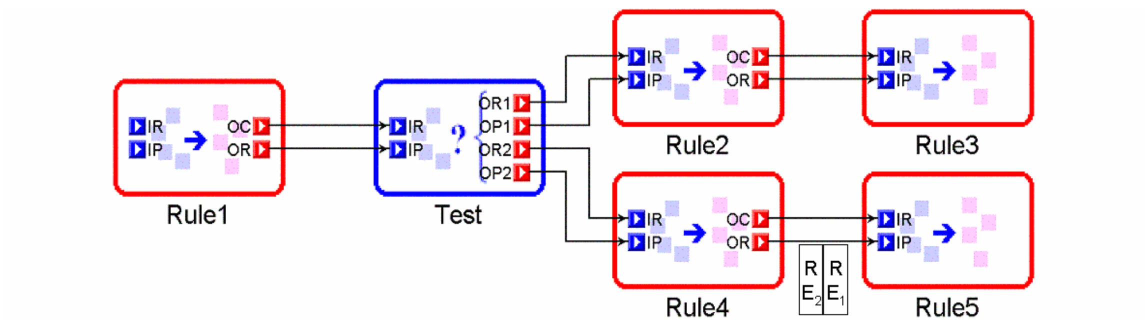
(c)


IR
IP
OC
OR
Rule1
IR
IP
?
OR1
OP1
OR2
OP2
Test
IR
IP
OC
OR
Rule2
R
D2
R
D1
IR
IP
Rule3
R
C2
IR
IP
OC
OR
Rule4
IR
IP
Rule5

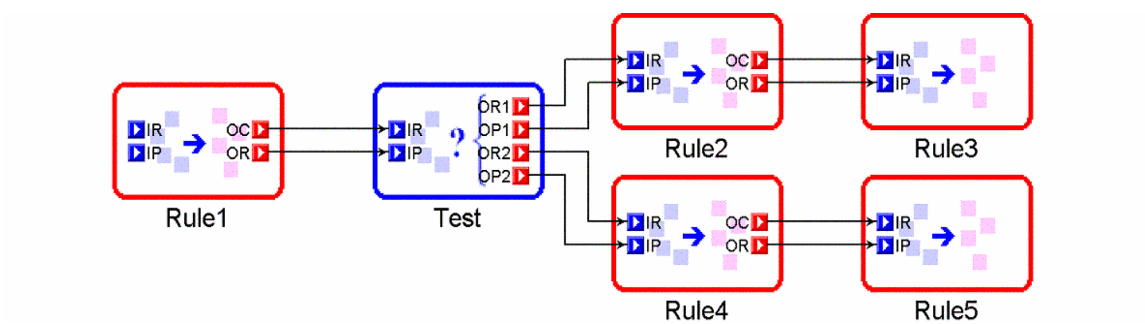
(d)



(e)



(f)



(g)

Figure 20 A parallel execution sequence

Figure 20 shows the execution sequence for parallel execution. Here the parallel execution is caused because of a test condition but it could also have been a rule connected to more than one other rule. After the branch there are packets at both the output interfaces of the test. Thus both rule 2 and rule 4 are ready to fire, in this case rule 2 is chosen and fired, followed by the execution of following rules. This ends at rule 3. Then rule 4 & 5 are fired.

5.7. Global Container

The control flow language of GReAT specifies an execution order of the elementary transformation steps. A transformation step always starts the pattern matching with an initial context. This context is passed along from rule to rule via ports during the transformation, similar to parameter passing in procedural languages. The main weakness of this approach is that the programmer needs to specify the context passing through several rules, even if the context is actually used only in one remote, non-adjacent, step.

To further simplify development, we have introduced the concept of the global container. The input(s) and the output(s) of the transformations reside in containers that hold objects and links of the input and output graphs. These containers are selected at the beginning of the transformation, and each production matches/deletes/creates objects within these implicit containers.

The general idea of the global container is that the objects it contains have global scope; that is, they are accessible throughout the whole transformation, and it is not necessary to pass them along in the context. Starting from these globally available objects, the programmer can have access to shared data variables and various portions of the host graph without having to obtain them from an input port.

GReAT containers are temporary, non-persistent objects that exist only during the transformation. It is the programmer’s job to define the “syntax” (i.e. the type-graph) of the container by drawing a UML class diagram, much like when defining the input and output domain(s) of the transformation. The programmer is free to specify as many global containers as he wants, as GReAT will manage the single instance of each container within the rules.

One can create an arbitrary type system for the global container, including defining new classes with attributes, associations, etc. with all the capabilities of a standard UML class diagram. The only globally accessible object per container is one instance of the root type. From this single global root object, other model objects can be reached via pattern matching, whose type in turn can be part of any type system defined in the transformation, such as the source or target domain. Data variables, like the ones in ordinary programming languages, can be modeled with UML class attributes in GReAT. Global data variables can be modeled as attributes of global class attributes.

Global containers are most useful in large transformations, when they can eliminate a large portion of context passing, or recurring complex pattern matching. One example is generating code from models, where components are used to model the functional decomposition of a system. Suppose that the transformation consists of several rules, and the leftmost and rightmost rules are as shown in Figure 21 Using global containers . Furthermore suppose that the model contains hundreds of components, and some of them were incorrectly named for code generation (e.g. their name begins with a number). We need to perform multiple operations on the set of these incorrectly named components in different transformation steps. The number of such components is negligible compared to the total number of components, so it makes sense to reuse the pattern matching results to cut down on the search time. However, it is also inconvenient to specify context passing over dozens of rules, especially when the context is used only in the last rule. To save the programmer from doing the excess work, we suggest using the global container feature.

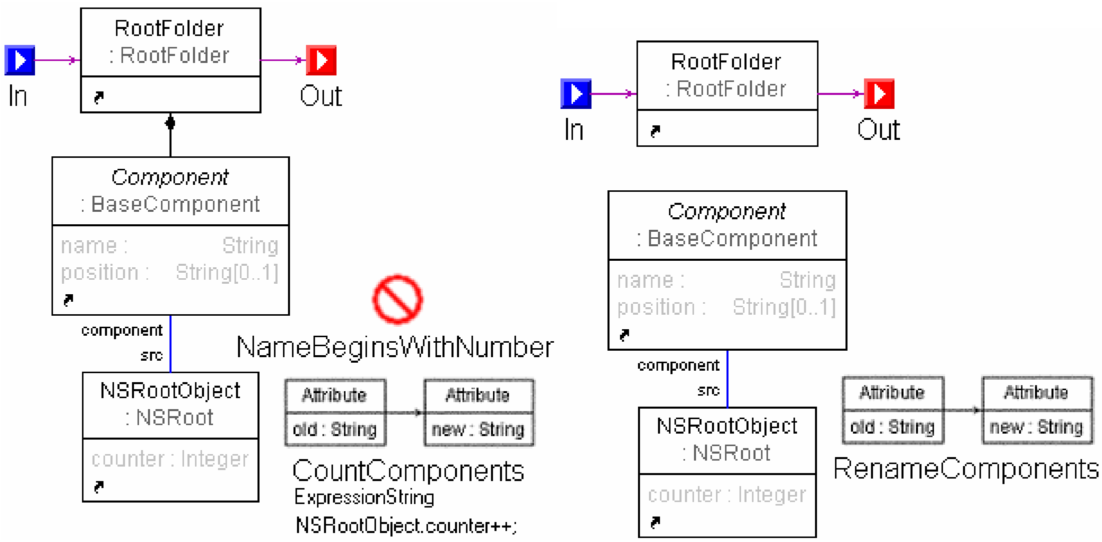


Figure 21 Using global containers

The left rule in Figure 21 Using global containers , (1) associates components that have invalid names with a global object “NSRootObject”, (2) counts them using the counter attribute of “NSRoot”. The right rule, which can be far away, in a distant part of the transformation program, renames these selected components to conform to the target language naming conventions. Notice that the pattern matching finds the components through the “NSRootObject-Component” association starting from “NSRootObject”, as there is no pattern containment relationship specified starting from “RootFolder”.

