Model-Based Software Engineering

Lecture 08 – Transformation

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SOFTWARE ENGINEERING

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Leibniz Universität Hannover

in the last lecture...

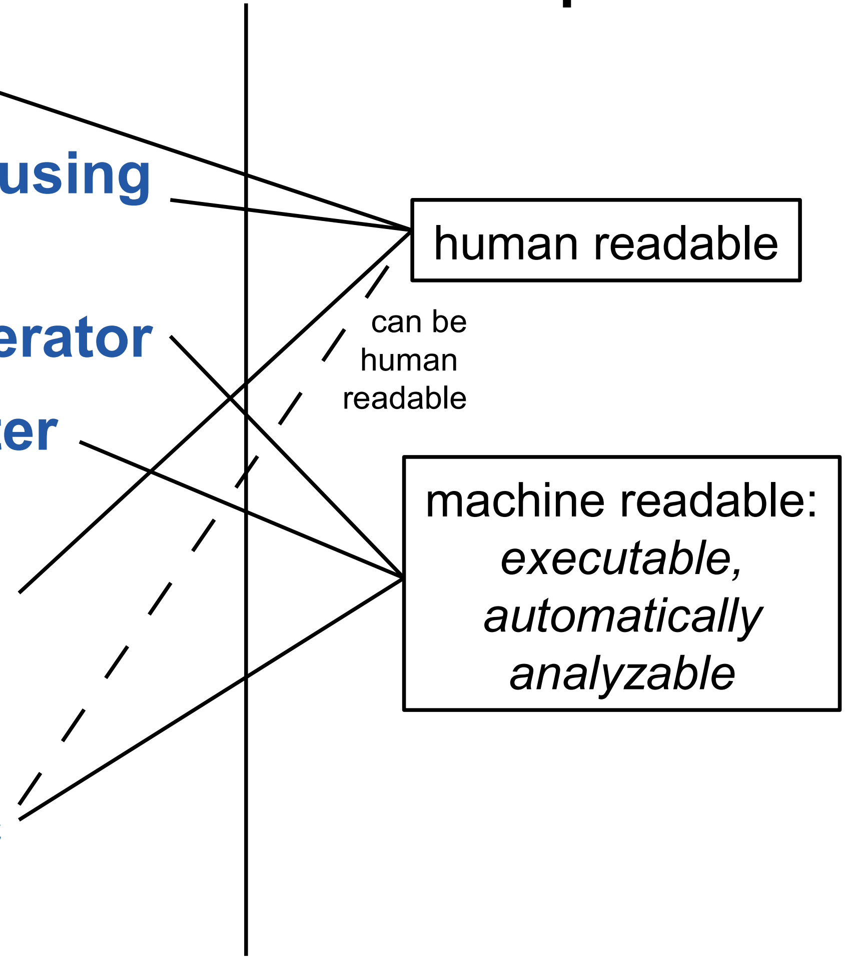
5.1. Introduction to semantics, transformations, execution, analysis

Ways to Define Semantics?

in the last lecture...

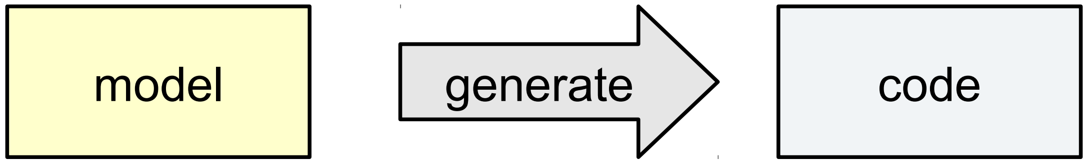
- How do we define the semantics of a formal language?
  - By **using natural language**
  - By **giving a formal definition using mathematics**
  - By **implementing a code generator**
  - By **implementing an interpreter (“virtual machine”)**
  - By **specifying a mapping to a semantic domain model**
  - By **implementing a model transformation to a semantic domain model**

Purpose:



Code Generator

in the last lecture...

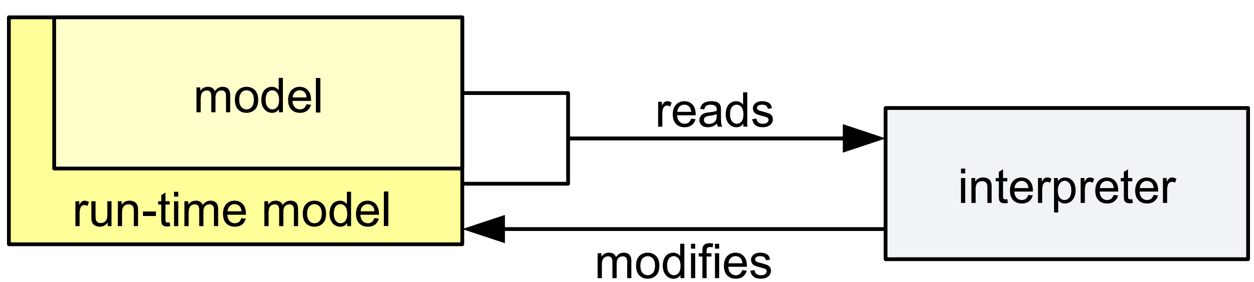


- for example: A state machine to Java generator defines the semantics of state machines **by a mapping to Java**
  - the semantics of Java is precisely specified in a specification https://docs.oracle.com/javase/specs/jls/se8/jls8.pdf
  - the semantics of Java is also precisely defined **through its mapping to Java byte code**,
    - which is again precisely specified in a specification, see https://docs.oracle.com/javase/specs/jvms/se8/jvms8.pdf
    - or for which the semantics is defined **in the form of different virtual machine implementations**

Programming an Interpreter ("Virtual Machine")

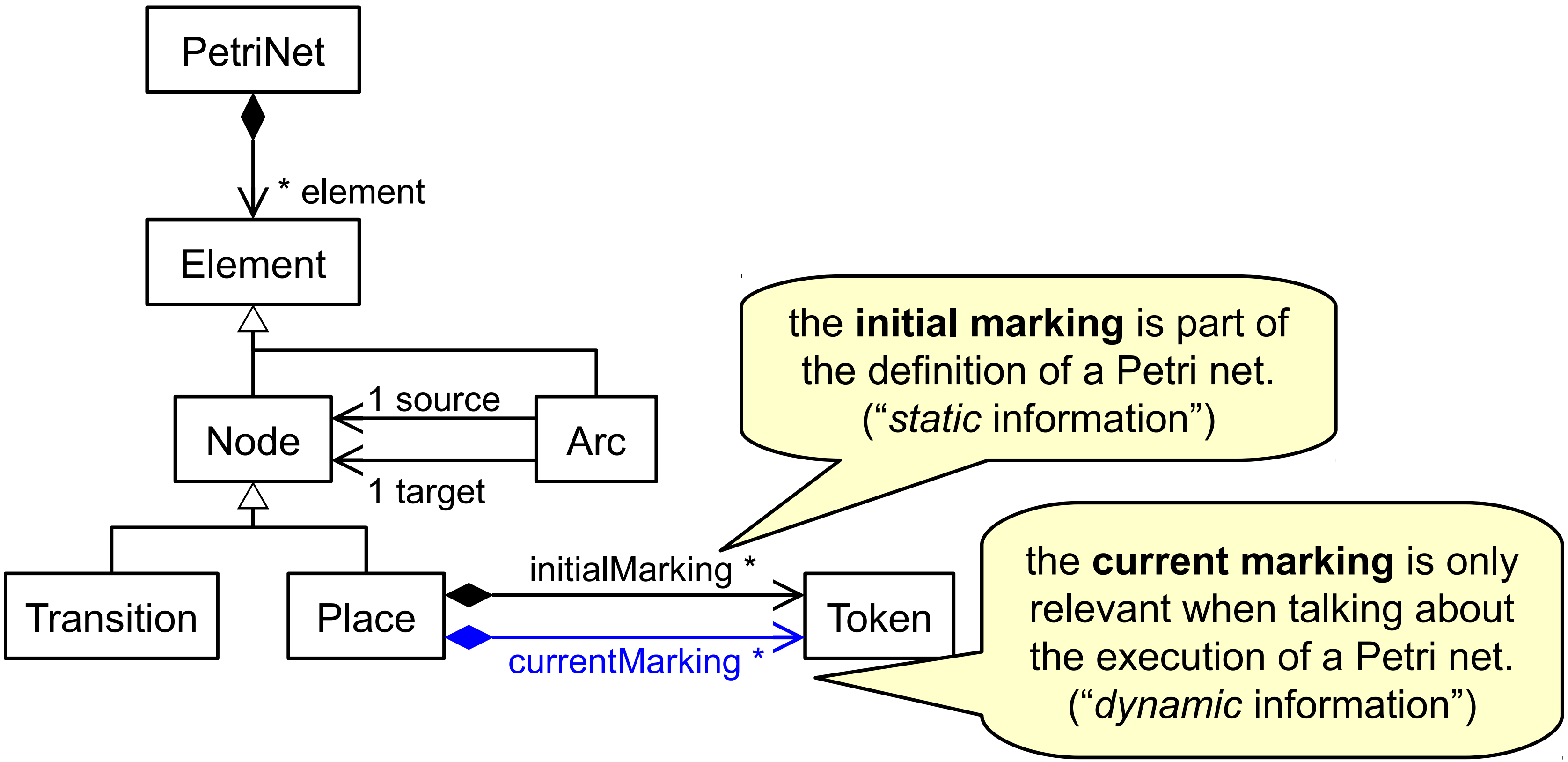
in the last lecture...

- for languages dealing with behavior, we can extend the metamodel by constructs that capture **run-time concepts**
  - for example: model "heap", "stack", "variable bindings", etc. for a programming language
- The interpreter can read the model and its runtime extension
- The runtime extension part captures the "current state" of execution, which the interpreter can modify



Interpreter and Run-time Model Extension

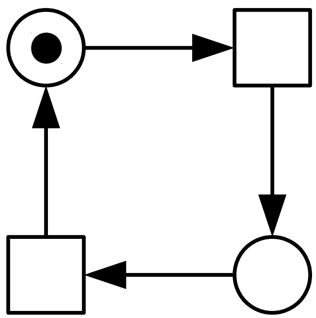
- Example: Petri net runtime extension



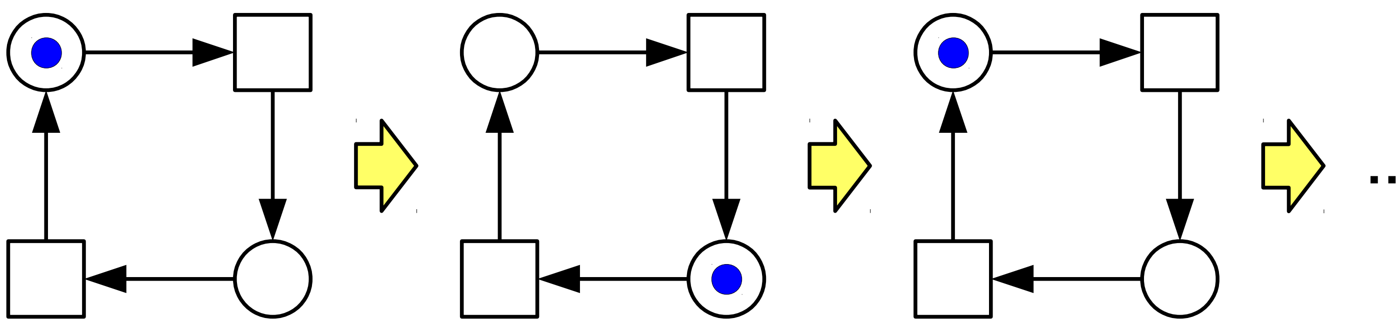
Interpreter and Run-time Model Extension

