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iGRT: A Generic Interface for GRoundTram

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Abstract

Bidirectional transformation plays an important role in maintaining the consistency of two models, and it has many potential applications, such as model synchronization, software evolution, etc. Currently we have a powerful tool called GRoundTram, which is designed for compositional development of well-behaved and efficient bidirectional graph transformations. However, as the graph representation in GRoundTram is a directed edge-labelled graph, it is quite difficult to apply it to real-world graphs directly, as graphs have more sophisticated representations usually.

In this paper, we present iGRT, a generic interface for GRoundTram. It serves as the connection between the graphs in real world and GRoundTram system. We have designed the representation for real world graphs, and provided traceable transformations between real-world graph representation and GRoundTram representation without losing any information. By using iGRT, we can easily shuttle between the different representations and maintain the synchronization as well. We have implemented iGRT and offered a friendly user interface based on the eclipse framework. Experiment result shows that iGRT enhances GRoundTram's application work to a large extent.

1 Introduction

From Wikipedia, "bidirectional transformations (bx) are programs whose code expresses a transformation both from input to output and back to the corresponding input (possibly with modifications) in a single piece of code".[1]

[1]http://en.wikipedia.org/wiki/Bidirectional_transformation/

It aims at maintaining the consistency of two (or more) related sources of information, especially for software engineering domains [5].

It has been realized nowadays that *bx* can provide solutions to a diverse set of problems, such as model synchronization, software evolution, etc [12]. Figure 1 shows one example in model-driven software development. Suppose M_1 and M_2 are two models, and there already exists one *bx* (t_1 and t_2) between them. t_1 is a transformation from M_1 to M_2, and t_2 is the corresponding backward transformation. From the picture we can see that once M_2 has evolved to ${M_2}^+$ with some modifications (signified as the grey part in ${M_2}^+$), by using the transformation t_2, we can easily get the relevant evolved model ${M_1}^+$, with the reflected modifications on M_1 (signified as the grey part in ${M_1}^+$), thus keeping the synchronization of the two models.

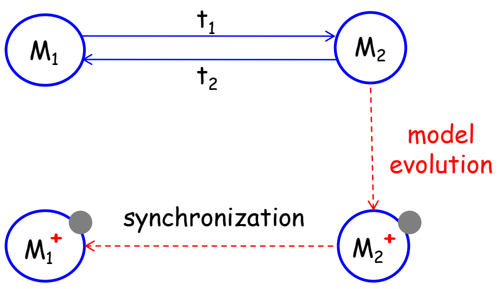


Figure 1: Model evolution by bidirectional transformation.

Currently, we have developed a powerful tool called GRoundTram [9] [11]. It is an integrated framework for developing well-behaved bidirectional model transformations, and it also provides *bx* on graphs [7] [6] [10] [4]. Bidirectional graph transformation has long been regarded as an important but difficult problem, because a large part of the objects in real world can be modeled as graphs, while treating graphs is more difficult than treating trees, as it has a more complicated structure which contains cycles. By using GRoundTram, graphs can be processed so that operations such as queries and transformations can be done quite efficiently on graphs. Figure 2 is the overview of the GRoundTram system. It is composed of four main parts, input, validation, *bx* and graphic user interface. The input to the system is a source model together with its schema, a transformation described in UnQL$^+$, and a target model schema. The validation part serves as a mechanism to detect errors during development as early as possible and help users to develop correct models and transformations. The *bx* part makes GRoundTram unique as it provides well-behaved bidirectional transformation, and it also provides a user-friendly GUI to make itself easily used. Readers can refer to the user manual of GRoundTram [8] for more information.

However, one problem falls on the practical utility of GRoundTram, for it does not support processing real-world graphs directly. The reason is that

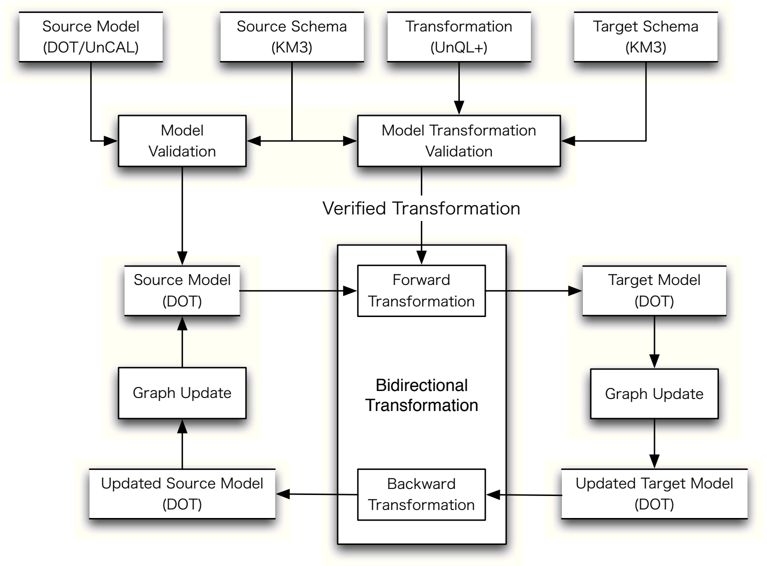


Figure 2: Overview of GRoundTram.

the internal graph representation in GRoundTram is directed edge-labeled graph [3], and it is not a direct representation for most graphs in real world as they usually hold information on nodes. For example, the edge may be directed or undirected, and the node may also have labels.

Such shortage will lead to the fact that GRoundTram cannot be easily applied to most common graphs, as the different representations of the graphs in two parts have placed a big obstacle between real world and GRoundTram. Therefore, the ability of this powerful tool to process *bx* on graphs has been decreased a lot.

In this paper, we present *iGRT*, a generic **i**nterface for **GR**ound**T**ram. It provides a way to make GRoundTram more applicable by giving transformations between general graphs and internal graphs in GRoundTram. By taking advantage of iGRT, users can easily shuttle between the two kinds of graphs without losing any information, thus being able to use GRoundTram to treat general graphs in real world directly. For example, giving two real-world graphs with general representation, we can first use iGRT to transform them into GRoundTram graphs, and then use GRoundTram to transform them with each other. When finishing processing these graphs, we can use iGRT to transform them back to general graphs with reflected modification or other impact on the original ones. In this way, a connection between these two real-world graphs has been created.

In order to work out solutions on how to do transformations between general graphs in real world and graphs in the GRoundTram system, we have studied several specific graphs at first, and then summarized the common attributes and structures from them, therefore designed methodology for processing general graphs. Here we have selected three specific graphs: *usecase* diagram, *class* diagram and *state* diagram. The former two are very popular graphs from UML diagrams. They are quite necessary in software development process. And *state* diagram is also very common for it models the behaviour of a system, specifying the sequence of events that a system goes through during its lifetime in response to events. Due to the representativeness of these three graphs, the common attributes and transformation methodology concluded from them can be well applied to most graphs in real world.

The rest of the paper is organized as follows: the next section presents the overview of iGRT. Section 3 illustrates how to represent general graphs in real world as well as in the GRoundTram system. The transformation algorithms between these two kinds of graphs are explained in Section 4. Meanwhile, the representations and algorithms for the three specific graphs will also be shown as concrete examples along with the description for general graphs in these two sections. Some useful operations based on iGRT such as graph modification propagating and graph query propagating which can be used to support solving the updating problem between real-world graphs and GRoundTram graphs will be described in Section 5. Section 6 gives the technical details of the implementation of iGRT, and Section 7 concludes the paper.

2 Overview

Figure 3 shows an overview of our approach. As can be seen from the picture, iGRT has three main parts: InterRep, TransAlg and UncalRep. The two outside mediums of iGRT are real-world graphs and GRoundTram graphs, and our work seems like a middleware connecting real world and the GroundTram system. Now let us have a first look at how iGRT behaves.