5.8. <u>Sorting</u>

The pattern matching in GReAT is deterministic in the sense that it returns the set of all the valid matches for a given pattern, and that set of matches will always be the same for a given pattern and host graph. Pattern matching is non-deterministic in the sense that the order of the elements (matches) in the set may vary between different executions. This kind of non-determinism is not acceptable in some model transformations, where certain elements need to be created in a fixed order. One example when deterministic order of matches is compulsory is interpreting hierarchical concurrent state machines, e.g. Matlab’s StateFlow. The operational semantics of StateFlow prescribes that parallel (AND) states evaluated and executed from left to right and top to bottom. In other words, every concurrent (AND-decomposed) compound state has multiple active sub states, and is responsible for executing all its children in this specific order during performing a state machine step.
Consider an example of a StateFlow to C code generator in GReAT. The code generator essentially produces a C function definition for each StateFlow state. For concurrent compound states, the generated C function is responsible for calling the functions representing the child states. For example, suppose that the concurrent state “Parent”

contains three parallel states from left to right and top to bottom: “ChildA”, “ChildB” and “ChildC”. Then the generated state execution function should look like:

```
void Parent_exec() {
        ChildA();
        ChildB();
        ChildC();
}
```

Note that the first “ChildA” is executed, then “ChildB” and last “ChildC”, and any other state evolution order does not conform to the StateFlow operational semantics. Consider that we have a metamodel that captures the abstract syntax of a stylized subset of C. Then, during the transformation steps we create model elements representing C code segments. The resulting model is then printed out into C text format in a post-processing step.

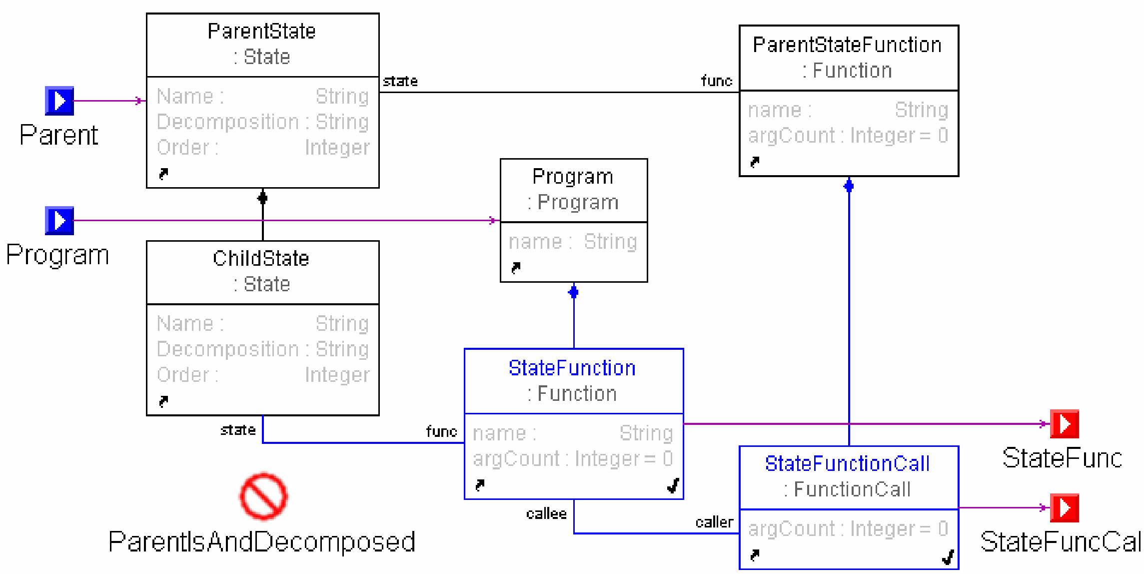


Figure 22 Create State execution functions

Figure 22 shows one solution for concurrent state code generation. The specified pattern finds all children of “ParentState”, and the associated state function definition for “ParentState” (through a cross link generated earlier in the transformation). Then those matches with sequential (non-concurrent) compound states are discarded by evaluating the guard condition. Finally, state execution function definitions and function callers referring to the functions definitions are created in the last step. The problem with this pattern specification is that the function callers are created in a random order, so nothing will enforce the correct execution order of the parallel states. In the case of the previous example, if the pattern matcher returns with the set: {(Parent, ChildB, Prg, ParFunc), (Parent, ChildA, Prg, ParFunc), (Parent, ChildC, Prg, ParFunc)}, then the generated code will look like:

```
void Parent_exec() {
        ChildB();
        ChildA();
        ChildC();
}
```

Clearly, we need to specify an ordering of parallel states, based on the “Order” attribute of the “ChildState”-s. In other words, we want to reorder the set of matches using some ordering criteria, e.g. sort the matches based on the “Order” attribute of “ChildState”-s. This sorting step should take place after pattern matching, or even after the effector, so that newly created objects can also be reordered. This entails that the sorted matches can be used only in subsequent transformation steps. The sorting step is the last operation executed before leaving the rule.

The GReAT programmer can specify sorting by setting the attribute “Compare function” of an output port in a rule. He first specifies the sorting criteria in the form of a C++ compare function in a common placeholder for reusable routines in the transformation. Then he can refer to this compare function by name throughout the transformation. In Figure 23 , the compare function “StateOrder” is used to order the parallel states. The compare function is a Standard C++ predicate taking two arguments, the two objects to compare. An example compare function is shown in Figure 24 . The programmer needs to specify only the function name and the body, the function signature is automatically generated.

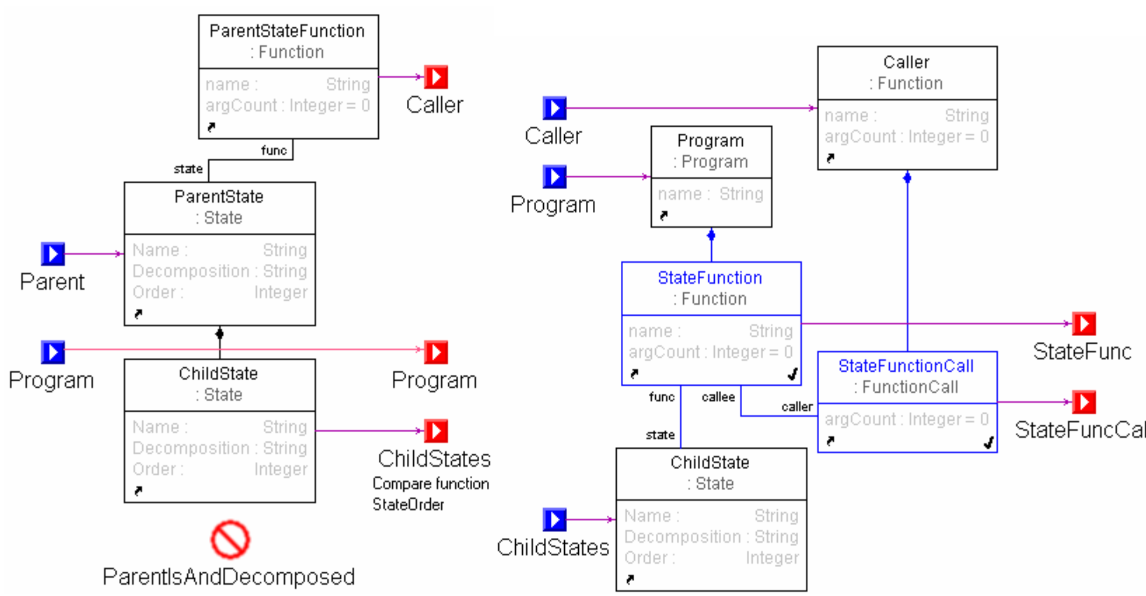


Figure 23 Create ordered State execution functions

During the sorting step, matches produced by the pattern matching are reordered by sorting the objects associated with the sorting pattern object. In our example, {(Parent, ChildB, Prg, ParFunc), (Parent, ChildA, Prg, ParFunc), (Parent, ChildC, Prg, ParFunc)} is reordered yielding {(Parent, ChildA, Prg, ParFunc), (Parent, ChildB, Prg, ParFunc), (Parent, ChildC, Prg, ParFunc)}. These matches are then passed along in the identical order to the next rule as shown in Figure 23 . Finally, “StateFunction”-s and “StateFunctionCall”-s are created for each match in the correct order, ensuring that the generated C function will execute the parallel states in the correct order.

```
template <class T>
bool StateOrder( const T& lhs, const T& rhs) {
       return lhs.Order() < rhs.Order();
}
```