- Example: Petri net runtime extension

static:



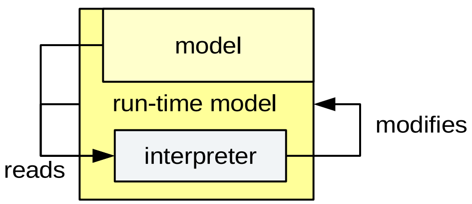
dynamic:



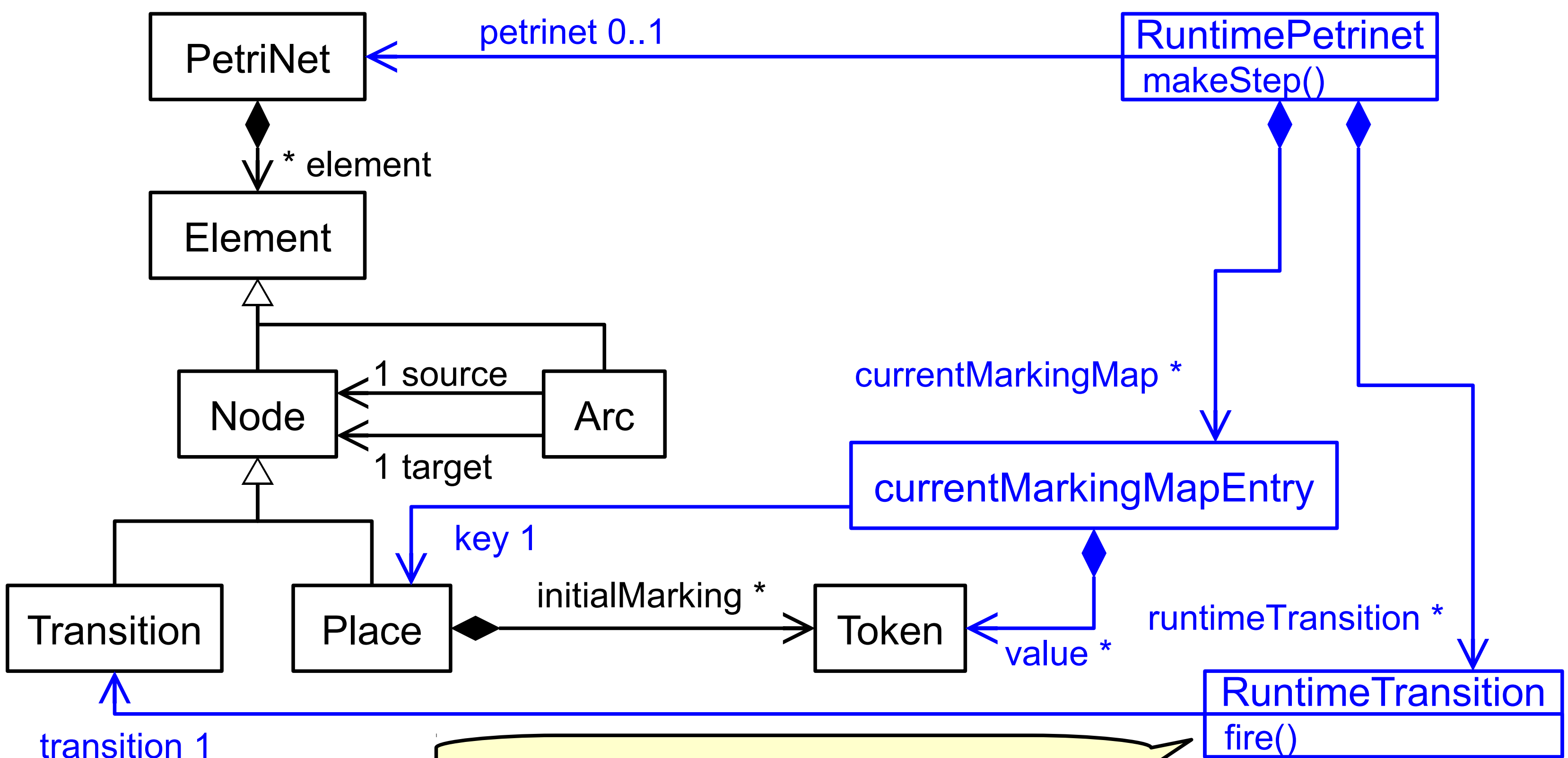
Interpreter and Run-time Model Extension

in the last lecture...

- Example: Petri net interpreter part of the runtime model



Better separation of concerns: the dynamic logic becomes part of the runtime model extension

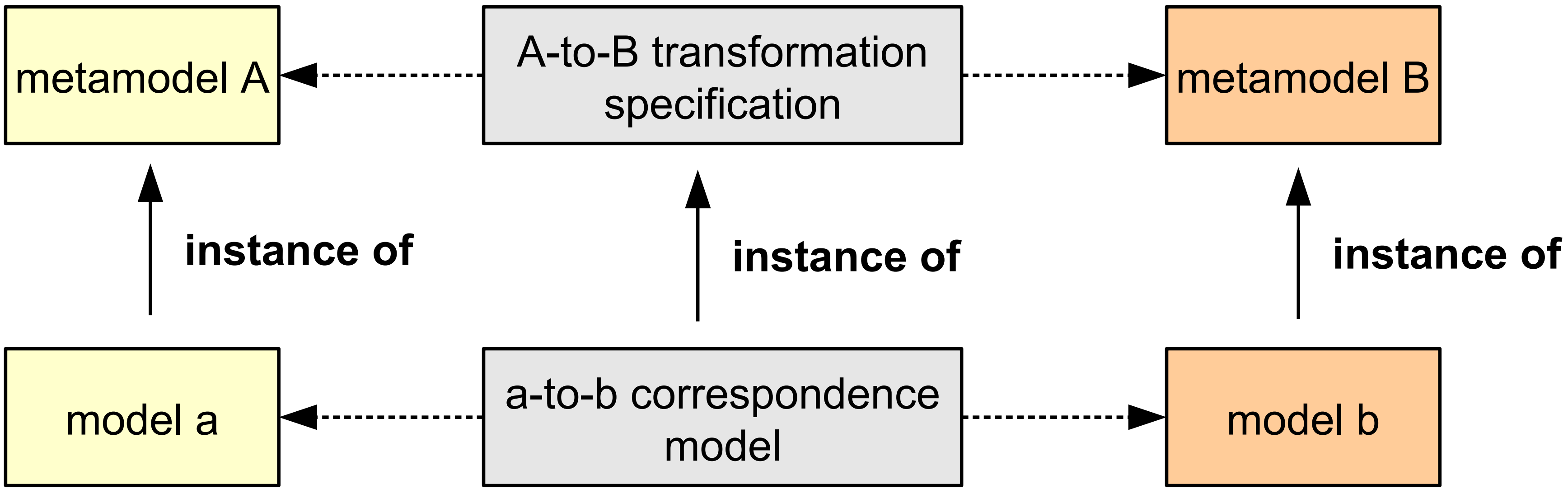


good encapsulation (in spirit of OO)

Model-to-Model Transformations

in the last lecture...

- A typical way to view model-to-model transformations
  - transformation from language A to language B
  - the transformation specification refers to metamodels A and B
  - sometimes: the transformation creates a *correspondence model* of how elements of model a and b relate specifically

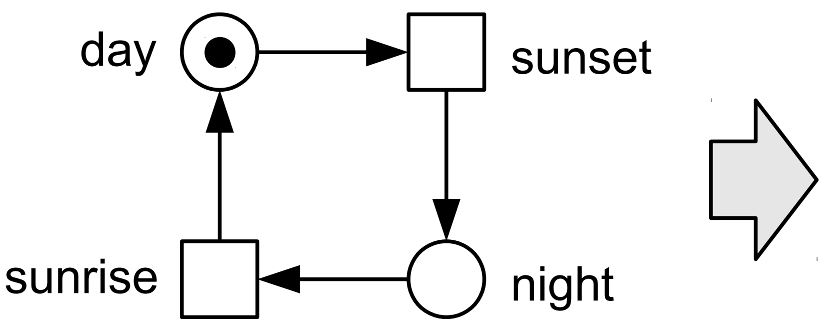


5.2. Model-to-text transformation (code generation)

Example: Petrinet to Java

in the last lecture...

- Example:




```java
public class DayAndNight {
	// places
	int day=1; int night=0;
	// main makeStep method
	public void makeStep(){
		if (canFireSunset()){
			doFireSunset()
		} else
		if (canFireSunrise()){
			doFireSunrise()
		} else
		{ System.out.println("Cannot fire");}
	}
	// transition's canFire and doFire methods
	protected boolean canFireSunset(){
		return (day > 0);
	}
	protected void doFireSunset(){
		day--; night++;
	}
	protected boolean canFireSunrise(){
		return (night > 0);
	}
	protected void doFireSunrise(){
		night--; day++;
	}
}
```

Xtext and Xtend

in the last lecture...

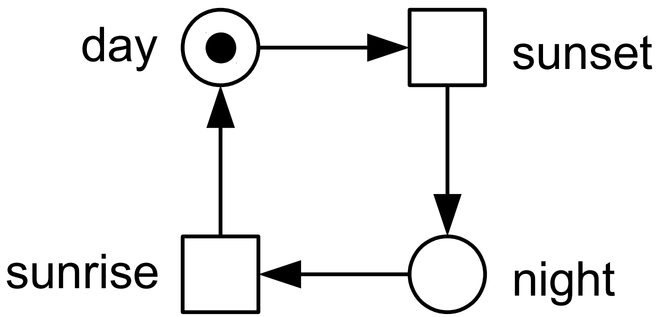
- We can implement our custom code generator for example as follows:

```
    override void doGenerate(Resource resource,
        IFileSystemAccess2 fsa,
        IGeneratorContext context
    ) {
        for (pn : resource.allContents.toIterable.filter(Petrinet)){
            fsa.generateFile(
                "petrinets/" + pn.name + ".java",
                pn.compile
            )
        }
    }

    def compile(Petrinet pn){
        '''
        package petrinets;

        public class «pn.name» {

            // places
            «FOR p : pn.element.filter(Place)»
                «p.compile»
            «ENDFOR»
            // main makeStep method
            public void makeStep(){
                «FOR t : pn.element.filter(Transition)»
                    «t.compileForMakeStep»
                «ENDFOR»
                { System.out.println("Cannot fire");}
            }

            // transition's canFire and doFire methods
            «FOR t : pn.element.filter(Transition)»
                «t.compile»
            «ENDFOR»
        }
        '''
    }
```

...