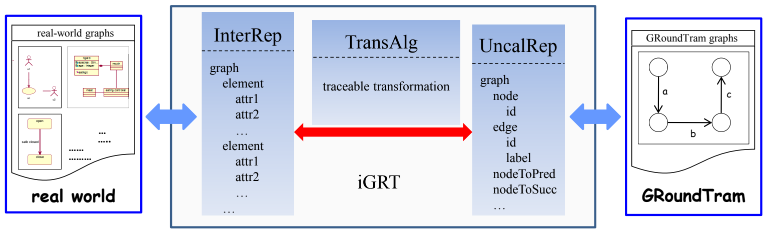


Figure 3: Overview of iGRT.

iGRT is targeting at making the GRoundTram system more applicable to real-world graphs. As there are so many kinds of graphs in real world with different structures, for example, flow diagram, class diagram, etc, and they are always saved in distinct formats, such as XML [2], dot, etc. In order to treat various graphs using the same methodology, we need to unify them into a solitary representation. The InterRep part is responsible for this unification work. Given a real-world graph as input, InterRep part will normalize it with the specified graph schema . We have defined several default schemas for some popular graphs, and the schemas can also be provided by the users. According to the schema, different graphs can be unified into the same intermediate representation (InterRep graph), thus being able to be treated in one way.

As pointed out before, the GRoundTram system has its internal graph representation which is directed graph with edge labeled. Serving as a connector connecting GRoundTram with real world, iGRT also has another part, UncalRep, targeting at representing the graphs in GRoundTram. The graph representation in UncalRep (UncalRep graph) is quite similar to graphs in GRoundTram, other than it may contain some additional attributes to make the transformation algorithms work more conveniently, such as "nodeToSucc" attribute, which signifies the succeeding nodes of each node.

So far iGRT already has two parts representing the graphs in real world and GRoundTram. What we need now is a way to shorten the distance between them. This work is done by the TransAlg part. In this part, we have presented traceable transformation algorithms, on purpose of doing transformation between InterRep graphs and UncalRep graphs bidirectionally without losing any information. "traceable" here specifies that the algorithms will save the trace information when doing the transformation work [13]. Therefore, when one graph has been transformed to another graph by these algorithms, it can be traced back to the original one directly.

In addition, according to the saved trace information, when one graph is updated with some modifications, the modifications can be easily propagated to the other graph by some additional operations based on the trace, such as modification propagating and query propagating, so that the two graphs can be kept synchronized. Moreover, graph query can also be transferred from InterRep graph to UncalRep graph. When users want to do query on real-world graph, the query will be translated onto the corresponding graph in GRoundTram system, hence the query task can be fulfilled by GRoundTram.

Figure 4 is a usage scenario of our work. From the picture we can see that iGRT stands between real world and the GroundTram system. If we want to use GRoundTram to treat some real-world graph, say one *state* diagram in Figure 4, we can input it to iGRT, and iGRT will first normalize it to InterRep graph according to state diagram's graph schema. Then the TransAlg part will transform it to UncalRep graph, and finally it will be outputted with the internal representation of GRoundTram, so that it can be input to GRoundTram for further processing. The transformation from the right

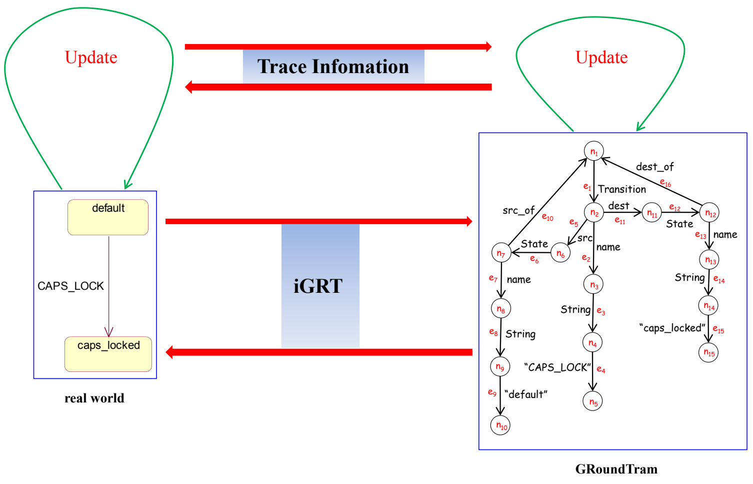


Figure 4: Usage scenario of iGRT.

part to the left part is quite similar. And due to the saved trace information, when there are some modifications on the InterRep graph, the modifications will be directly propagated to the UncalRep one. For example, after iGRT transforms the state diagram to the edge-labeled graph, if the edge labeled "CAPS_LOCK" has been changed to edge labeled "CAPS_UNLOCK" when GRoundTram does some operations on the graph, the iGRT will transfer the modification back to the original state diagram according to the trace information. As a result, the transition "CAPS_LOCK" will be evolved to transition "CAPS_UNLOCK".

iGRT is developed based on the Eclipse platform, and all the graphs and algorithms are coded in Java. The detailed techniques about the implementation will be discussed in Section 6. In the next section, we will first explain the working mechanism of the InterRep part and the UncalRep part in iGRT.

3 InterRep and UncalRep in iGRT

From the description in last section, we have an overview of iGRT, which has three main parts, InterRep, TransAlg and UncalRep. In this section, we will explain two parts of them, InterRep and UncalRep, which are serving for normalizing and representing graphs. We will first describe what general graphs look like by using the graph schema as well as how to normalize them according to the graph schema. After that, we will use three specific diagrams as concrete examples to illustrate our methodology.

3.1 General InterRep and UncalRep Graph

Generally speaking, graphs are composed of nodes and edges, and they have their own properties with different types. Here we will first generalize graphs by regarding all their contents as elements and attributes. More specifically, all the nodes and edges in the graph are considered as "element". And their properties are thought of as the "attribute" of the "element". Moreover, if the type of the property is reference rather than primitive, the property itself also becomes an "element", according to this mechanism, the type of the "attribute" will be primitive or "element".

In this way, we can easily normalize the real-world graph in the following schema, and it is also the cornerstone of iGRT's InterRep part. Here the language for specifying graph schemas is similar with KM3 [1], a neutral language to write metamodels and to define domain specific languages. From the schema we can see that the graph may contain several elements. Each element may contain several attributes a_i whose type is another element. By using " Primitive" to specify some primitive element such as string. "number = ..." signifies the number of this attribute that the element can hold.

```
Schema S = {

    Element Primitive $E_1$;
    Element Primitive $E_2$;
    ...
    Element $E_i$ {
        attribute $a_1$ : $E_j$[number];
        attribute $a_2$ : $E_k$[number];
        ...
    }

    Element $E_{i+1}$ {
        attribute $a_1$ : $E_j$[number];
        attribute $a_2$ : $E_k$[number];
        ...
    }

    ...

}
```

For each kind of real-world graph, it will have its own graph schema, and usually it is not unique. So when users want to process a specific kind of graph, they had better provide the corresponding graph schema at the same time. But for some popular graphs, we have already designed default schemas embedded in iGRT. After the graph and its schema being offered, InterRep part will automatically give the corresponding schema instance, i.e. the InterRep graph in the following style. Notice that e_i are elements of the relevant graph schema, and a_i are their attributes.

```
Instance i of S = {

    e_i1 = {
        a_1 = ...;
        a_2 = ...;
        ...
    }
    e_i2 = {
        a_1 = ...;
        a_2 = ...;
        ...
    }
    ...
}
```

The attained InterRep graph will then be transformed to UncalRep graph by iGRT's TransAlg part. In this section we will not explain how the algorithm works, instead, we will first show the relevant UncalRep graph.

As the graph schema has signified clearly all the properties of the correlated graph, and iGRT should not lose any information while doing the transformation, the UncalRep graph can be just created according to each element and its attributes by extending them to one branch in the UncalRep graph. In detail, for each element, we will use one edge labeled with its name to represent the element itself. For each of its attribute, if it is primitive type, we will use three edges labeled with its name, type and the attribute itself to represent the attribute, and if it is "element" type, we will use one edge to label its name and then connect it with the corresponding element. In this way, the labels of the edges in the UncalRep graph can capture all the properties of the InterRep graph. Because UncalRep graph is quite similar to the internal graph representation in GRoundTram, it can be directly transferred to the graph that can be input to the GRoundTram system.