Figure 24 Predicate for comparing States by using the Order attribute

5.9. Distinguished Merging

In graphical languages, subsystems typically expose their interfaces with the help of ports. For example, in signal flow languages, data ports indicate the types of signals the component accepts. The programmer specifies the signal flow by connecting the output ports of the source component to the input ports of the destination component. As the interface gets larger, the number of connecting ports increases rapidly. Connecting each pair of source-destination ports manually becomes cumbersome and tedious, thus the process lends itself to automation.

This problem can be regarded as a model transformation problem: new signal flow connections need to be added between selected ports specified by some criteria. The pattern matching algorithm must find and return pairs of ports that need to be connected. The search space is the cross product of all output ports of the source by all input ports of the destination. For example in **Error! Reference source not found.**, the total search space is {(O1,I1), (O1,I2), (O1,I3), (O2,I1), (O2,I2), (O2,I3), (O3,I1), (O3,I2), (O3,I3)}.

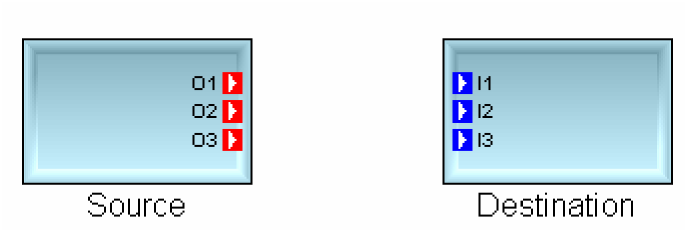


Figure 25 The Connecting Ports Problem

Of course, the pattern matching cannot figure out automatically which are the connecting ports, so some restricting criteria are needed to specify the acceptable combinations. A simple criterion can be given using the physical layout ordering of the ports: the topmost output port should be connected with the top most input port, the second output port from the top should be connected with the second input port, and so on. Using this criteria the search space is restricted to {(O1,I1), (O2,I2), (O3,I3)}, and this set indeed represents the connecting ports.

We need to find a distinguished subset of matches in the original search space. The two most prominent properties of the elements in the subset are (1) each port occurs only once in the set (2) the ports are sorted: they are paired up to form elements in a specific order. The selection algorithm, called distinguished merging, is outlined below:

Name: **Distinguished merging**
Inputs: Total cross product of input and output ports, sorting criteria
Output: Distinguished subset of input and output ports, where the elements represent the wanted connections

1. Break apart the elements of the total cross product and create two corresponding sets for input and output ports.
2. Sort the elements of the input port set and output port set independently using the sorting criteria.
3. Remove duplicates of consecutive elements with the same value.

4. Compute the distinguished subset, by arranging the elements vertically into pairs.

Input: {(O1,I1), (O1,I2), (O1,I3), (O2,I1), (O2,I2), (O2,I3), (O3,I1), (O3,I2), (O3,I3)}

After step 1: {O1,O1,O1,O2,O2,O2,O3,O3,O3},{I1,I2,I3,I1,I2,I3,I1,I2,I3}
After step 2: {O1,O1,O1,O2,O2,O2,O3,O3,O3},{I1,I1,I1,I2,I2,I2,I3,I3,I3}
After step 3: {O1,O2,O3},{I1,I2,I3}
After step 4 & output: {(O1,I1), (O2,I2), (O3,I3)}

demonstrates the algorithm with the ports shown in **Error! Reference source not found.**, and sorting ports based on their vertical position.

Input: {(O1,I1), (O1,I2), (O1,I3), (O2,I1), (O2,I2), (O2,I3), (O3,I1), (O3,I2), (O3,I3)}
After step 1: {O1,O1,O1,O2,O2,O2,O3,O3,O3},{I1,I2,I3,I1,I2,I3,I1,I2,I3}
After step 2: {O1,O1,O1,O2,O2,O2,O3,O3,O3},{I1,I1,I1,I2,I2,I2,I3,I3,I3}
After step 3: {O1,O2,O3},{I1,I2,I3}
After step 4 & output: {(O1,I1), (O2,I2), (O3,I3)}

Figure 26 Connecting Ports

Distinguished merging can easily be extended to multiple sets. Suppose we want to execute the algorithm on N sets. Then we have an input set containing N-ary tuples as elements, which is broken down into N individual sets during step 1. After sorting and creating 'unique', we form N-ary tuples by taking the elements of each set vertically.

Note that the algorithm fails if the number of elements of the individual sets differ after step 3. Indeed, step 4 needs sets of the same size to complete forming tuples, otherwise it will produce incomplete tuples. In GReAT, it is the user's responsibility to ensure that each set will contain the same number of elements after step 3. For the port-connection example this means that the source must have as many output ports as the destination has inputs.

Also note that the algorithm does not necessarily select a subset in the input, but rather computes new elements out of the constituent parts, i.e. the graph objects. For example, consider the following input {(I1,O2),(I2,O1)}. The algorithm output is going to be {(I1,O1),(I2,O2)}, demonstrating that neither of the elements of the distinguished subset is contained in the input set. Instead, graph objects have been reorganized or merged to form new elements, hence the name distinguished merging.

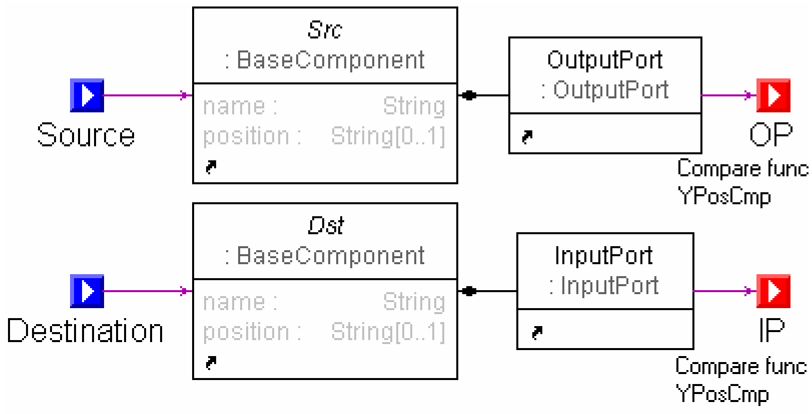


Figure 27 Rule that selects connecting ports

Distinguished merging is performed in the last phase of the rule execution. The input set is provided by the pattern matching, but the sorting criteria must be specified by the programmer. He can provide the sorting criteria by compare functions, as in the case of sorting, only that all the output ports must have a compare function specified, so that each set can be sorted and made unique during steps 3 and 4, respectively. **Error! Reference source not found.** shows a pattern that selects "OutputPort"-s and "InputPort"-s in "BaseComponent"-s. The predicate "YPosCmp" used as a compare function for both output ports (the programmer can specify different compare functions, of course). In addition, a rule attribute "distinguished" must be set to true (not shown in the figure). The selected component ports are connected in a subsequent rule.