Xtext and Xtend

- For execution, we also need a main method...




```
public class DayAndNight {

    // main method
    public static void main(String[] args) {
        DayAndNight dayAndNight
            = new DayAndNight();
        // make 100 steps
        for (int i = 0; i < 100; i++) {
            dayAndNight.makeStep();
        }
    }

    public void makeStep(){
        ...
    }

    ...
}
```

Xtext and Xtend

creates main method that calls makeStep() 100 times.

```
def compile(Petrinet pn){
    '''
    package petrinets;

    public class «pn.name.toFirstUpper» {

        // main method
        public static void main(String[] args) {
            «pn.name.toFirstUpper» «pn.name.toFirstLower»
                = new «pn.name.toFirstUpper»();
            // make 100 steps
            for (int i = 0; i < 100; i++) {
                «pn.name.toFirstLower».makeStep();
            }
        }

        // places
        «FOR p : pn.element.filter(Place)»
            «p.compile»
        «ENDFOR»
        // main makeStep method
        public void makeStep(){
            «FOR t : pn.element.filter(Transition)»
                «t.compileForMakeStep»
            «ENDFOR»
            { System.out.println("Cannot fire");}
        }
```

Xtend Template Expressions

- Everything enclosed in three single quotes (''' … ''') is a **template expression** in Xtend
- Use guillemets («, » "french quotes") to insert **interpolated expression**
  - other Xtext expressions that evaluate to a String
  - their result will be inserted into the template string

```
def compile(Petrinet pn){
    '''
    package petrinets;

    public class «pn.name.toFirstUpper» {
```

Xtend Template Expressions

- In template expressions, there are special loop constructs
  - using FOR / ENDFOR

template expression loop

```
// places
«FOR p : pn.element.filter(Place)»
    int «p.name»=«p.initialMarking»;
«ENDFOR»
```

normal Xtend loop (Java-like)

```
for (pn : resource.allContents.toIterable.filter(Petrinet)){
    fsa.generateFile(
        "petrinets/" + pn.name + ".java",
        pn.compile
    )
}
```

Xtend Template Expressions

- In template expressions, there are special loop constructs
  - using FOR / ENDFOR
- The loops also support BEFORE, AFTER, and SEPARATOR expressions
  - for example

```
«FOR p : paragraphs
    BEFORE '<div>'
    SEPARATOR '</div><div>'
    AFTER '</div>'»
  <h1>«p.headline»</h1>
  <p>
    «p.text»
  </p>
«ENDFOR»
```

SOFTWARE ENGINEERING

5.3. Model-to-model transformation – foundations and classification

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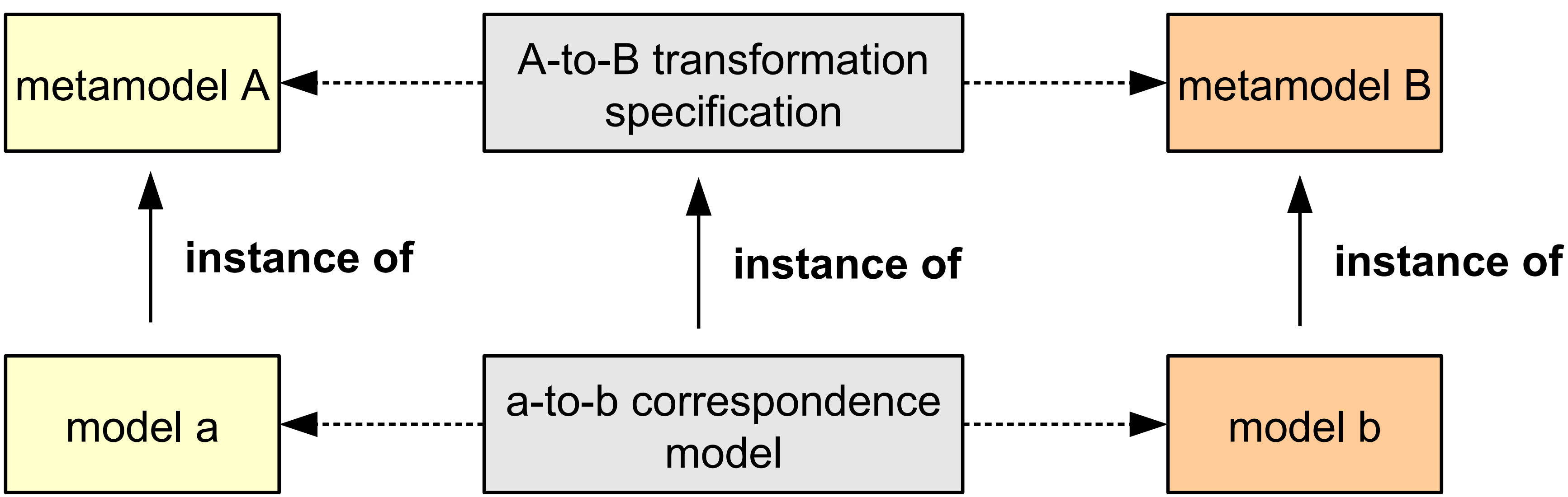
Model-to-Model Transformations

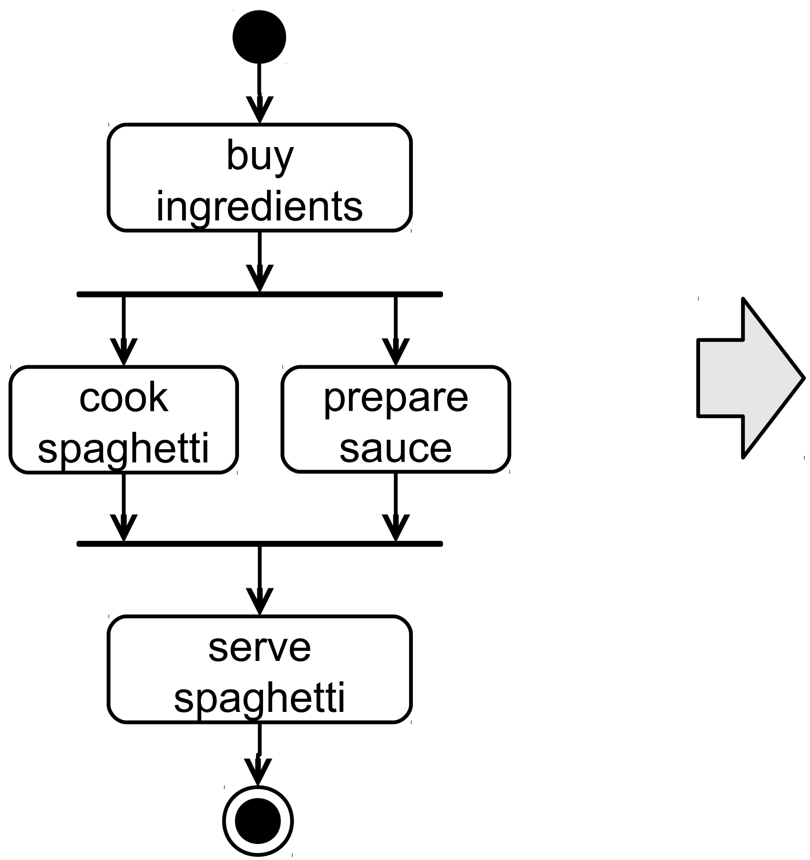
in the last lecture...

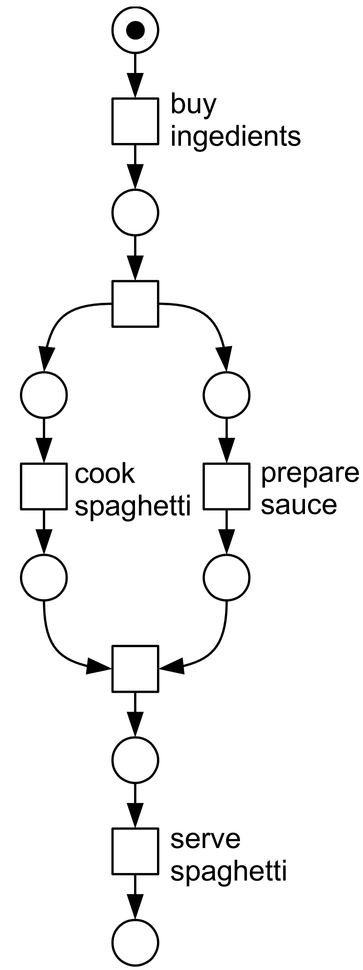
- A typical way to view model-to-model transformations
  - transformation from language A to language B
  - the transformation specification refers to metamodels A and B
  - sometimes: the transformation creates a *correspondence model* of how elements of model a and b relate specifically



Model-to-Model Transformations

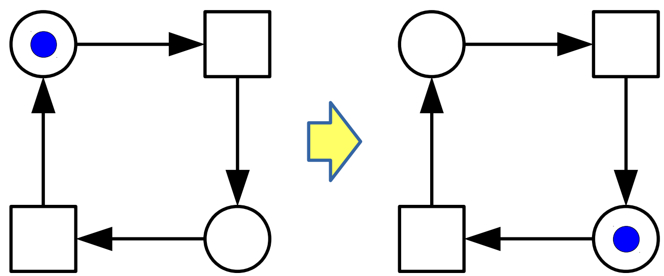
- Example Model-to-Model transformation:
  - Transform UML Activity Diagrams to Petri nets
  - To support formal analysis and execution

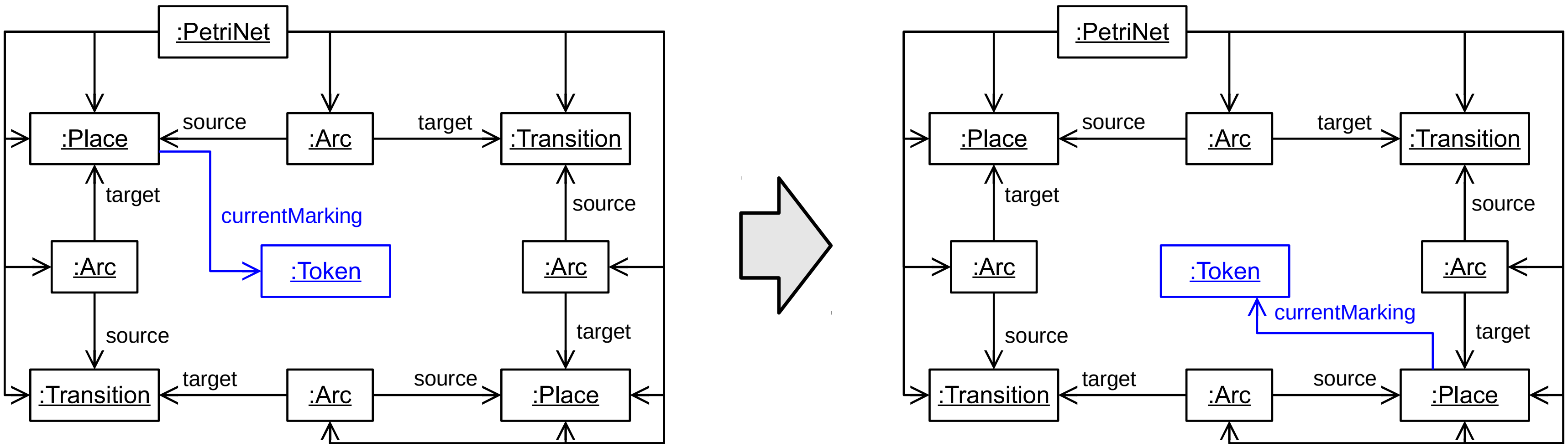




Model-to-Model Transformations

- Example Model-to-Model transformation:
  – Transform one Petri net into another





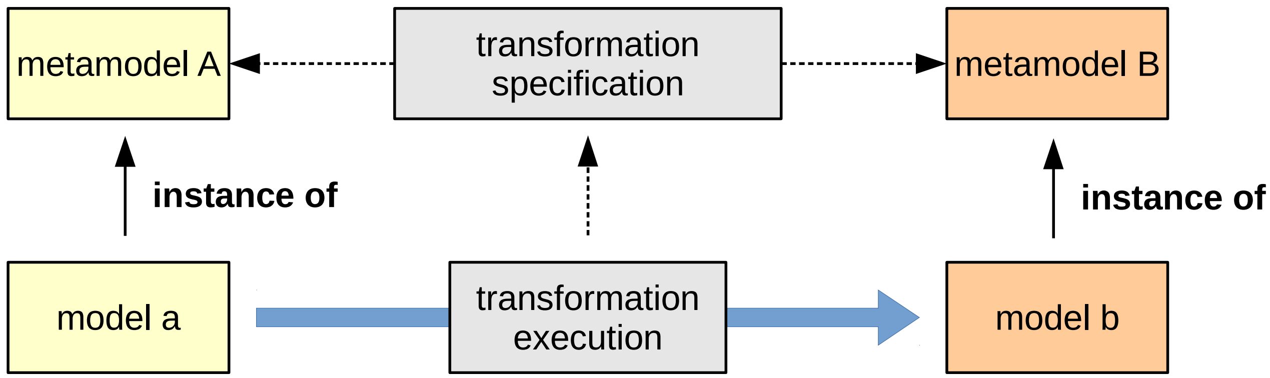
Exogenous vs. Endogenous Model Transformations