After showing iGRT's InterRep part and UncalRep part based on the general graphs, let us get down to the following three specific graphs in order to have a further understanding of our work.

3.2 Concrete Cases

A. Use Case Diagram

In the Unified Modeling Language, use case diagram overviews the usage requirements for a system. They are useful for presentations to management and/or project stakeholders as well as developers.

As Figure 5 depicts, usually use case diagram contains three main elements: Actor, Usecase and Relation. An Actor is a person, an organization, or an external system that plays a role in one or more interactions with the system and is drawn as a stick figure. A Usecase describes a sequence of actions that provide something of measurable value to an actor. Usecases are drawn as horizontal ellipses. Relation shows which Actor carries out which Usecase, or which Usecase includes other Usecase, and use case diagram also includes other Relations between Usecases beyond the simple "include", such as "extend", "generalize". Relation can be directed (signified with an arrow) or undirected, which means the two parts are related with each other. And relation is drawn as solid line (for "associate" and "generalize") or dashed line (for "include" and "extend") according to different represented meanings.

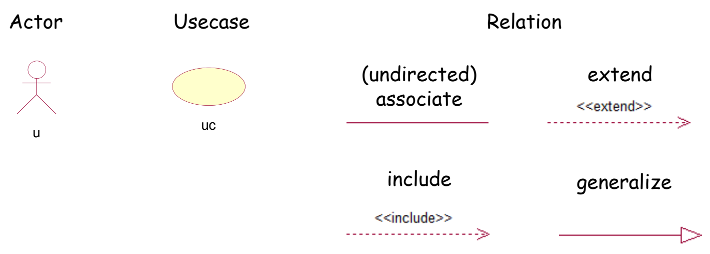


Figure 5: Elements of use case diagram.

Each of the above elements has its own attributes. Actor or Usecase has an attribute called "name", with type "string" to explain what it is. And when it has some outgoing Relation, it will have "src_of" attribute, with the content of the connected Relation. Meanwhile, Actor or Usecase may have "dest_of" attributes for incoming edges. For element Relation, it also has the attribute "name", showing what kind of the relation it is. And it has two subtypes, UniRelation and BiRelation, representing the directed relation and the undirected relation separately. For UniRelation, it will have one "src" attribute and one "dest" attribute, corresponding to the source and the destination of the relation. For BiRelation, it does not have "dest" attribute. In exchange, it has two "src" attributes. According to the above description, it is straightforward to write the graph schema for use case diagram as follows:

```
Schema UCD = {

    Element Primitive String;

    Element Entity {
        attribute name : String[1];
    }
    Element Actor extends Entity {
        attribute src_of : Relation[0-*];
        attribute dest_of : Relation[0-*];
    }
    Element Usecase extends Entity {
        attribute src_of : Relation[0-*];
        attribute dest_of : Relation[0-*];
    }

    Element Relation {
        attribute name : String[1];
    }
    Element UniRelation extends Relation {
        attribute src : Entity[1];
        attribute dest : Entity[1];
    }
    Element BiRelation extends Relation {
        attribute src : Entity[2];
    }
}
```

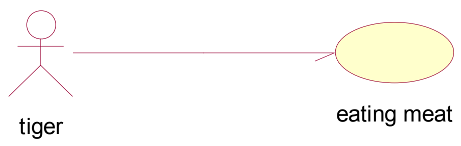


Figure 6: Real case of use case diagram.

Figure 6 gives a real example of use case diagram. In the diagram, there is one Actor names "tiger", and one Usecase names "eating meat". They are connected with the "associate" Relation from "tiger" to "eating meat", means the "tiger" will take the "eating meat" action. This graph is a real-world graph, and according to the description of its elements and attributes, we can easily normalize it by the InterRep graph as follows:

```
Instance ucd of UCD = {

    actor = {
        name = “tiger”;
        src_of = relation;
    }
    usecase = {
        name = “eating meat”;
        dest_of = relation;
    }
    relation = {
        name = “associate”;
        src = actor;
        dest = usecase;
    }

}
```

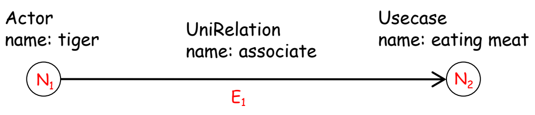


Figure 7: Illustration of InterRep graph of Figure 6.

Figure 7 illustrates the InterRep graph of the given use case diagram. It is composed of two elements shaped as nodes, Actor “tiger” and Usecase “eating meat”, and one element shaped as edge, UniRelation “associate”, from “tiger” to “eating meat”.

The TransAlg part of iGRT will then use the transformation algorithm to transform this normalized graph to UncalRep one. Now let’s see what the UncalRep graph is.

As Figure 8 depicts, the UncalRep graph for the real-world use case diagram in Figure 6 is a directed edge-labeled graph (the node’s label “n_i” and edge’s label “e_i” are only for explanation, and they are not meaningful in the real representation). In the UncalRep graph, each element of the InterRep graph is extended to several nodes and edges, with labels to show what the element is, what the element’s attribute’s name is, what the element’s attribute’s type is and what the element’s attribute is. For example, in Figure 8, $\{n_1, e_1, n_2\}$ means the element is “UniRelation”, and $\{e_2, n_3, e_3, n_4, e_4, n_5\}$ means this attribute has a name attribute “associate”, with the type “String”. $\{e_5, n_6, e_6, n_7\}$ tells that the “UniRelation” element has another attribute “src”, whose type is “Actor”, etc.

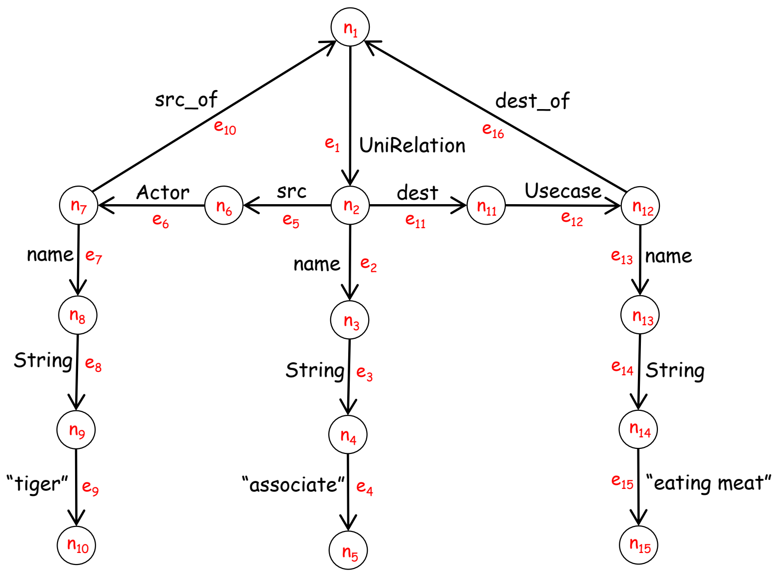


Figure 8: UncalRep graph of Figure 6.

B. Class Diagram

Class diagram is another useful diagram in the Unified Modeling Language. It is a type of static structure diagram that describes the structure of a system by showing the system's classes, their attributes, operations (or methods), and the static relations that exist among the classes.

Figure 9 shows the two main elements of the class diagram: Class and Relation. Class represents both the main objects and interactions in the application and the objects to be programmed. Classes are drawn as boxes which contains three parts: the name of the class, the attributes of the class and the methods or operations the class can take or undertake. Relation depicts the specific types of logical connections found among classes. There are five kinds of relations: associate, aggregate, composite, depend and generalize, each is drawn as a solid/dashed line with different kinds of arrows accordingly.