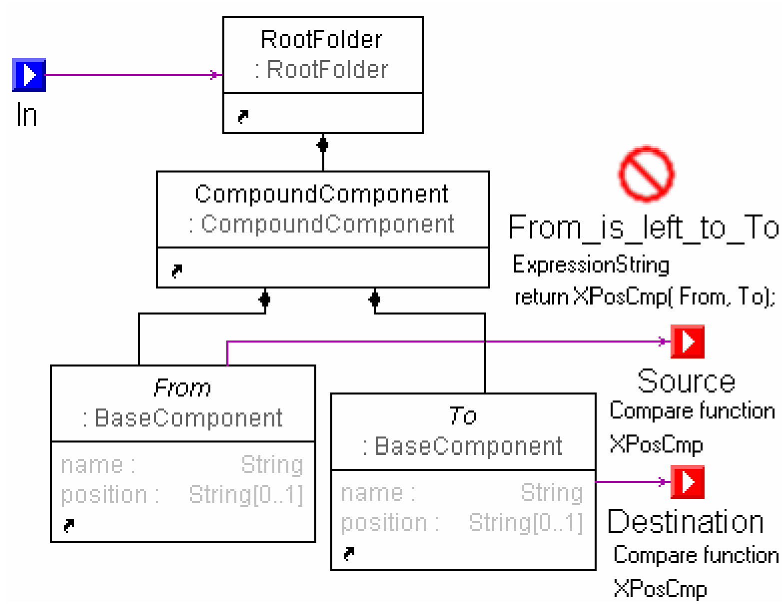


Figure 28 Rule that selects adjacent component pairs

It is interesting that distinguished merging can also be used for selecting the source and destination components in another rule earlier in the transformation. **Error! Reference source not found.** shows a rule that selects component pairs that are laid out horizontally right next to each other. Input:

{(C1,C2),(C1,C3),(C1,C4),(C2,C1),(C2,C3),(C2,C4),(C3,C1),(C3,C2),(C3,C4),(C4,C1),(C4,C2),(C4,C3)}

After Guard: {(C1,C2),(C1,C3),(C1,C4),(C2,C3),(C2,C4),(C3,C4)}
After step 1: {C1,C1,C1,C2,C2,C3},{C2,C3,C4,C3,C4,C4}
After step 2: {C1,C1,C1,C2,C2,C3},{C2,C3,C3,C4,C4,C4}
After step 3: {C1,C2,C3},{C2,C3,C4}
After step 4 & output: {(C1,C2), (C2,C3), (C3,C4)}

shows how the rule works. Let us denote the four input components to connect as C1, C2, C3 and C4. The pattern matching first finds all possible ordered pairs from the set of input components (there are 4!/2!=12 such pairs). To ensure that component "From" lays left to component "To", we utilize the compare function "XPosCmp" in a guard condition "From_is_left_to_To", which discards all pairs where "From" is right to "To". Finally, the distinguished merging gets rid of all non-adjacent pairs. These source-destination component pairs are then passed along one-by-one to the rule depicted in **Error! Reference source not found.** shown above.

Input:
{(C1,C2),(C1,C3),(C1,C4),(C2,C1),(C2,C3),(C2,C4),(C3,C1),(C3,C2),(C3,C4),(C4,C1),(C4,C2),(C4,C3)}
After Guard: {(C1,C2),(C1,C3),(C1,C4),(C2,C3),(C2,C4),(C3,C4)}
After step 1: {C1,C1,C1,C2,C2,C3},{C2,C3,C4,C3,C4,C4}
After step 2: {C1,C1,C1,C2,C2,C3},{C2,C3,C3,C4,C4,C4}
After step 3: {C1,C2,C3},{C2,C3,C4}
After step 4 & output: {(C1,C2), (C2,C3), (C3,C4)}

Figure 29 Selecting Source-Destination Rule Pairs

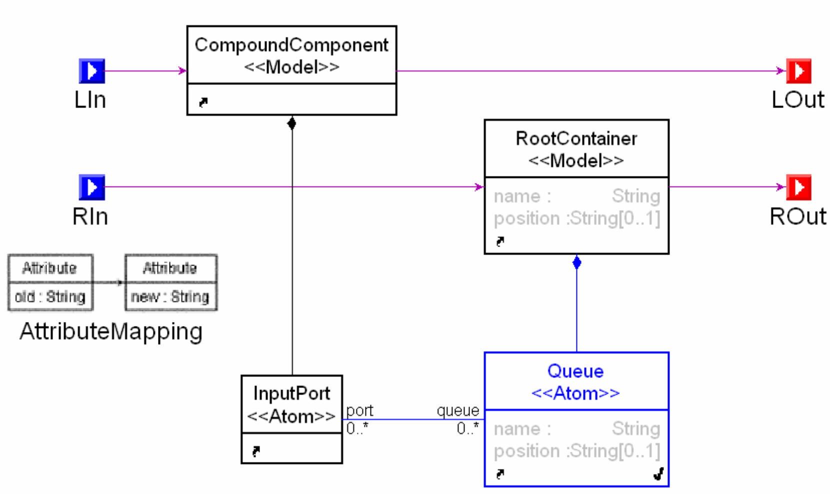
5.10. Termination

A rule sequence is terminated either on a rule having no output interface or on a rule with having an output interface but not producing any packets.

Thus if the firing of a rule produces zero output packets then the rules following it will not be executed. Hence in Figure 20 if rule 4 produced zero output packets then rule 5 would not have been fired. However, the there should be a construct to sequence rules without having to bind the ports.

5.11. Embedded with Customized Code

The final item to discuss is the embedded transformation rules with customized code. In order to provide more complicated and flexible operations within the transformation rule, user can write its own code with UDM APIs to manipulate the bound objects in `Guard` and `AttributeMapping`. For example, in the following transformation rule,



if we want set the name for the new created object of `Queue`, then in the attribute panel of `AttributeMapping`, input the following code:

```
Queue.name() = (string)InputPort.name()+"_Queue";
```

Then after the new object of Queue is created, the above code will be executed and the name will be set.

Also users are allowed to link the transformation rule with predefined libraries and other code. To do so, users are required to specify such library files, include files and corresponding directories in configuration model (please refer 9.1).

5.12. Code Library

The CodeLibrary is a place for specifying executable cpp code fragments. To insert a code library, right click on the "Config" folder, and select "Insert Mode->CodeLibrary". Currently, the CodeLibrary is used to compare functions as seen in the Sorting section (please refer 5.8). The compare function can also be called from the `Guard` and `AttributeMapping` objects. Future support will be added so that reusable code snippets can be added to the CodeLibrary, and called from the `Guard` and `AttributeMapping` objects.

If UDM features are used, you are required to specify the UDM_DYNAMIC_LINKING preprocessor directive in the project options. This is needed because the generated files are linked against UdmDll(d).lib. You must also conform to the library naming convention of using the 'd' suffix for debug libraries. The generated project file links with <your-library>d.lib for Debug configuration, and <your-library>.lib for Release configuration

6. GR Engine

The Graph Rewrite Engine (GR Engine) is a fully meta-model-driven interpreter which is developed to take in the configuration file, get all meta-models dynamically for accessing input and output models, apply the transformations to input models, and directly generate the output model.

GReAT provides two different usages of GREngine. It can either be used as command line or be invoked as interpreter for transformation model.