- Model transformations can create target models from source models (**Exogenous, *“Out-place”***)
  - possibly different source and target metamodels
  - source model is retained
  - example: UML activity diagram to Petri net

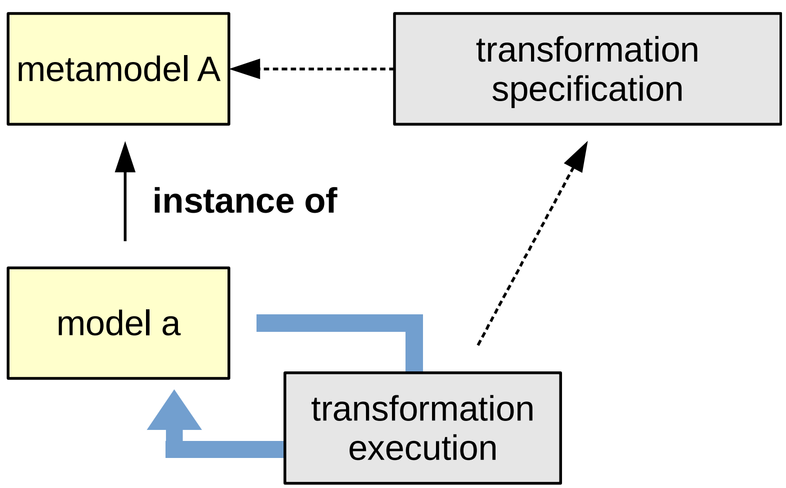
- Model transformations can also modify a source model (**Endogenous, *“In-Place”***)
  - target model is an updated version of the source model
  - original version of the source model is discarded
  - source and target model has the same metamodel
  - example: Petri net “move token” transformation

Exogenous vs. Endogenous Model Transformations

- **Exogenous**:



- **Endogenous**:



Why Model-to-Model Transformations?

- We may need model transformations for various purposes
  - As a step towards code generation
  - Execution
  - Define the semantics to the modeling language
  - Support formal analysis
  - Generate Documentation
  - Creating different view models from a base model
    - for different purposes and for different stakeholders
  - Refactoring
  - Model evolution (metamodel changed, instances need to be changed accordingly)

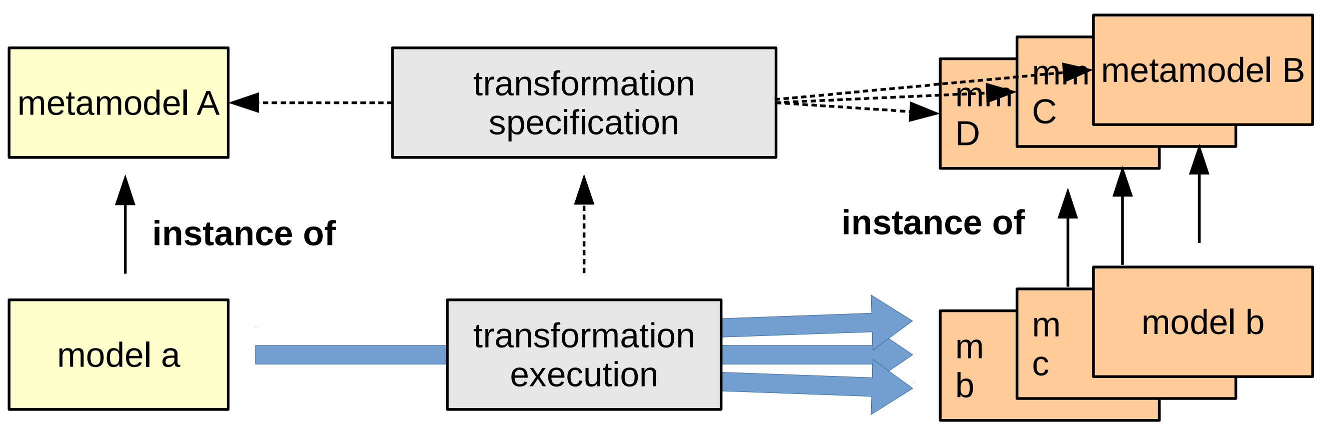
Why Model-to-Model Transformations?

- We may need model transformations for various purposes
  - As a step towards code generation (***ex****ogenous*)
  - Execution (***end****ogenous*)
  - Define the semantics to the modeling language (***end/ex***)
  - Support formal analysis (***end/ex***)
  - Generate Documentation (***ex***)
  - Creating different view models from a base model (***ex***)
    - for different purposes and for different stakeholders
  - Refactoring (***end***)
  - Model evolution (metamodel changed, instances need to be changed accordingly) (***ex***)

One-to-Many, Many-to-One, Many-to-Many Model Transformations

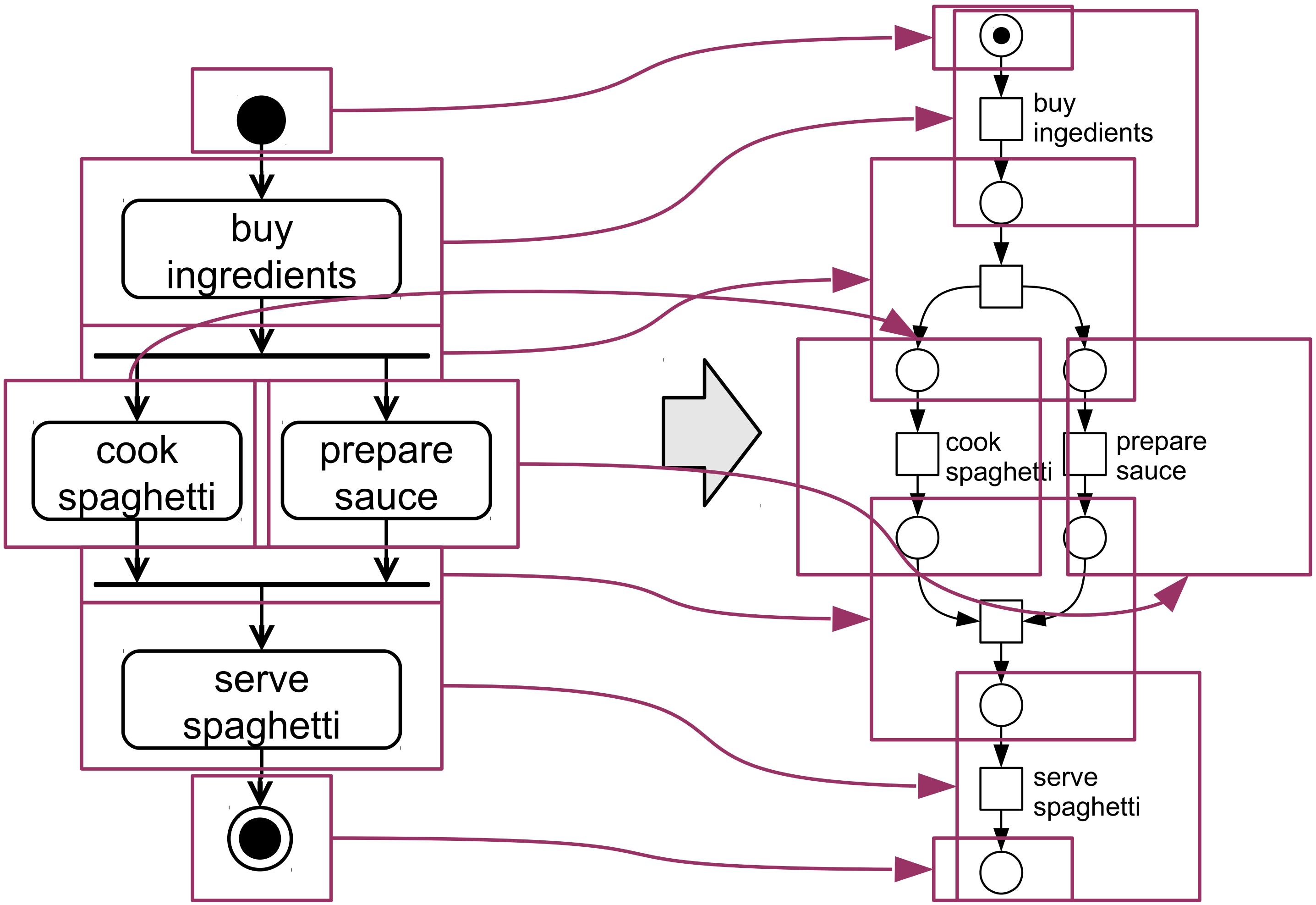
- Transformations can also
  - create multiple target models from one source model (**one-to-many**)
  - create one target model from multiple source models (**many-to-one**)
  - or create many target models from many source models (**many-to-many**)
  - Multiple source/target models may have different metamodels

- illustration: one-to-many



Model Transformation Rules

- Most model transformation formalisms use some form of **rules** to modularize a transformation for its different cases



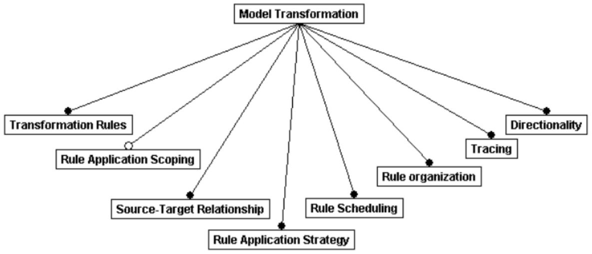
Model Transformation Technology

- Many model transformation languages and tools exist
  - many different ideas and underlying philosophies
    - inspired by compiler theory, constraint solving, graph theory, procedural programming, functional programming,
  - some approaches have perished, some have evolved