The schema of class diagram is described as follows. Here the Class's attributes "attribute" and "operation" themselves are also elements.

```
Schema CD = {

    Element Primitive String;

    Element Attribute {
        attribute name : String[1];
```

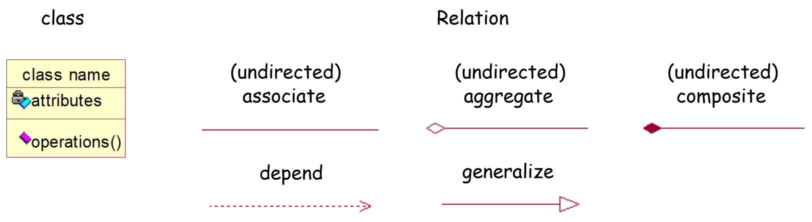


Figure 9: Elements of class diagram.

```
        attribute type : String[1];
    }
    Element Operation {
        attribute name : String[1];
    }
    Element Class {
        attribute name : String[1];
        attribute attribute : Attribute[0-*];
        attribute operation : Operation[0-*];
        attribute src_of : Relation[0-*];
        attribute dest_of : Relation[0-*];
    }
    Element Relation {
        attribute name : String[1];
    }
    Element UniRelation extends Relation {
        attribute src : Class[1];
        attribute dest : Class[1];
    }
    Element BiRelation extends Relation {
        attribute src : Class[2];

    }
}
```

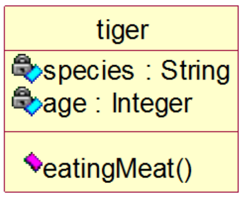


Figure 10: Real case of class diagram.

Figure 10 is a simple concrete class diagram in the real world. It only contains one class, with name "tiger", attributes "species" and "age", and operation "eatingMeat". The following is the InterRep graph of the class diagram:

```
Instance cd of CD = {

    attribute1 = {
        name = "species";
        type = "String";
    }
    attribute2 = {
        name = "age";
        type = "Integer";
    }
    operation = {
        name = "eatingMeat";
    }
    class = {
        name = "tiger";
        attribute = attribute1;
        attribute = attribute2;
        operation = operation;
    }

}
```

Then the UncalRep graph of Figure 10 can be easily given by iGRT as Figure 11 shows.

C. State Diagram

State diagrams are used to give an abstract description of the behavior of a system. This behavior is analyzed and represented in series of events, which could occur in one or more possible states. State diagrams have four main elements which are shown in Figure 12. A state represents a stage in the behavior pattern of an object in the system. An initial state, also called a creation state, is the one that an object is in when it is first created, whereas a final state is one in which no transitions lead out of. A transition is a progression from one state to another and will be triggered by an event that is either internal or external to the object.

The schema of the state diagram is as follows:

Schema SD = {

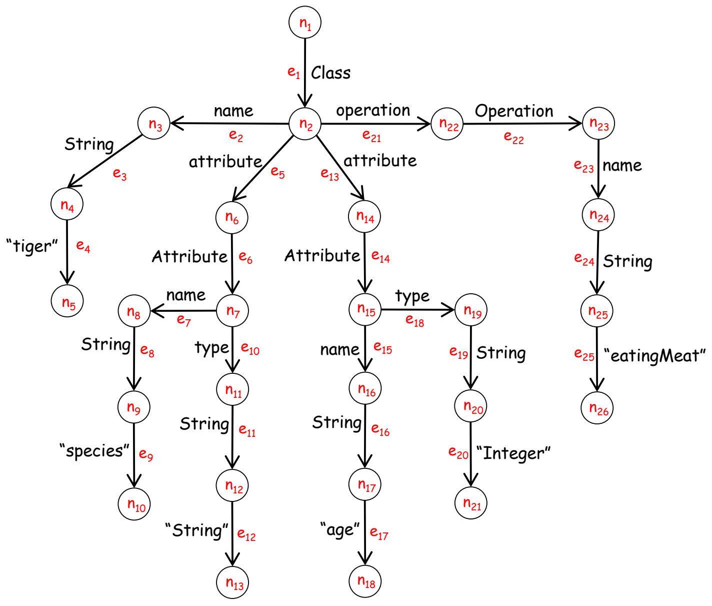


Figure 11: UncalRep graph of Figure 10.

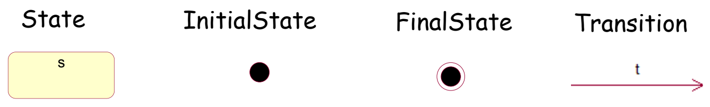


Figure 12: Elements of state diagram.

Element Primitive String;
Element Entity {
    attribute name : String[1];
}
Element InitialState **extends** Entity {
    attribute src_of : Transition[0-*];
}
Element FinalState **extends** Entity {
    attribute dest_of : Transition[0-*];
}
Element State **extends** Entity {
    attribute src_of : Transition[0-*];
    attribute dest_of : Transition[0-*];
}
Element Transition {
    attribute name : String[1];
    attribute src : Entity[1];

```
        attribute dest : Entity[1];
    }
}
```

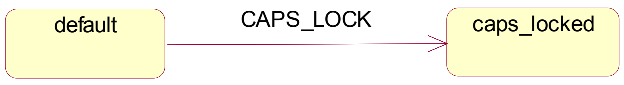


Figure 13: Real case of state diagram.

Figure 13 is a fragment of a concrete state diagram. It is composed of two states "default" and "caps_locked", and one transition "CAPS_LOCK" from the former state to the latter one. This state diagram implies that by doing the "CAPS_LOCK" transition, the "default" state can be transformed to the "caps_locked" state. Following is the InterRep graph of the state diagram according to the schema:

```
Instance sd of SD = {

    state1 = {
        name = "default";
        src_of = transition;
    }
    state2 = {
        name = "caps_locked";
        dest_of = transition;
    }
    transition = {
        name = "CAPS_LOCK";
        src = state1;
        dest = state2;
    }

}
```

Similarly, the UncalRep graph of the state diagram in Figure 13 can be easily given by iGRT as Figure 14 shows.

Now we have finished introducing how the InterRep part and UncalRep part of iGRT work on general graphs as well as three specific graphs: use case diagram, class diagram and state diagram. iGRT regards all the properties in the real world graph as elements and their attributes, so that they can be normalized to edge-labeled graph in GRoundTram system. In the next section, we will explain how the traceable algorithms in TransAlg part are designed so that iGRT manages to do transformation between InterRep

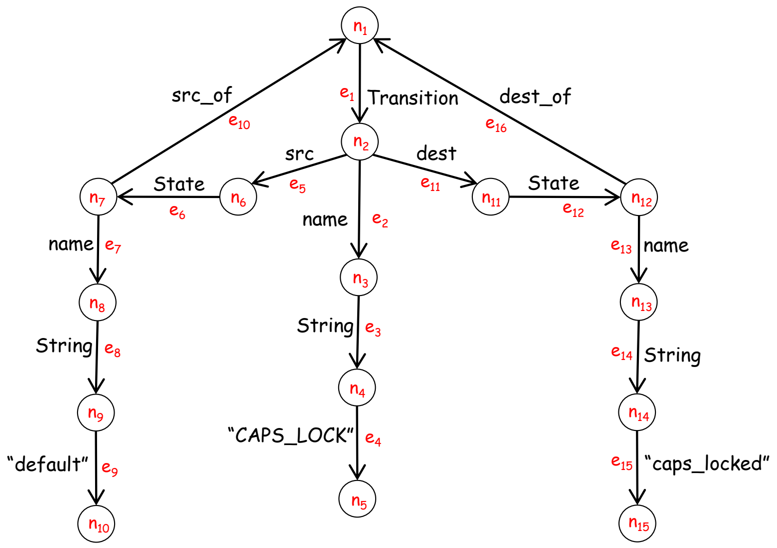


Figure 14: UncalRep graph of Figure 13.

graph and UncalRep graph bidirectionally without losing any information.

4 TransAlg in iGRT

In this section, we will explain the mechanism of iGRT's last part, the TransAlg part. This part targets at doing traceable transformation between InterRep graph and UncalRep graph bidirectionally. We will first introduce the algorithms for general graphs, and then instantiate it by taking a look at how it works on use case diagram.

4.1 General Algorithm

As we have stated before, for real-world graphs, according to the general schema designed, all the properties such as nodes and edges are regarded as elements and their attributes in the InterRep graph. Meanwhile, in the UncalRep graph, all of the elements and attributes are transformed to corresponding edge-labeled branches.