6.1. <u>GRE.exe</u>

6.1.1. NAME

GRE.exe – directly use configuration file as input to generate output model

6.1.2. SYNOPSIS

GRE <configurationFile> [<fileSpec>] ……

<configuraitonFile>	the name of the configuration file (“.mga” or “.xml”) generated by the interpreter GenerateConfig on the GReAT configuration model created with GReAT language.
< fileSpec >	the string to specify the file with file Id and file name. If the file mode is read only, or write only, or read and write, the format is: FileID=FileName If the file mode is read, write and copy, the format must be: FileID=FileName1;FileName2 FileName1 will be used to read in model, FileName2 will be used to write and copy model. If the FileName contains white space characters, then the use of quotes “ ”is obligatory. ***For more info read Chapter 10***
-d	print out run time transformation rule name during execution
-dv	print out run time transformation rule name, input packets, pattern matches, output packets info during execution

6.1.3. SAMPLE

GRE.exe SF2FSF.mga SF=“SFInput.mga” FSF=“FSFOutput.mga”

- SF2FSF.mga : configuration file
- SF, FSF : file ID

- SFInput.mga, FSFOutput.mga : file name

6.1.4. DESCRIPTION

GRE takes in the <configurationFile> to generate the output model directly. The other arguments <fileSpec> are optional. If there are <fileSpec>s following <configurationFile>, GREngine will use the file provided in <fileSpec> instead of the corresponding InputFile with the same FileID in <configurationFile>. If there is no InputFile specified in <configuratioFile>, user must provide the <fileSpec> as input arguments. The order of multiple <fileSpec> can be arbitrary.

6.1.5. FILES

GReATConfig.dtd	If the <configurationFile> is XML format (“.xml”), it must compliant with this DTD.

6.2. InvokeGRE.dll

6.2.1. NAME

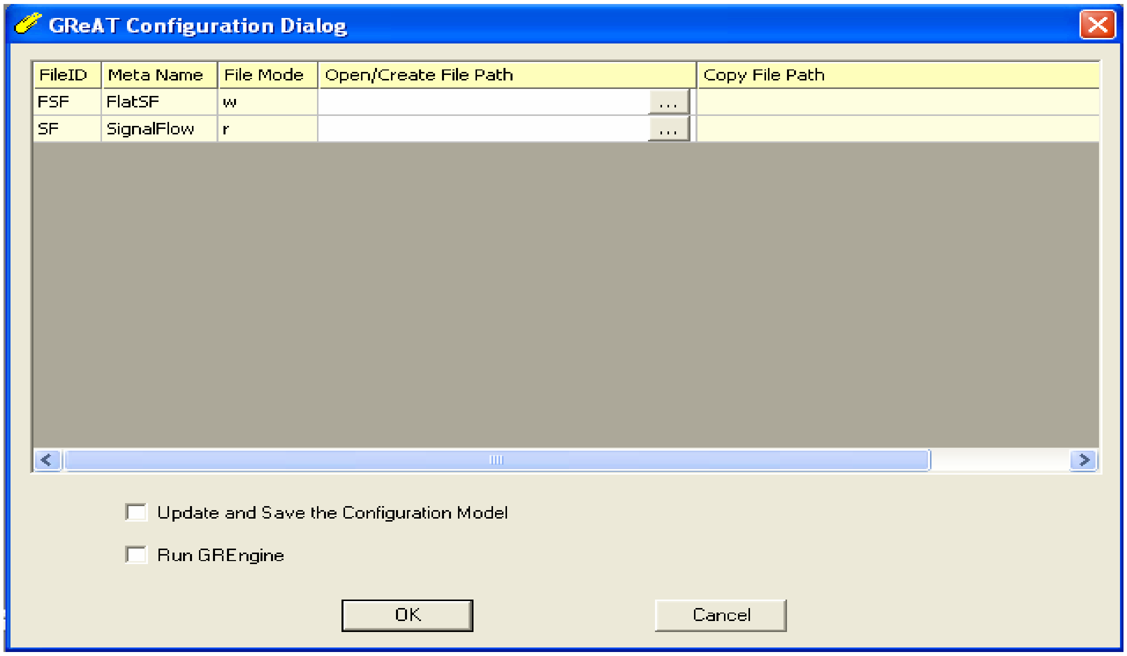
InvokeGRE.dll – GME model interpreter used to generate the output model and update the configuration file.

6.2.2. USAGE

Register and run the interpreter within GME/ UMLModelTransformer. The interpreter can (1) run GR Engine with the configuration file and (2) update the current configuration model.

If there is “NoPrompt” atom in the configuration model, then the following dialog will pop up:

If there is no “NoPrompt” atom in the configuration model, user can give the file path, and choose the task through the following dialog:


GReAT Configuration Dialog
FileID
Meta Name
File Mode
Open/Create File Path
Copy File Path
FSF
FlatSF
w
SF
SignalFlow
r
Update and Save the Configuration Model
Run GREngine
OK
Cancel

7. Code Generator

Code Generator is a GR to C++ translator utility, which can be used to generate C++ code from your GR rules.

What is in the package

1. bin/CG.exe - Code Generator command line executable
2. UMLModelTransformer/CodeGenerator.dll - Code Generator GME interpreter add-on
3. etc/GR.xsd - must be in path to execute CG.exe
4. etc/InputFileRegistry.h - must be in path to compile output
5. etc/GReATSort.h

Command line tool usage

You can execute CG.exe from the command prompt.

```
CG.exe <GenFileName> <ConfigFileName> [-m|-t]
GenFileName  - the generated rewriting code file name base.
ConfigFileName - GReAT Configuration information file.
[-m]   Generate the main.cpp file only.
[-t]   Generate the translator files only.
[-p]   Generate Visual Studio projects files also.
[-e]   Generate transformation executable file (Compile transformation)
```

Examples:

```
CG.exe SF2FSF SF2FSFConfig.mga
CG.exe generated\HSM2FSM HSM2FSMConfig.mga -t
```

The translator files consist of the code which perform the transformation specified in your rules. The generated main.cpp file drives this translator code by opening and/or creating the models related to the translation and assigning input objects to the start translation rule.

GME interpreter usage

Just click on the icon  on the GME interpreter toolbar. Be sure, that the configuration is saved prior to executing the Code Generator interpreter. (See more info in Chapter 8.). If you did not specify runtime info in your configuration, the main.cpp file will not be generated. The translator files are always generated.

Code Generator specific configuration data:

1. *Filename base for Code Gen:* the generated rewriting code file name base. Example if you give Gen\MyTransformation, then CG generates the following files:

   .\Gen\ MyTransformation.cpp

   .\Gen\ MyTransformation.h

   .\Gen\ MyTransformation_main.cpp,

   .\Gen\MyTransformation.vcproj

where *.\Gen* is relative to the directory of the configuration file.

2. *Meta code generation mode for Code Gen:* This is an enumeration attribute that controls how the translator files are linked with the generated paradigm-specific API files and another file containing Attribute Mapping / Guard code. The CG can create the following C++ static link libraries from these files as part of the code generation process.

   [GR filename]_Static<_D>.lib contains the Attribute Mapping / Guard code.

   [GR filename]_Meta<_D>.lib contains the generated paradigm-specific API files.

   where *[GR filename]* is the GR file which is output of the GenerateGR interpreter, and the *_D* suffix is added for debug libraries.

   - ***No Library (Source code)* –** Code generator does not create any libraries. It is the task of the user to compile and link the paradigm-specific API files with the compiled translator files, whereas the Attribute Mapping / Guard code is printed out directly into the translator .cpp file.

   - *Static Link Library Debug Configuration* – CG will create *[GR filename]_Static_D.lib* and *[GR filename]_Meta_D.lib.* The user's job is to compile the translator files in debug configuration, and then link the resulted object code with these libraries.

   - *Static Link Library Release Configuration* - CG will create *[GR filename]_Static.lib* and *[GR filename]_Meta.lib.* The user's job is to compile the translator files in release configuration, and then link the resulted object code with these libraries.