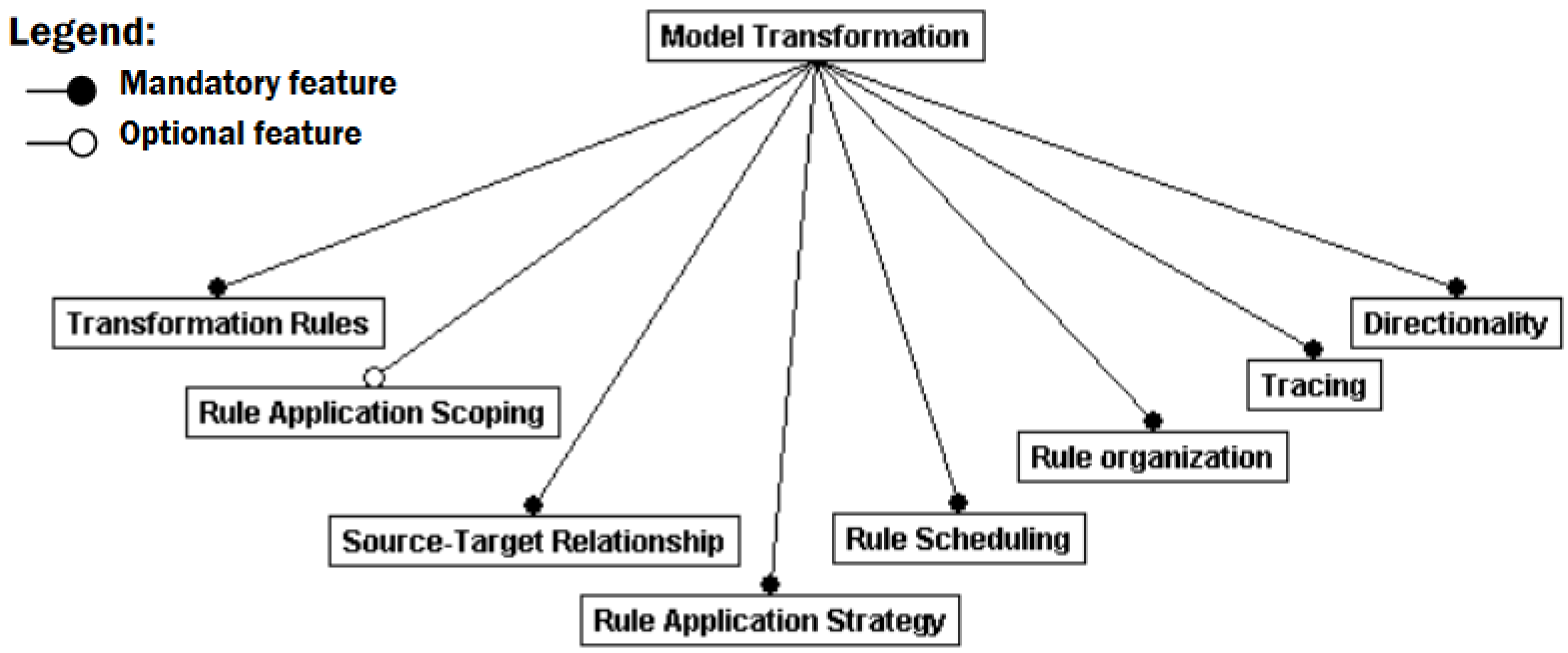
- Examples:
  - Query/View/Tranformation-Relations (QVT-R), QVT-Operational (QVT-O), Atlas Transformation language (ATL), Epsilon Transformation language, Story Diagrams, MOFLON, Triple Graph Grammar Interpreter (TGG-Interpreter), VIATRA, UMLX, ATOM, Tefkat, Modgraph, GROOVE, Henshin, ...

Model Transformation Taxonomy

- Krzysztof Czarnecki and Simon Helsen, “Classification of Model Transformation Approaches”, Workshop on Generative Techniques in the Context of Model-Driven Approaches, OOPSLA 2003
  - http://www.s23m.com/oopsla2003/czarnecki.pdf

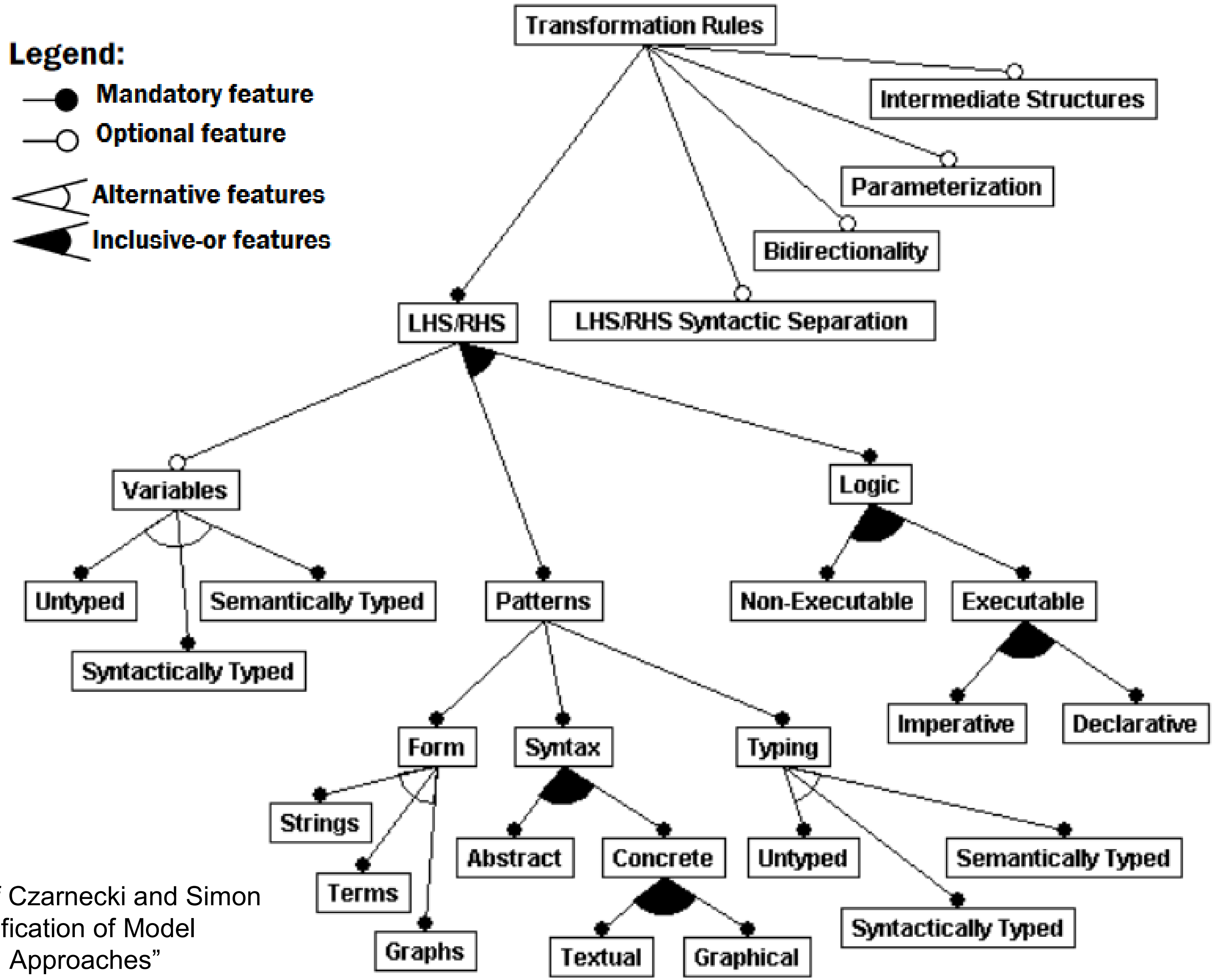


Model Transformation Taxonomy



From Krzysztof Czarnecki and Simon Helsen, “Classification of Model Transformation Approaches”

Model Transformation Taxonomy



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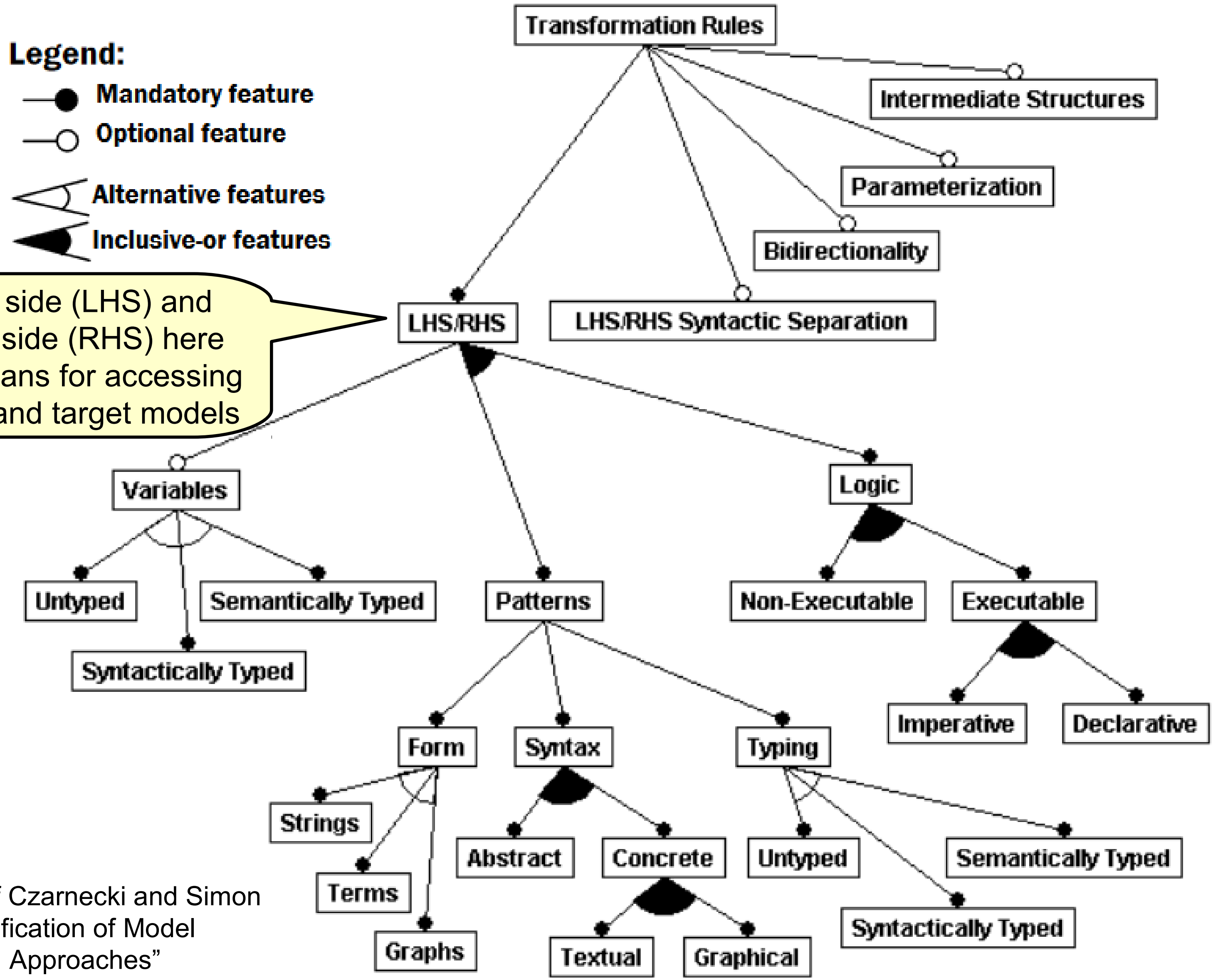
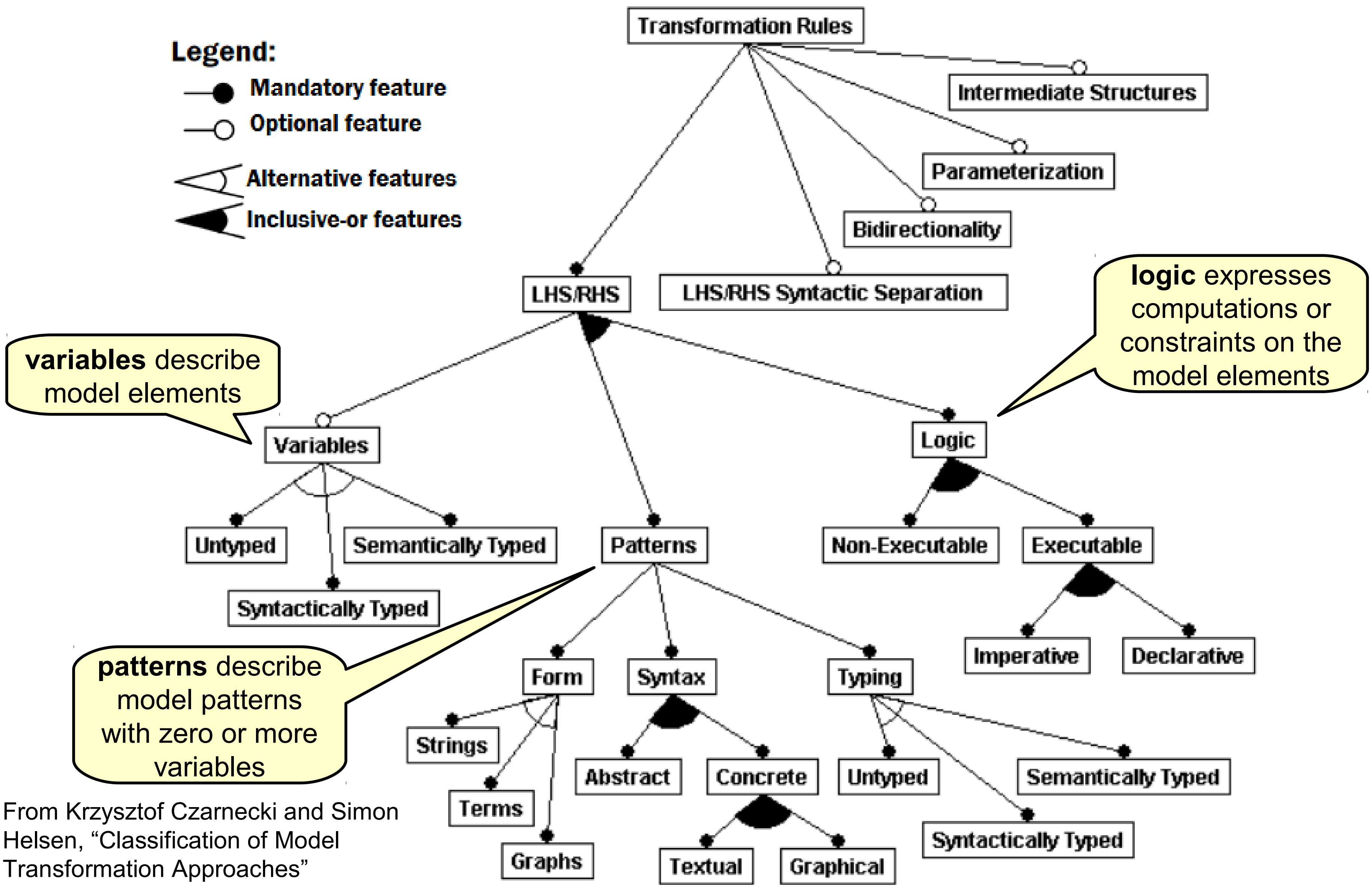