Now let's see how the TransAlg works on these two kinds of graphs so that they can be transformed to each other without losing any information. First we will explain the traceable transformation from InterRep graph to UncalRep graph, and then the reversed one.

A. InterRep to UncalRep

For each UncalRep graph, we will scan all the elements one by one, and reconstruct them as two nodes plus one edge. The edge is labeled with the element's name. For each attribute of the element, if it is primitive type, we will expand it to a new branch with three nodes and three edges. The edges are labeled with the attribute's name, the attribute's type and the attribute itself separately. If the attribute's type is element type, we will first add one edge labeling the attribute's name, and then check whether the element has been processed yet. For processed element, we will connect the edge to the element's first node. Else we will process the element using the above procedure and then connect the attribute with it.

In order to keep this transformation traceable, while doing the transformation, we will save the trace information in both parts at the same time. In detail, after transforming the element, we will save the corresponding UncalRep branch in the element and attribute, and save the element in the first node of the branch. After transforming the element's attribute, we will save the relevant branch in the element. In this way, all the trace information is kept well.

The pseudo code of the algorithm is as follows:

```
Algorithm traceable transI2U ( InterRep irg ) {

    for each unprocessed element e in irg:
        transform(e){
            record: e has been processed;
            expand it to $node_1 \rightarrow edge_1 \rightarrow node_2$;
            set $edge_1$'s label with e's name;
            save: $\{node_1, edge_1, node_2\} \rightarrow e$;
            save: $e \rightarrow node_1$;

            for each attribute a in e:
                if a's type is primitive
                    expand it to $edge_a \rightarrow node_a \rightarrow edge_b \rightarrow node_b \rightarrow edge_c \rightarrow node_c$;
                    set the source of $edge_a$ with the e's $node_2$;
                    set $edge_a$'s label with a's name;
                    set $edge_b$'s label with a's type;
                    set $edge_c$'s label with a's value;
                    save: $edge_a, node_a, edge_b, node_b, edge_c, node_c \rightarrow a$;
                else if its type is element e*
                    if e* has been processed
                        expand it to $edge_a$;
                        set $edge_a$'s label with a's name;
                        set the source of $edge_a$ with e's $node_2$;
                    set the destination of $\text{edge}_a$ with e*'s $\text{node}_1$;
                    *save*: $\text{edge}_a \rightarrow$a;
                else
                    expand it to $\text{edge}_a$;
                    set $\text{edge}_a$'s label with a's name;
                    set the source of $\text{edge}_a$ with e's $\text{node}_2$;
                        ***transform***(e*);
                        set the destination of $\text{edge}_a$ with e*'s $\text{node}_1$;
                        *save*: $\text{edge}_a \rightarrow$a;
        }

    }
```

When getting the UncalRep graph by this traceable transformation algorithm, we can easily trace back to the InterRep graph again by scanning all the nodes and picking up the InterRep elements saved in them as trace information. Then they all can automatically compose the original InterRep graph. The pseudo code of the trace back algorithm is as follows:

```
Algorithm ***back2InterRep*** ( UncalRep urg ) {

    create InterRep graph irg;

        for each node n in urg:
            if find an InterRep element e saved in n
                add e to irg;

        return irg;

}
```

B. UncalRep to InterRep

The traceable transformation algorithm from UncalRep graph to InterRep graph is quite like a reversion of the previous algorithm. In this algorithm, first of all, we will scan all the edges in the UncalRep graph. When finding one unprocessed edge l whose label is an element's name according to the pre-defined or user-defined graph schema, we will create a corresponding element e in the InterRep graph. And then we will scan all the branches below edge l. Here each branch will correspond to one attribute of e as described in the graph schema. If the type of the attribute is primitive, we will just compress the branch to an attribute and add it to e. Else if the type is element, we will check whether the element has been processed or not. If so, we will add the processed element as an attribute to element *e*. Else we will first process the element and then add it as an attribute to *e*. Trace information is also saved while doing the transformation. When compressing each branch to one element, we will save the element in the branch's first node, and save the branch in the element at the same time. When compressing the corresponding branch of an attribute, we will save it in the relevant attribute. The pseudo code of the algorithm is as follows:

```
Algorithm traceable transU2I (UncalRep urg){

    for each edge e with unprocessed start node in urg:
        transform(e){
            record: e's start node has been processed;
            if e's label signifies an element
                compress $node_a$→e→$node_b$ to element ele;
                save: $node_a$, e, $node_b$→ele;
                save: ele→$node_a$;
                for each outgoing edge from $node_b$ oe:
                    if oe signifies a primitive type attribute pa
                        compress oe→$node_a$→$edge_a$→$node_b$
                                    →$edge_b$→$node_c$ to ele's attribute;
                        save: oe, $node_a$, $edge_a$, $node_b$, $edge_b$, $node_c$→ele;
                    else if oe signifies an element type attribute ea
                        if ea has been processed
                            compress ea to ele's attribute;
                            save: oe→ele;
                        else
                            /* process oe→$node_a$→$edge_a$ */
                                transform($edge_a$)
                                compress $edge_a$'s corresponding element
                                            to ele's attribute;
                                save: oe→ele;
        }

}
```

Similarly, when getting the InterRep graph by this traceable transformation algorithm, we can easily trace back to the UncalRep graph again by scanning the elements and picking up all the UncalRep nodes and edges saved in them as the trace information. Then they all can automatically make up the original UncalRep graph. The pseudo code is as follows:

```
Algorithm back2UncalRep ( InterRep irg ) {
    create UncalRep graph urg;

    for each element e in irg:
        if find UncalRep nodes $n_1$, $n_2$, ..., $n_i$
                    and edges $e_1$, $e_2$, ..., $e_j$ saved in e
            add $n_1$, $n_2$, ..., $n_i$ and $e_1$, $e_2$, ..., $e_j$ to urg;

    return urg;

}
```

After introducing the general traceable transformation algorithms in TransAlg, let's see how it can work on the specific graph, use case diagram, in order to have a further understanding.

4.2 An Example

In this part, we again use the use case diagram in Figure 6 as concrete example. As Figure 15 illustrates, when given the InterRep graph in Figure 7 as the input for our TransAlg part, it will start transformation by scanning all the elements. When it meets the element Actor "tiger" (N_1), it will transform it to {n_6, e_6, n_7}, then the "name" attribute is being processed. Because this attribute's type is primitive, TransAlg will just expand it to {e_7, n_8, e_8, n_9, e_9, n_{10}}. When processing its "src_of" attribute, as the type is the "UniRelation" element and it has not been processed before, TransAlg will transfer to treat this element (E_1). {n_1, e_1, n_2} is first created and then {e_2, n_3, e_3, n_4, e_4, n_5} is also added corresponding to its "name" attribute. When processing its "src" attribute, as the attribute's type is "Actor" element and it has already been transformed, TransAlg will just add e_5 and connect it to n_6. For the "dest" attribute, as its type is "Usecase" element and it has not been processed before, TransAlg will again focus on this element. Then {n_{11}, e_{12}, n_{12}} and {e_{13}, n_{13}, e_{14}, n_{14}, e_{15}, n_{15}} is added. As the "dest_of" attribute is the processed element "UniRelation", TransAlg will just add e_{16} and connect it to n_1. After the element Usecase "eating meat" is processed, TransAlg will add e_{11} and let it point to n_{11}, and now the element UniRelation "associate" has also been processed. At last, TransAlg will add e_{10} and connect it to n_{11}. While doing the transformation, TransAlg will save the trace information as Figure 15 shows. In the InterRep graph, {n_6, e_6, n_7, e_7, n_8, e_8, n_9, e_9, n_{10}, e_{10}} is saved in element N_1 and its attributes. {n_1, e_1, n_2, e_2, n_3, e_3, n_4, e_4, n_5, e_5, e_{11}} is saved in element E_1 and its attributes, and {n_{11}, e_{12}, n_{12}, e_{13}, n_{13}, e_{14}, n_{14}, e_{15}, n_{15}, e_{16}} is saved in element N_2 and its attributes. In the other part UncalRep graph, N_1 is saved in n_6, N_2 is saved in n_{11} and E_1 is saved in n_1.