   The libraries are regenerated each time after you invoked the GReAT Master Interpreter. Note that it is a time consuming task to compile and link the source files, but an inevitable task if you want to execute the generated translator files. CG supports this library creation feature only to simplify and accelerate the process of getting the generated translator files compile (see 7.1).

TranslatorLog.txt – This is log file created by Code Generator consisting helpful information of the generating process. Compiler warnings and errors are reported here.

7.1. How to compile the generated files

A VC project file is generated by the Code Generator. You can open this .vcproj file in Visual Studio and choose “Build Solution” to compile it. If Visual Studio prompts you to save the Solution, select a name and save the solution to continue the build.

If you set the attribute “Meta code generation” to “Static Link Library”, then you will be able to build only the debug/release configuration depending on your settings.

7.2. How to execute the generated files

If the compile was successful, the resulted .exe can be executed by either specifying the -d default switch, or specifying non-default input files as command line arguments. For a full example of the usage of command line arguments please see Chapter 10. For every .mga input file the corresponding meta models must be registered in GME, and for every .xml input file the corresponding meta dtd files must be in path.

8. GR Debugger

GRDebugger provides an integrated debugger to help locate bugs in a GReAT program.

GRDebugger has all the basic features that any programming language's debuggers could have: you can execute your GReAT program step by step, i.e. rule by rule. You can have breakpoints at certain point of the program, so the transformation can be paused at any point the values to peek the values of variables.

8.1. Overview: The Debugging Interface

Debugging is the process of correcting or modifying the code in your GReAT project so that your project can run smoothly, act as you expected, and be easy to maintain later.

GRDebugger provides a tool to help of tracking down errors in the code and program components.

The debugger interface provides menus, toolbars, dialog boxes and windows. Occasionally the debugger is paused in break mode, meaning the debugger is waiting for user input after completing a debugging command (like break at breakpoint, step into/over/out, break at exception).

8.2. Starting the Debugger

8.2.1. To start the application

From command line,

Mode	Features
Debug mode	grd.exe configFileName [-d] The application brings up the debuggers graphical user interface.
Release mode	grd.exe configFileName -nd It runs GReAT engine without any debugging capabilities.

8.2.2. To start debugging

Load a configuration file using **Load** command.

Click **Run**, or **Step Into**.

8.3. Call Stack Window

During a debug session, the Call Stack window displays the stack of rule calls that are currently active. When a rule is called, it is pushed onto the stack. When the rule returns, it is popped off the stack.

The Call Stack window displays the currently executing rule at the top of the stack and older rule calls below that. The window also displays variable types and values for each rule call.

You can navigate to a rule's source code from the Call Stack window using right mouse click.

8.4. Debug Options on the Control Toolbar

8.4.1. Debug Commands that Control Program Execution

Debug command	Action
Execute	Executes code without debugging information. The program can be stopped using **Stop** button.
Run	Executes code from the current statement until a breakpoint or the end of the program is reached, or until the execution stopped or paused by the user or the application exits.
Stop	Terminates the execution either in Debug mode or in Release mode.
Pause	Halts the program at its current location.
Step Into	Single-steps through rules in the program, and enters each rule call that is encountered.
Step Over	Single-steps through rules in the program. If this command is used when you reach a rule call, the rule is executed without stepping through the rule's instructions.
Step Out	Executes the program out of a rule call, and stops on the rule immediately following the call to the rule. Using this command, you can quickly finish executing the current function after determining that a bug is not present in the function.

8.5. Running Debug Mode Versus Release Mode

When you invoke GRDebugger both a Debug and a Release mode can be achieved using command line options or you can start using **Execute** button from toolbar.

Mode	Features
Debug mode	Debugging information in is stored. Speed is reduced.
Release mode	No debugging information Maximum speed

8.6. Debugger Toolbar And Menu Items

The **File** menu contains commands such as **Open, Close, Save** and **Exit**. GReAT configuration files can be opened using these commands.

The **View** menu contains commands that display the various windows, such as the **Stack** window, **Log** window and the **Status Bar**.

The **Help** menu contains commands that display the **Help** window or the **About** window.

Commands for debugging can be found on the control toolbar and the breakpoint toolbar. These commands start the debugging process (**Go**, **Step Into**, **Step Out, Step Over, Run**).

8.7. Debugger Windows

Three specialized windows display debugging information for your program. You can access these windows using the **View** menu.

The following table lists the debugger windows and describes the information they display.

8.7.1. Debugger Windows

Window	Displays
Log	Information about the loading, saving and execution, including loading, running or saving errors, exceptions. The executed rule names will be shown here in the case of **Log** command.
Source	Names and values of variables and expressions.
Call Stack and Variables	Information about variables used in the current and previous statements and function return values (in the **Auto** tab), variables local to the current function (in the **Locals** tab), and the object pointed to by **this** (in the **This** tab).

Debugger windows can be docked or floating.

When a window is in floating mode, you can resize or minimize the window to increase the visibility of other windows.

8.8. Halting a Program

8.8.1. To halt execution

Click **Pause** on the control toolbar and the control will return to GRDebugger

8.9. Running to a Location

8.9.1. To run until a breakpoint is reached

Set a breakpoint.

On the tool bar, click **Run** button.

8.10. Stepping Into Rules

8.10.1. To run the program and execute the next rule (Step Into)

While the program is paused in break mode (program is waiting for user input after completing a debugging command), click **Step Into** on toolbar.

The debugger executes the next rule, then pauses execution in break mode. If the next statement is a rule call, the debugger steps into that rule, then pauses execution at the beginning of the rule.

Repeat step 1 to continue executing the program one rule at a time.

8.10.2. To step into a specific rule

Set a breakpoint just before the rule call.

Use the **Run, Step Into**, or **Step Over** command to advance the program execution to that point.

8.11. Stepping Over or Out of Rules

8.11.1. To step over a rule

- Open a source file, and start debugging.
- Execute the program to a rule call.
- On the **Debug** menu, click **Step Over**.
- The debugger executes the next rule, but pauses after the rule returns.
- Repeat step 3 to continue executing the program, one statement at a time.

8.11.2. To step out of a rule

- Start debugging, and execute the program to some point inside the rule.
- On the **Debug** menu, click **Step Out**.
- The debugger continues until it has completed execution of the return from the rule, then pauses.

Caution In general, to avoid very slow execution, you should not step out of a rule containing a loop. Instead, you should set a breakpoint at the end of the rule, and then choose **Go** from the **Debug** menu to execute to the end of the rule. Then choose **Step Out**.

8.12. Viewing and Enabling Breakpoints

8.12.1. To set a breakpoint

- In the source code window, select the line containing the breakpoint you want to enable.
- Click the **Toggle Breakpoint** toolbar button.
- A red dot appears at selected line in the left margin of the source window.

8.12.2. To remove a breakpoint

- For a location breakpoint in a source code window, select the line containing the breakpoint you want to disable.
- Click the **Toggle Breakpoint** toolbar button.
- For a location breakpoint, the red dot in the left margin disappears.

8.12.3. To view the list of current breakpoints

- On the toolbar, click **Show All Breakpoints** button.

8.12.4. To remove all breakpoints

- Click the **Remove All Breakpoints** toolbar button.
- The red dots in the left margin disappear.

8.13. Viewing the Call Stack for a Rule

8.13.1. To view the call stack for a rule

- Place a breakpoint in the rule.
- On the toolbar, click **Run** to execute your program to the location of the breakpoint.
- On the **View** menu, click **Stack** if the stack window is not visible.

- The calls are listed in the calling order, with the current rule (the most deeply nested) at the top.