Left-hand side (LHS) and right-hand side (RHS) here refers to means for accessing the source and target models

From Krzysztof Czarnecki and Simon Helsen, "Classification of Model Transformation Approaches"

Model Transformation Taxonomy

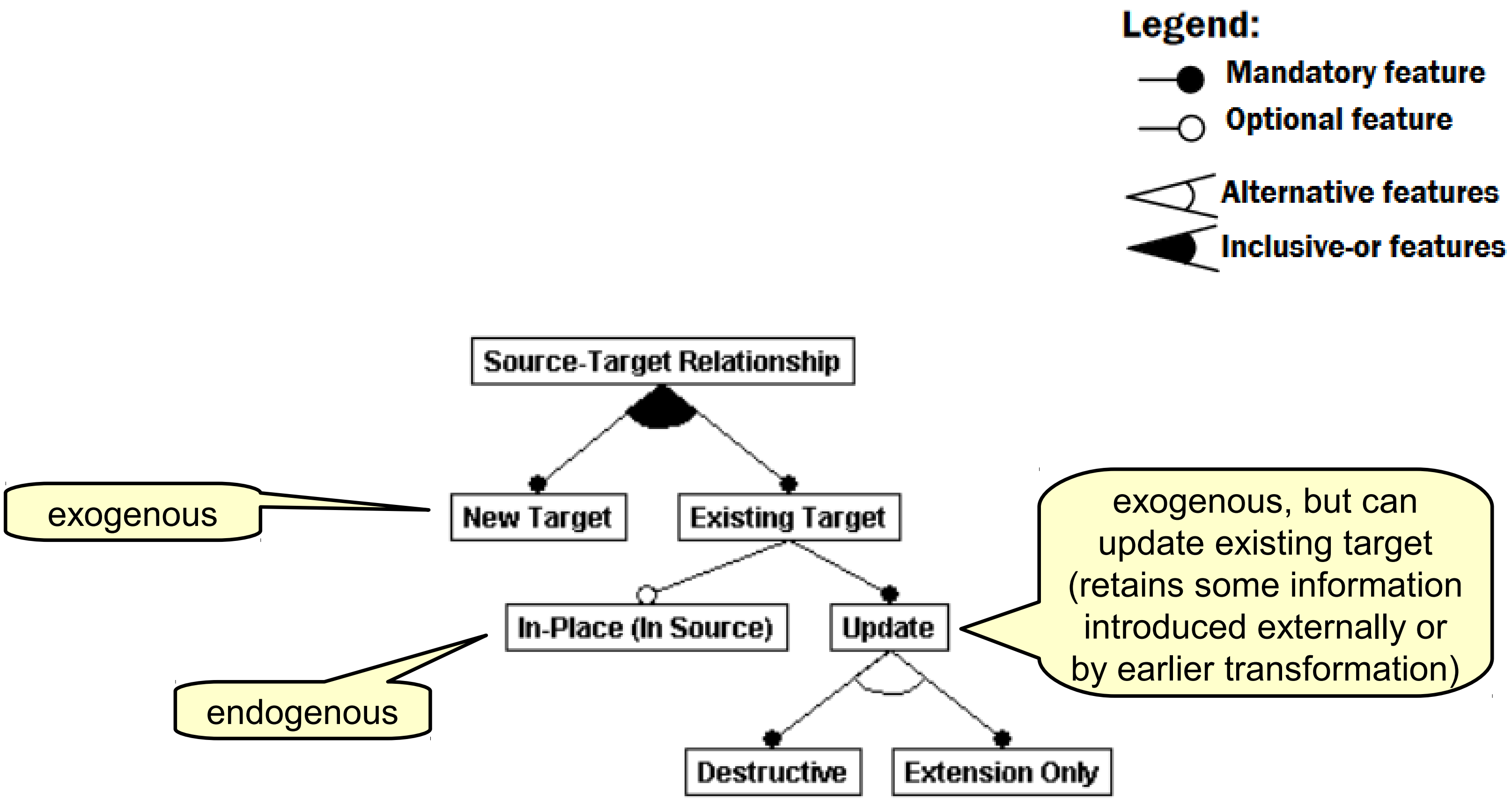


From Krzysztof Czarnecki and Simon Helsen, "Classification of Model Transformation Approaches"

Model Transformation Taxonomy
Imperative vs. Declarative

- **Imperative** (also called **operational**) Logic:
  - Detailed instructions are given on how a certain computation must be carried out
    - by a list of instructions or in form of an algorithm
- **Declarative** Logic:
  - constraints or conditions that describe a correct outcome of a computation are given
  - declarative logic can be **executable** if some solver or algorithm exists that can find a solution that satisfies the given constraints or conditions
- for declarative logic the processing is *potentially slower* than for imperative logic
- declarative logic is often *easier to understand* by users

Model Transformation Taxonomy



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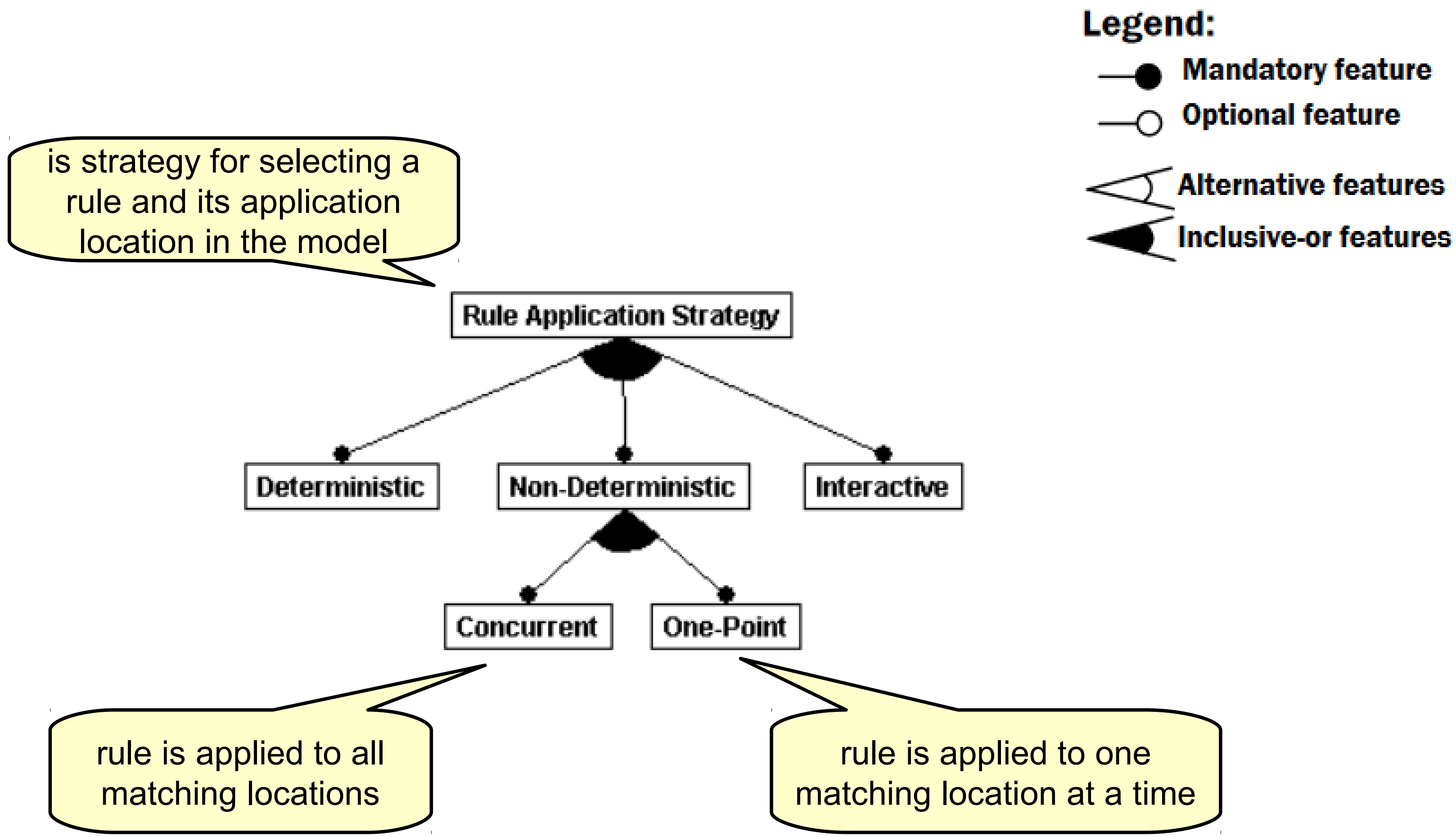