After the transformation from InterRep graph to UncalRep graph, if we want to trace back to the original InterRep graph, we can just scan all the nodes in the UncalRep graph and pick up N_1, N_2 and E_1 saved in them. Then these three elements will make up the InterRep graph.

On the other hand, when given the UncalRep graph in Figure 8 as input, our TransAlg part will start the transformation by scanning all the edges to find one whose label is an element's name. Here it will first meet e_1, then the element "UniRelation" (E_1) is created. By scanning its branch {e_2, n_3, e_3, n_4, e_4, n_5}, the "name" attribute "associate" is added to E_1. When meeting the branch edge e_5, as it represents an unprocessed element "Actor", N_1 is created, and the "name" attribute "tiger" is added. Again TransAlg will meet another attribute with element type "UniRelation", and as it has already been processed, TransAlg will just add E_1 to N_1 as the "src_of" attribute. After that, the "Actor" N_1 is added as E_1's "src" attribute. Similarly, TransAlg will regard E_1 as N_2's "dest_of" attribute and N_2 as E_1's "dest" attribute. The trace information is also saved in both part while doing the transformation.

After getting the InterRep graph, if we want to trace back to the original UncalRep graph, we can just scan all the elements and their attributes in the InterRep graph and find the UncalRep nodes and edges saved in them. Then we can compose the UncalRep graph automatically by using these nodes and edges.

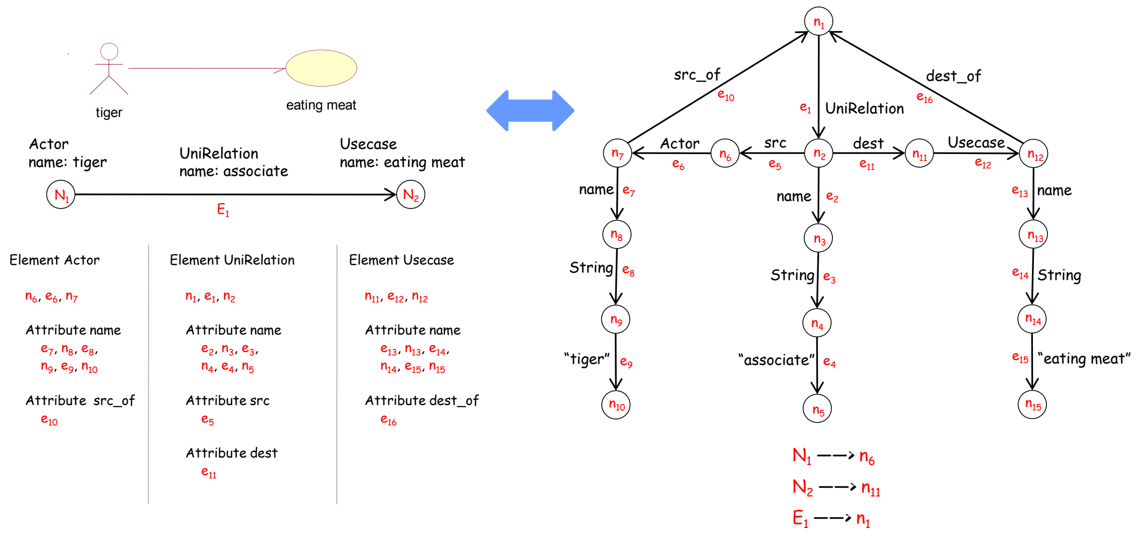


Figure 15: Transformation between Figure 7 and Figure 8 by TransAlg part.

Now we have a deep insight of how iGRT's TransAlg part works. As it presents traceable transformation between the graphs in InterRep part and UncalRep part without losing any information, we can take advantage of the "traceable" attribute and maintain the synchronization of the two kinds of graphs by propagating the graph update between them. In the next section, we will show two useful operations, graph modification propagating and graph query propagating, which help fulfill this synchronization task.

5 Operations for Synchronization

In order to synchronize the real world graph in InterRep and GRoundTram graph in UncalRep, a set of operations need to be provided for this purpose. In this section, we will describe two useful operations based on the trace information saved during the transformation. By these operations, users can keep two graphs being updated at the same time.

5.1 Graph Modification Propagating

In order to make two graphs synchronized, when one kind of the graph is modified, the other kind of the graph should also keep this modification in parallel. In detail, when we modify some elements or attributes in the IntreRep graph, the nodes and edges in the UncalRep graph corresponding to this modified part should also be changed. Meanwhile, changes in the InterRep graph ought to be reflected in the UncalRep graph as well.

This work consists of two main steps, the first step is difference analysis. In this step, we need to compare the original graph and the modified one to extract all the changed part between them. The second step is change impact analysis. After modified part being extracted, we need to recognize the relevant changes in the other kind of the graph by checking the saved trace information.

Here we will explain methodology on propagating two kinds of modification, adding and deleting, from InterRep graph to UncalRep graph. Solutions for propagating modifications of other kinds can easily be worked out by referring to these algorithms.

Suppose we have two graphs, oig and oig$^+$, being the original InterRep graph and the modified one separately, the modification only includes adding and deleting. By using the traceable transformation algorithm explained before, we have transformed the InterRep graph to UncalRep graph ug, with trace information saved in both parts. Our target is to get the corresponding modified UncalRep graph ug$^+$, which exactly matches with oig$^+$.

As stated before, the first step is difference analysis. This step is same for either adding or deleting. We will compare oig with oig+ to get all the affected parts of the modifications, and then get all the trace information saved in them. The trace information here will exactly be the nodes and edges in the UncalRep graph according to the modification. The second step, change impact analysis, differs from adding to deleting operations. For deleting operation, we will simply delete all the affected nodes and edges in ug to get ug$^+$. For adding operation, we will use the traceable transformation algorithm to transform the modified part to UncalRep graph. When meeting some elements or attributes being treated before, we will just connect the new transformed edge with the existed corresponding part in ug and finally get ug$^+$.

For example, Figure 16 shows a graph modification on the use case diagram we have mentioned before. Here the relation from "tiger" to "eating meat" is deleted. In order to reflect this modification on the UncalRep graph, first we need to identify all the affected elements and attributes in the InterRep graph related with this change. By checking the graph schema of the use case diagram, we can easily find that there are three places being changed, the UniRelation element "associate", the "src_of" attribute of the Actor element "tiger" and the "dest_of" attribute of the Usecase element "eating meat". They all have been deleted. Then by checking the saved trace information in these three parts, we can easily synchronize the modification to the UncalRep graph by deleting the corresponding nodes and edges $\{n_1, e_1, n_2, e_2, n_3, e_3, n_4, e_4, n_5, e_5, e_{10}, e_{11}, e_{16}\}$.

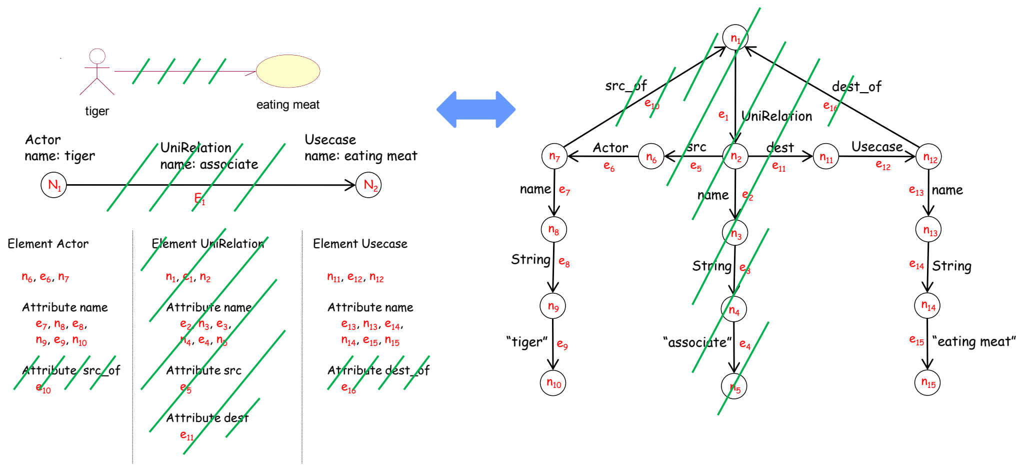


Figure 16: Example of graph modification.