8.13.2. To change the call stack display

- Double click on a Rule name expands all the variable types in that rule context.
- Double click on a variable type name will expand all the variable of that type.
- Double click on a variable name will expand all the variable values. If a value is empty it probably has empty string name.

8.14. Viewing the Value of a Variable

- To view the value of a variable
- Wait for the debugger to stop at a breakpoint.

– or –

- Click Pause on the toolbar.
- Find the variable in the Stack window.
- To view the value of a variable using right click
- When the debugger is stopped at a breakpoint, switch to a source window, and click the right mouse button on the line declaring the variable.
- Select the variable.
- To view type information for a variable in the Stack window
- In the Stack window, find the variable and see its parent.

9. GReAT Configuration

9.1. <u>High-level</u>

The operation of the various GR tools (GR Engine, Debugger and the Code Generator) is controlled by the GReAT configuration data. Visual setting of the GReAT configuration is available in GME, because the GReAT configuration is part of the UMT meta model. The GME visual configuration process involves the creation of a configuration model, and adding various configuration elements into it. Part of the configuration can be also edited in a configuration dialog box.

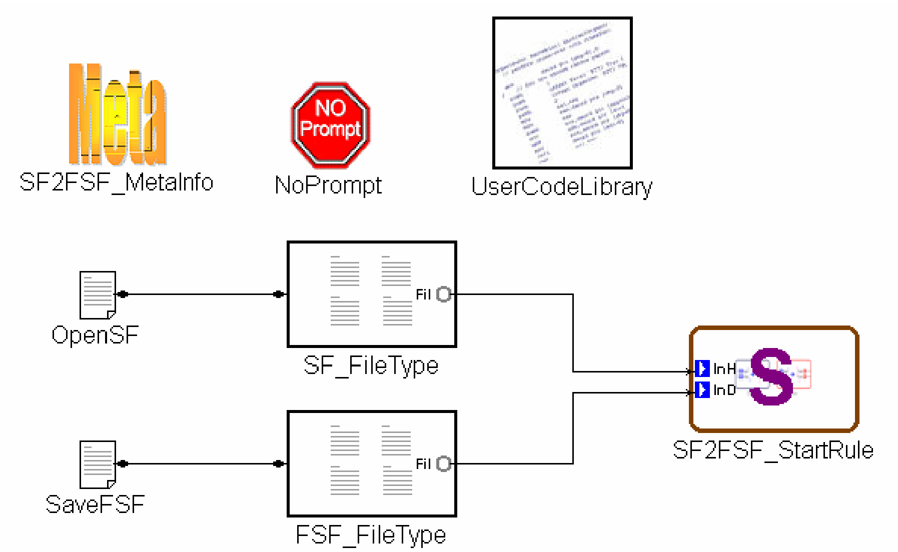


Figure 30 Visual configuration for the 'Signal Flow to Flat Signal Flow' transformation

Short description of the UMT Configuration elements follows:

SF2FSF_MetaInfo::MetaInfo contains the GR translation file name and the name of file which contain meta information of the participating input and output models in the translation.

OpenSF::File, SaveFSF::File refer to the input and output models, respectively.

SF_FileType::FileType, FSF_FileType::FileType refer to the input and output model types. Define the meta name, root folder and file mode of the corresponding file.

File::FileObject define which objects in the input or the output file to be assigned to which input ports of the start rule.

SF2FSF_StartRule designates the first rule to execute in the transformation process.

UserCodeLibrary contains the additional user predefined library files, include files and the corresponding directories.

NoPrompt do not display the GreatConfig configuration dialog.

Input, output files can also be selected by the Windows Open File Dialog in GReAT Configuration Dialog. See Fig. 8.2.

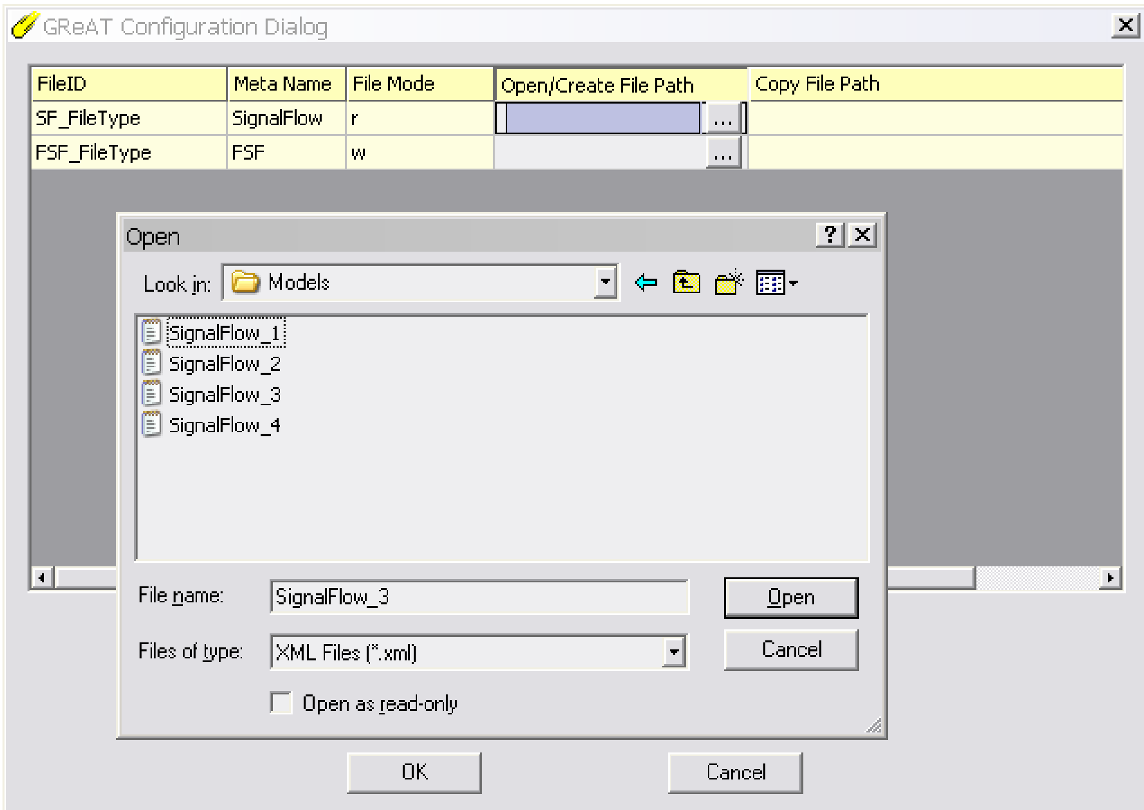


Figure 31 he GReAT Configuration Dialog

Changes in the dialog are reflected back into the configuration model, i.e. after completion the configuration model is updated with the selected input/ output files.

Here is the step by step guide how to create the configuration for your transformations:

1. **Open your existing UMT model you want configure in GME.**
2. **Create a Configurations folder.**
   Select the Root Folder in the Browser, select Insert Folder/Configurations.
3. **Create a Configuration model.**
   Select the Configurations folder created in Step 2 and select Insert Model/ Configuration.
4. **Set the Meta information.**
   Drag & drop a MetaInformation atom from the Part Browser into the Configuration model created in Step 3. Set the following attributes:
   - Transformation GR file: output file name of the "Convert transformation rules to GR format" interpreter.

- Udm Project File: output file name of the “UML 2 UDM/XML” interpreter.

Note: These attributes are not needed to be specified manually, they are going to be updated automatically after running the respective interpreters.