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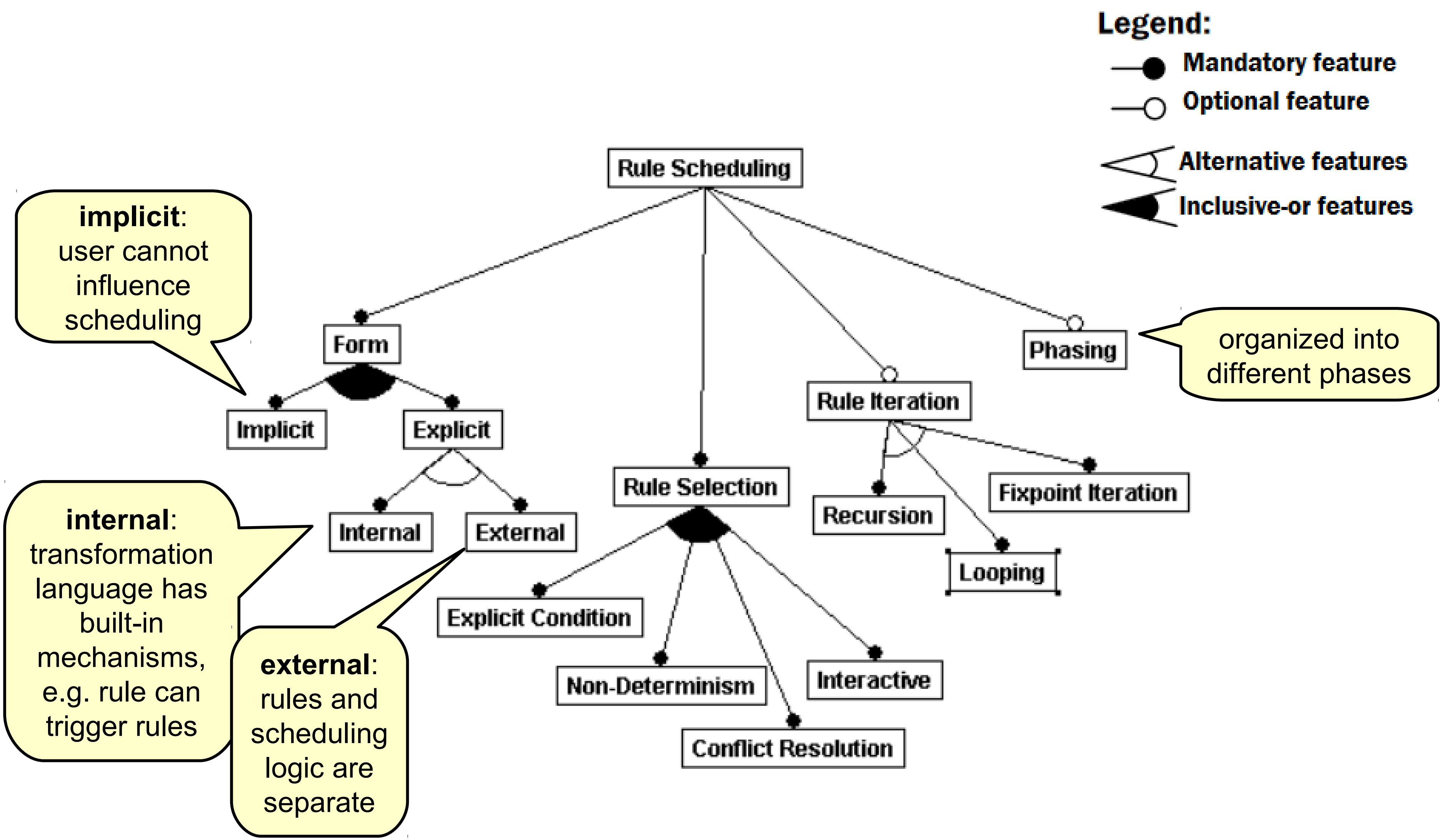

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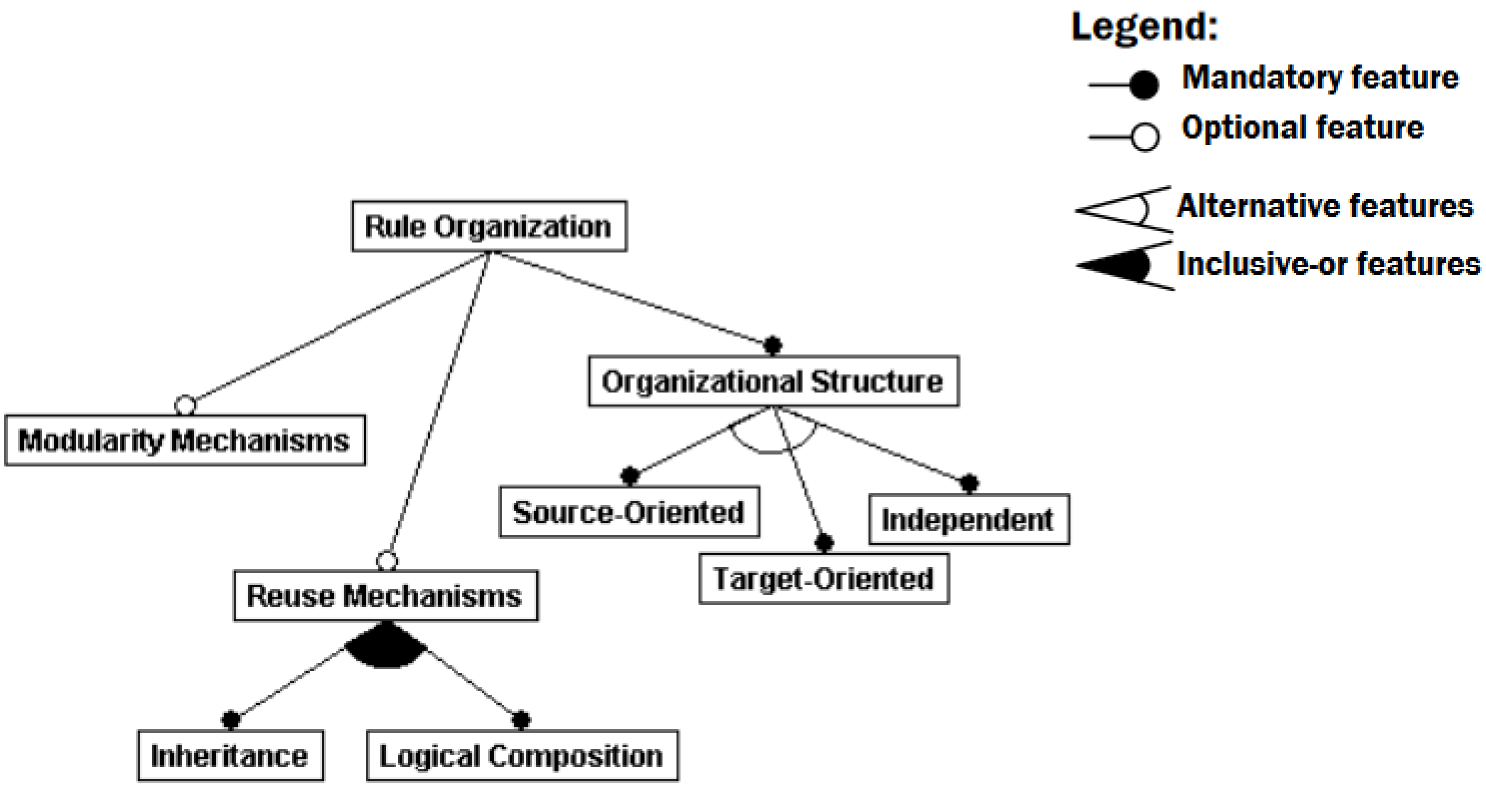

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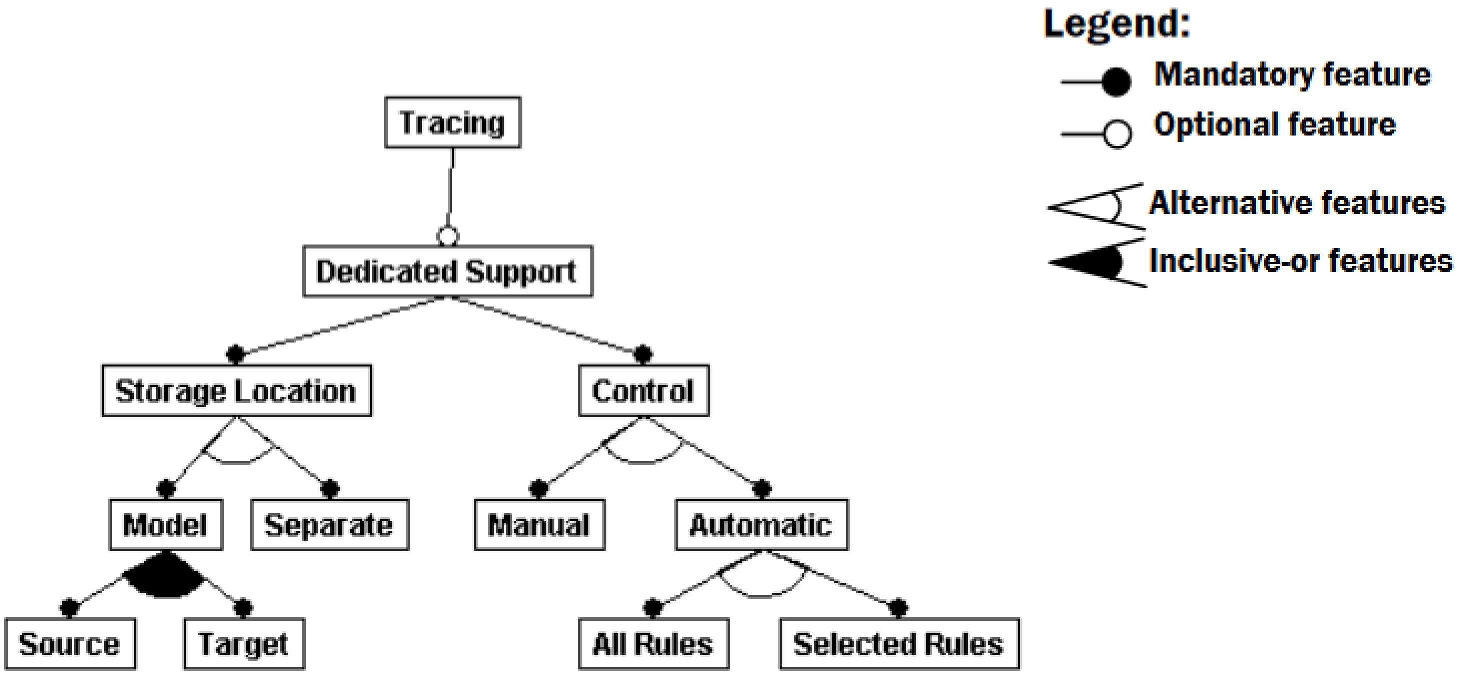