5.2 Graph Query Propagating

As described before, we have presented a bidirectional transformation framework between general graphs and the GRoundTram graphs. Here come two problems : one is how to operate on the general graphs; the other one is how to translate the operation on general graphs to the GRoundTram graphs. We solve these two problems by proposing a graph query language iGQL for querying general graphs. User can write query Q based on the graph schema of the specified real world graphs, then Q in iGQL can be automatically translated into query Q' in UnQL which queries on the GRoundTram graph. Since we get Q', we can use the powerful bidirectional GRoundTram system to execute the query Q'.

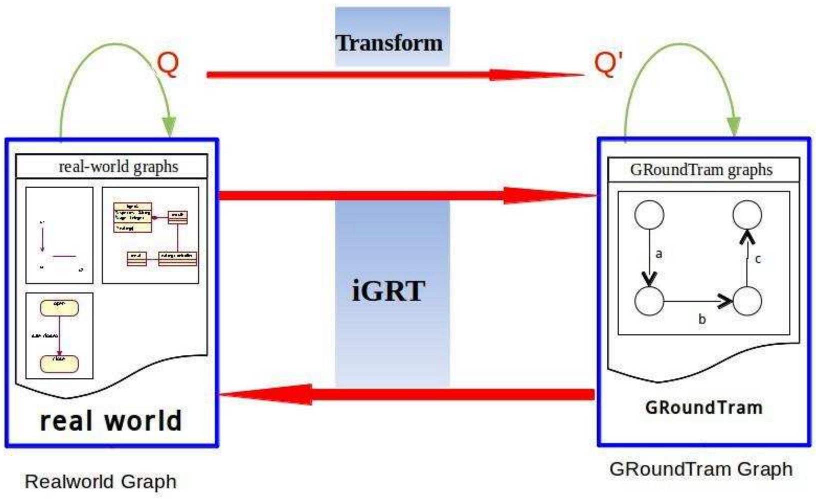


Figure 17: Overview of Query Translation

Figure 17 gives an overview of the propagating of query Q. The iGRT framework contains two parts: one is for transforming real world graphs into GRoundTram graphs; the other is automatically transformation of query Q into Q'.

Here let us take a look at a simple example for the use case diagrams illustrated in Figure 6. If we want to select the actor whose name is "tiger" in the use case diagrams as in Figure 7, we can write a query Q like this:

$Q =$ *select* { \$*a* }
  where { Actor : \$*a* } *in* \$db
    \$*a*.name = "tiger"

Query Q is written based on the schema UCD of the *usecase* graph. From the schema, we can see that Actor is the name of an element. The Actor has a *name* attribute, a *src_of* attribute and a *dest_of* attribute. The query is aiming at choosing actors whose name is "tiger".

In order to get the answer of Q by iGRT, we need to translate query Q into query Q' which is viewed as the input query of the GRoundTram system. Figure 8 illustrates the representation of a *usecase* graph in Figure 7 in GRoundTram system. The query Q' is expressed as follows:

$Q' =$ *select* { \$*a* }
  where { ∗.Actor : \$*a* } *in* \$db
    { name.String : { "tiger" } } *in* \$*a*

So in fact we execute query Q' on the GRoundTram system and then get the result through the bidirectional iGRT framework. When comparing Q' with Q, the main difference is that query Q does not give the information of types of each attribute, while in Q' the type of attribute also considered in the Query. This is because the graph data model of GRoundTram is for semi-structured data. So the type of attributes has been added as an edge label of the graph. This is just a simple case, the graph structure may also changed in complex situations.

6 Implementation

So far we have introduced all the concepts and methodologies used in iGRT. In this section, we will explain the technical details of iGRT.

We have implemented iGRT based on the eclipse platform. Figure 18 is the package explorer of iGRT. From the picture, we can see that it is composed of three modules, interRep, transAlg and uncalRep, responsible for graph representations and transformation algorithms.

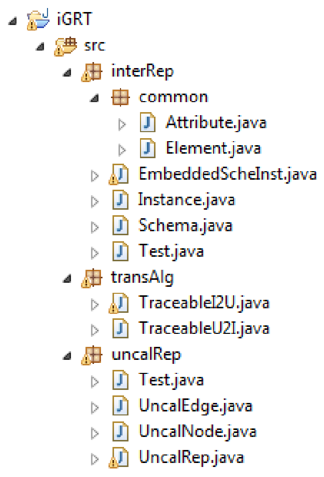
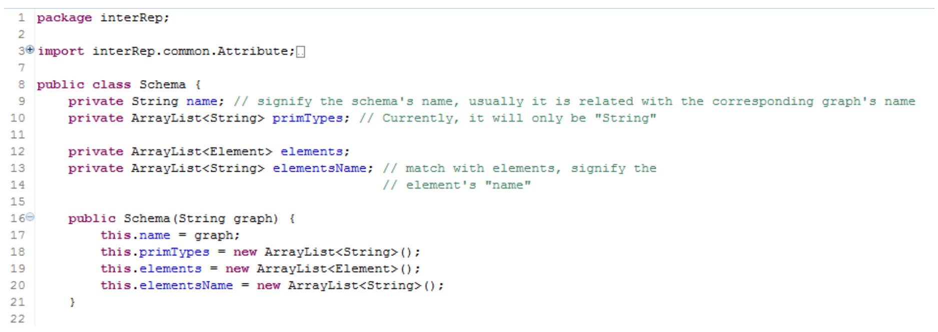

iGRT
src
interRep
common
Attribute.java
Element.java
EmbeddedScheInst.java
Instance.java
Schema.java
Test.java
transAlg
TraceableI2U.java
TraceableU2I.java
uncalRep
Test.java
UncalEdge.java
UncalNode.java
UncalRep.java

Figure 18: Package explorer of iGRT.

6.1 InterRep

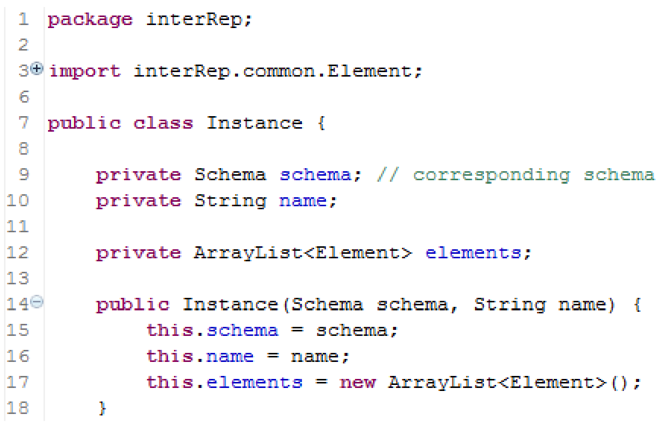
This module targets at normalizing the general graphs. It is composed of six classes, with two of them residing in the “common” package. Figure 19 is a code fragment of class “Schema”. It is used to save the schema of real-world graphs. As illustrated in the picture, it contains a name and several elements, represented by class “Element”. The “Element” possesses several attributes, represented by class “Attribute”, and “Attribute” has name, type and number.



```java
package interRep;

import interRep.common.Attribute;

public class Schema {
    private String name; // signify the schema's name, usually it is related with the corresponding graph's name
    private ArrayList<String> primTypes; // Currently, it will only be "String"

    private ArrayList<Element> elements;
    private ArrayList<String> elementsName; // match with elements, signify the
                                            // element's "name"

    public Schema(String graph) {
        this.name = graph;
        this.primTypes = new ArrayList<String>();
        this.elements = new ArrayList<Element>();
        this.elementsName = new ArrayList<String>();
    }

```

Figure 19: Code fragment of class ”Schema”.