5. **Set the Usage information.**
   Setting the usage information consist of the start rule selection, and the assignment of input model objects to input ports of the start rule.
   a. *Select the start rule.*
      Drag & drop a StartRule proxy into the Configuration model. Drag & drop any existing rule from your Transformation folder on the StartRule proxy.
   b. *Assign objects to input ports.*
      Drag & drop a FileType model into the Configuration model. Each FileType model represents a *template* for an input model. A file type model contains only meta information of the corresponding input model. The separation of FileType-s from actual File-s is very practical, because it makes the abstraction of the input object assignment possible: instead of specifying real objects in a specific input file, you specify *object path* in a type of input files. The object path is a semi-colon separated expression, where each expression element specifies an object type, starting from the type of the root folder.
      - Create a FileObject atom in the FileType model and specify the object path attribute of it.
      - Connect the created FileObject atom to the input port of the start rule, which input port you want the FileObject assigned to.

   Also, set the following FileType attributes:
   - Meta name: input (output) model paradigm name.
   - Root class name: root name of model paradigm.
     This must match with the first object type of the object path attribute specified in all of the contained FileObject-s.
   - File mode: File operation semantics:
     - Read: open read-only.
     - Write: open write-only (create new or overwrite existing).
     - Read and write: open read-write (open and update existing).
     - Read and write to a copy: open existing file and save under a different file name.
   - DTD pathname: if the model paradigm is an .xml file, the path of the corresponding .dtd file.
6. **Set the Runtime information**
   Specify the actual input and output models of the transformation. Drag & drop a File atom for each input and output model into the Configuration model, and set the following attributes:
   - File path name: Read/Write file name of the model depending on the selected File mode in the connected FileType attributes.

- Copy path and name: Specify only if ‘Read and write to a copy’ File mode is selected in the connected FileType attributes. The opened filed is saved under this file name.

Finally connect the corresponding File-s and FileType-s.
If you want to generate code by the “Generate code from rules” interpreter, the specification of the Runtime information is not obligatory, although specifying it enables the CG to generate a main.cpp file, which can open & save the files specified in the Runtime information by default. See chapter 6 for more details.

7. **Interpret your transformation**
If you have not executed the “Convert transformation rules to GR format” and the “UML 2 UDM/XML” interpreters yet, execute them prior to executing the “Generate Configuration file” interpreter. These interpreters update automatically your configuration meta information as described in step 4, which changes must be reflected in the output of “Generate Configuration file” interpreter.
8. **Interpret the configuration data by the “Generate Configuration file” interpreter**
The GR tools accept configuration models in the GReATConfig paradigm, which can be generated by executing the “Generate Configuration file” interpreter. If you have multiple configurations specified in your Configurations folder, be sure to select the Configuration model you want to interpret. In case you have only one configuration model specified, that one will be interpreted regardless of the actual selection. After interpretation completed, the ‘Config file path name’ attribute of the interpreted Configuration model is filled automatically with the generated config file name. Now you can execute the GR Engine on your transformation, or after specifying the ‘Filename base for Code Gen’ attribute, you can also execute the Code Generator interpreter. Failing of specifying this ‘Filename base for Code Gen’ attribute results in the code generation with default file name ‘.\output.cpp’ and ‘.\output.h’.

The ‘Transformation GR file’ and ‘Udm project file’ attributes specified in step 4 can be either in absolute or relative path format. If relative path is used, the specified attribute is considered relative to the generated config file path. E.g. if config file path is ‘c:/GReAT/Conf/config.mga’ and the ‘Transformation GR file’ attribute is ‘../Trans/trans-gr.xml’ then the GR tools will search for the transformation file in ‘C:/ GReAT /conf/../Trans’ or equivalently in ‘c:/ GReAT /trans’. Similarly, if the ‘Udm project file’ attribute is ‘../Meta/meta.udm’ then the project file is given by ‘c:/ GReAT/Meta/meta.udm’.

9.2. <u>Low-level</u>

The output of the “Generate Configuration file” interpreter is yet another model. This intermediate model format called GReATConfig is the direct configuration input for the GR tools.

There is no need of manually editing this file, however it might be useful to be familiar with the GReATConfig meta model, which is depicted below.

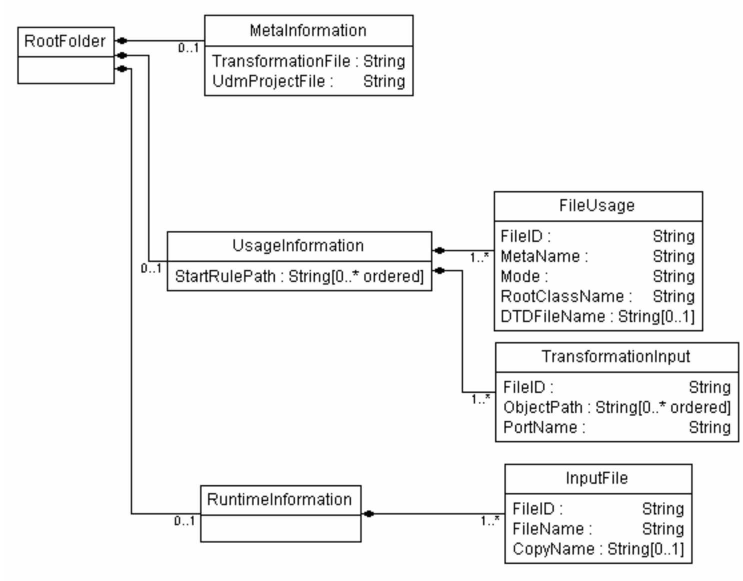


Figure 32 The GReATConfig meta model in UML notation

10. Specifying Command Line Arguments

The command line version of GRE and the generated code take command line arguments to open/create/save input and output models. Two examples are provided to illustrate how to specify these arguments.

10.1. Example 1

Suppose, you want configure the SignalFlow 2 FlatSignalFlow UmlModelTransformer model by specifying an input SignalFlow model and an output FlatSignalFlow model. This can be configured by creating two FileType atoms, :

- one for the SignalFlow model (fileID: "SF") with action read
- and another one for the FlatSignalFlow (fileID: "FSF) model with action write

Then, GRE or the CG generated code will take the following arguments:

SF="SFInputModel.mga" FSF="FSFOutputModel.mga"

where

- the order of SF and FSF arguments can be arbitrary
- If either file name contains white space characters, then the use of quotes " is obligatory, otherwise the file name will be split into two arguments.
- If the file name does not contain white space characters, the use of quotes " is optional.
- Any command line argument is considered legal, if the expression to be parsed has two strings separated by the equal character "=". The string literal before "=" is the fileID, the string literal after "=" is the filename.
- CG generates main code which is able to provide default arguments. The default arguments are meaningful only if the runtime information is specified in the GReATConfig model. The generated main.cpp behaves differently on the number of command line arguments:
  - If no arguments found, the usage of the program is printed out to the console.
  - If –d argument found, then the default arguments (specified in runtime information in the GReATConfing model) will be parsed and used in the program.
  - Otherwise each argument is going to be parsed and used in the program.

The user must specify only those input files (identified by file IDs), which are not default. E.g. if he want use SF="SFInputModel.mga" always but with different output FSFs, he can call specify FSF="myFSFOutputModel.mga" only.

If invalid expression found by the parser, exception is thrown. ("Invalid input file expression: <expr>" printed to the console)

10.2. <u>Example 2</u>

Configuring HSM2FSM involves specifying creating one FileUsage atom with action ReadWriteCopy (rwc). An input StateChart model gets read, and an output StateChart model is created, copied and saved by the generated code.

Then, GRE or the CG generated code will take the following arguments:

SC=”inputSC.mga”;”outputSC.mga”

- here quotes can be omitted as well, but do not forget to specify the separator “;”, because if you miss out “;” the entire expression after “=” is considered to be filename.
- The parser is able to ‘eat’ any white space characters around the separators “=” and “;”. This seems to be not useful in specifying command line arguments, because then the argument is split into two separate arguments.