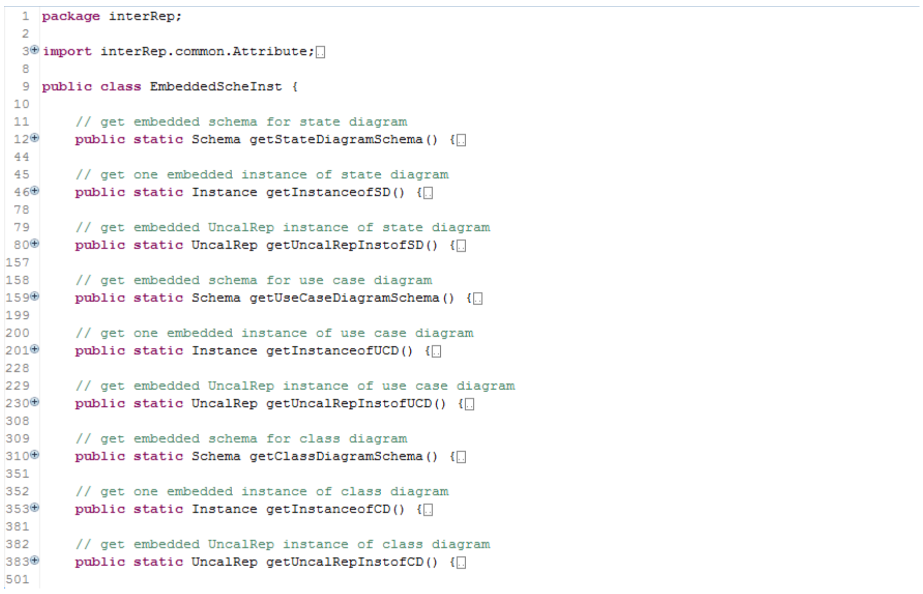
As described in Figure 20, class “Instance” signifies the instance of the schema. It still has some elements, and each element has some attributes. Here the element and attribute are also represented by class “Element” and “Attribute”. This is the reason why they are in the common” package. In order to separate them from being used in schema or in instance, they have one attribute called “role” to indicate their position.



```java
package interRep;

import interRep.common.Element;

public class Instance {

    private Schema schema; // corresponding schema
    private String name;

    private ArrayList<Element> elements;

    public Instance(Schema schema, String name) {
        this.schema = schema;
        this.name = name;
        this.elements = new ArrayList<Element>();
    }
```

Figure 20: Code fragment of class ”Instance”.

As stated before, we have embedded several schemas for the popular graphs as well as their instances in iGRT. These schemas and instances are located in class ”EmbeddedScheInst” as shown in Figure 21. They can be easily gotten by calling the static method.



```
package interRep;

import interRep.common.Attribute;

public class EmbeddedScheInst {

    // get embedded schema for state diagram
    public static Schema getStateDiagramSchema() {

    // get one embedded instance of state diagram
    public static Instance getInstanceofSD() {

    // get embedded UncalRep instance of state diagram
    public static UncalRep getUncalRepInstofSD() {

    // get embedded schema for use case diagram
    public static Schema getUseCaseDiagramSchema() {

    // get one embedded instance of use case diagram
    public static Instance getInstanceofUCD() {

    // get embedded UncalRep instance of use case diagram
    public static UncalRep getUncalRepInstofUCD() {

    // get embedded schema for class diagram
    public static Schema getClassDiagramSchema() {

    // get one embedded instance of class diagram
    public static Instance getInstanceofCD() {

    // get embedded UncalRep instance of class diagram
    public static UncalRep getUncalRepInstofCD() {
```

Figure 21: Code fragment of class "EmbeddedScheInst".

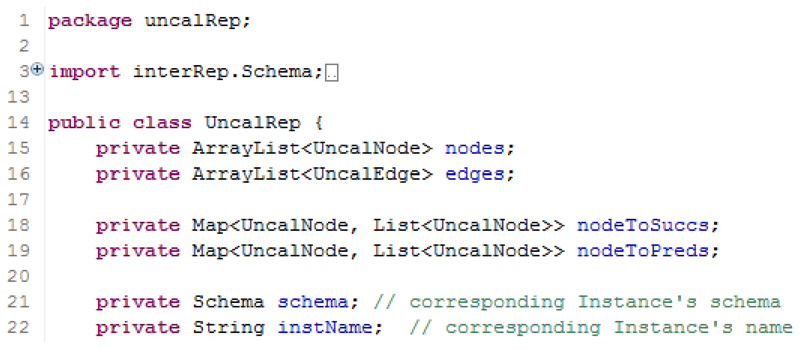
6.2 UncalRep

This module is responsible for representing the graphs in GRoundTram. Figure 22 is a code fragment of class "UncalRep". It is very much similar to graph representation. There are several nodes and edges inside it, represented by class "UncalNode" and "UncalEdge". And it has attribute "schema" to point out with which kind of graph schema it relates. As uncalRep graph is directed graph with edge labeled, "UncalNode" only has attribute "id" to identify different nodes, and "UncalEdge" has attribute "id" and "label", representing the label of the edge. One additional thing to mention in class "UncalRep" is that by calling the method "toDot", we can transform the UncalRep graph to graph in GRoundTram with its internal representation.

6.3 TransAlg

This module serves as the transformation algorithm part of iGRT. It is composed of two classes, "TraceableI2U" and "TraceableU2I", corresponding to the transformation from InterRep graph to UncalRep graph and the reversed one.

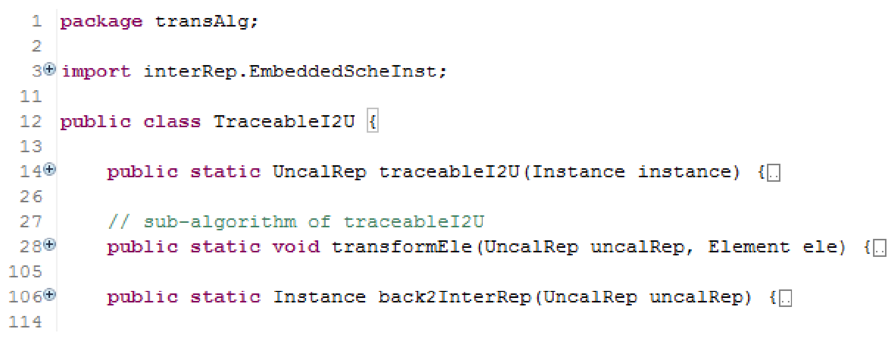
Figure 23 describes the class "TraceableI2U", it contains three mothods, "traceableI2U", "back2InterRep" and "transformEle". The former two methods works on doing traceable transformation from InterRep to UncalRep without losing any information, and the latter one is the sub-method



```java
package uncalRep;

import interRep.Schema;

public class UncalRep {
    private ArrayList<UncalNode> nodes;
    private ArrayList<UncalEdge> edges;

    private Map<UncalNode, List<UncalNode>> nodeToSuccs;
    private Map<UncalNode, List<UncalNode>> nodeToPreds;

    private Schema schema; // corresponding Instance's schema
    private String instName;  // corresponding Instance's name
```

Figure 22: Code fragment of class ”UncalRep”.

used in “traceableI2U”. The “TraceableU2I” is quite the similar, so we will not explain it here.



```java
package transAlg;

import interRep.EmbeddedScheInst;

public class TraceableI2U {

    public static UncalRep traceableI2U(Instance instance) {

    // sub-algorithm of traceableI2U
    public static void transformEle(UncalRep uncalRep, Element ele) {

    public static Instance back2InterRep(UncalRep uncalRep) {
```

Figure 23: Code fragment of class ”TraceableI2U”.

7 Conclusion

This paper presents iGRT, a generic interface for GRoundTram system. iGRT serves as a bridge between the real world and the GRoundTram system. We have designed a general representation called InterRep for real world graph according to the graph schema and UncalRep for internal graph of GRoundTram. Meanwhile, we have provided traceable transformation algorithms on these two kinds of graphs so that they can be transformed to each other bidirectionally without losing any information. Moreover, we can easily keep InterRep graph and UncalRep graph synchronized by operations such as graph modification propagating and graph query propagating based on the saved trace information. By using iGRT, we manage to make GRoundTram system more applicable to the real world, thus taking advantage of its powerful bx processing ability.

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