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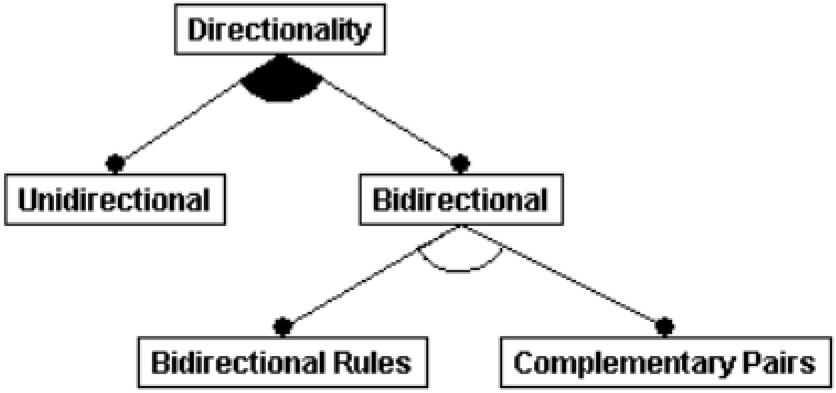
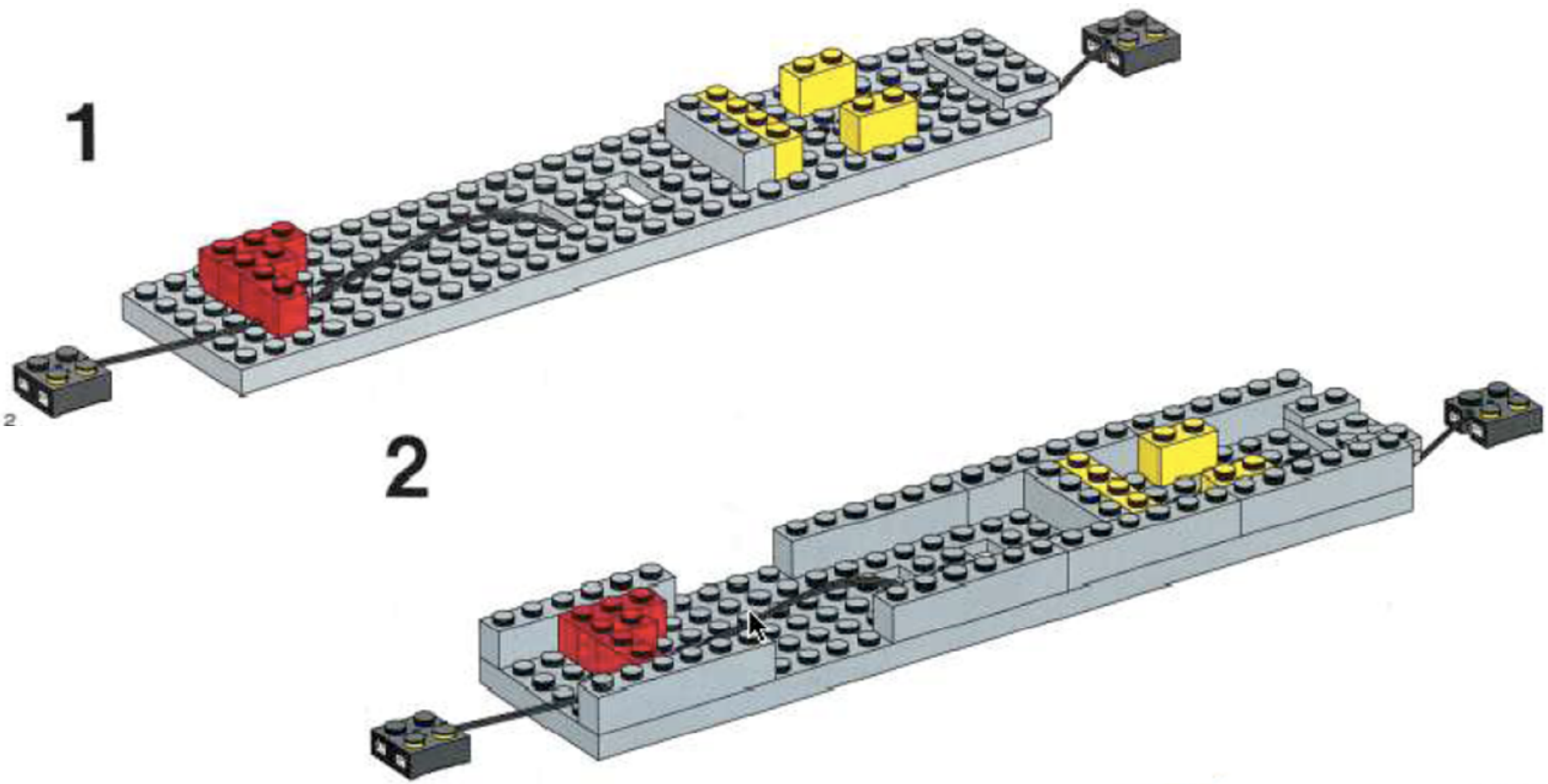


From Krzysztof Czarnecki and Simon Helsen, “Classification of Model Transformation Approaches”

5.3. Model-to-model transformation – graph transformations

Describe Structural Changes

- Most children understand this way of describing structural changes:



Graph Transformations

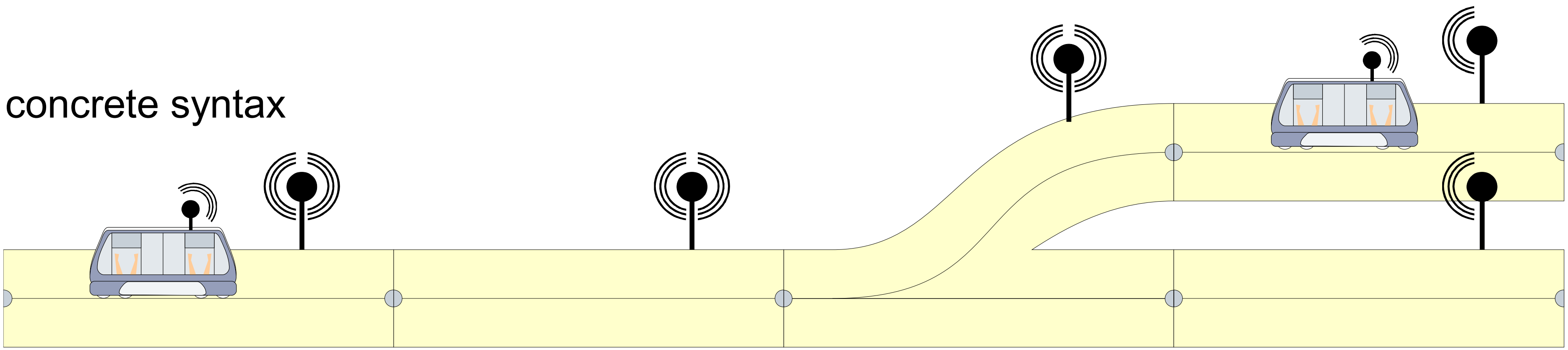
- Idea: View the model as a graph
  - objects are nodes
  - links are edges

- Describe the transformation by rules that describe how and when a particular part of the graph can be modified
  - (similar to the Lego manual)
  - we use **graph grammars**
  - also called **graph transformation rules**

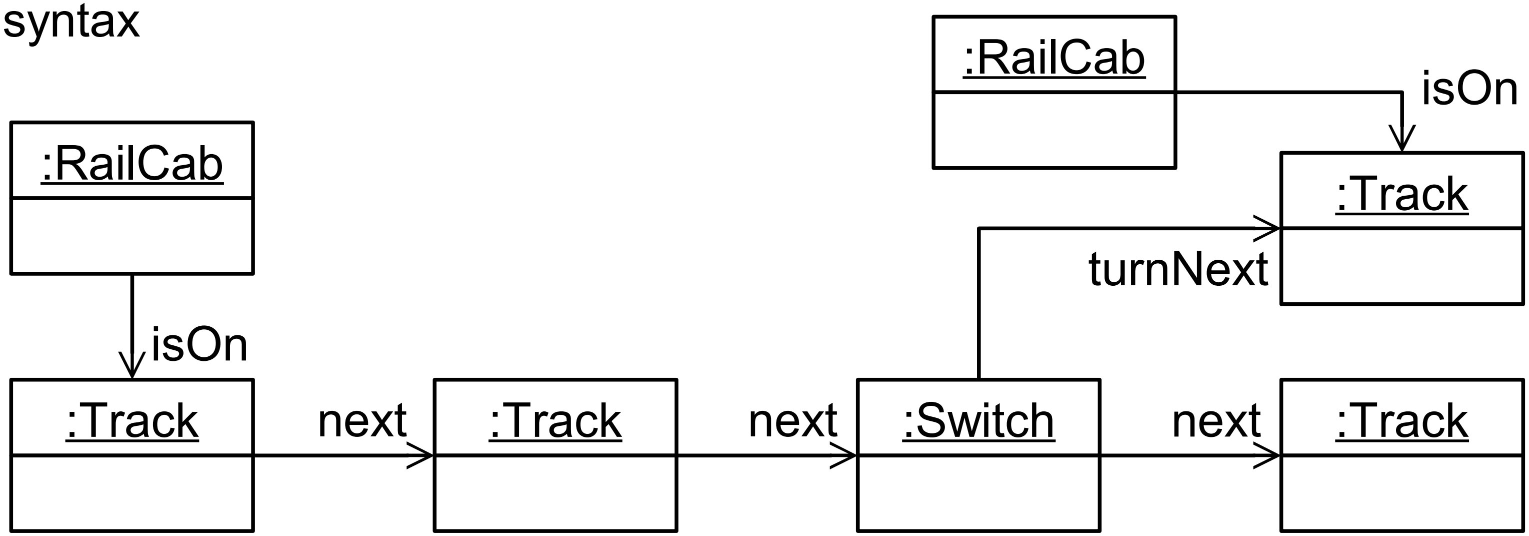
View the System as a Graph

- Idea: View the model as a graph
- **Example**: train system “RailCab”

concrete syntax



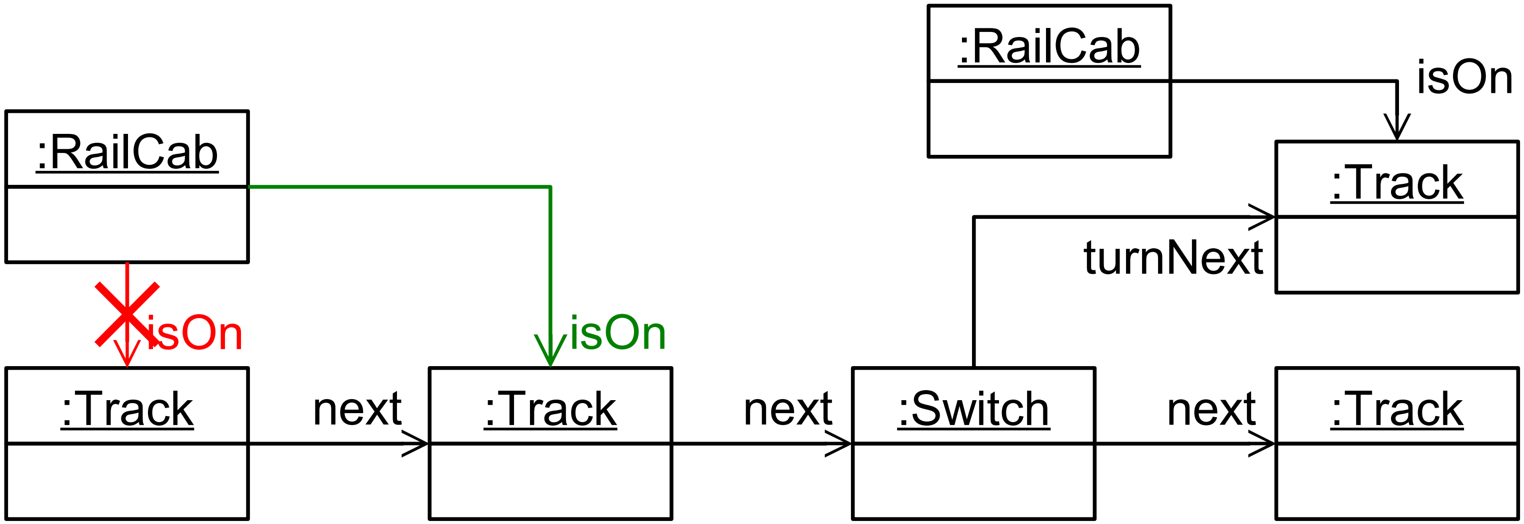
abstract syntax



Graph Reconfiguration Behavior

- Describe the transformation by rules that describe how and when a particular part of the graph can be modified

- **Example**: Movement of the RailCab



Graph Reconfiguration Behavior

- Describe the transformation by rules that describe how and when a particular part of the graph can be modified

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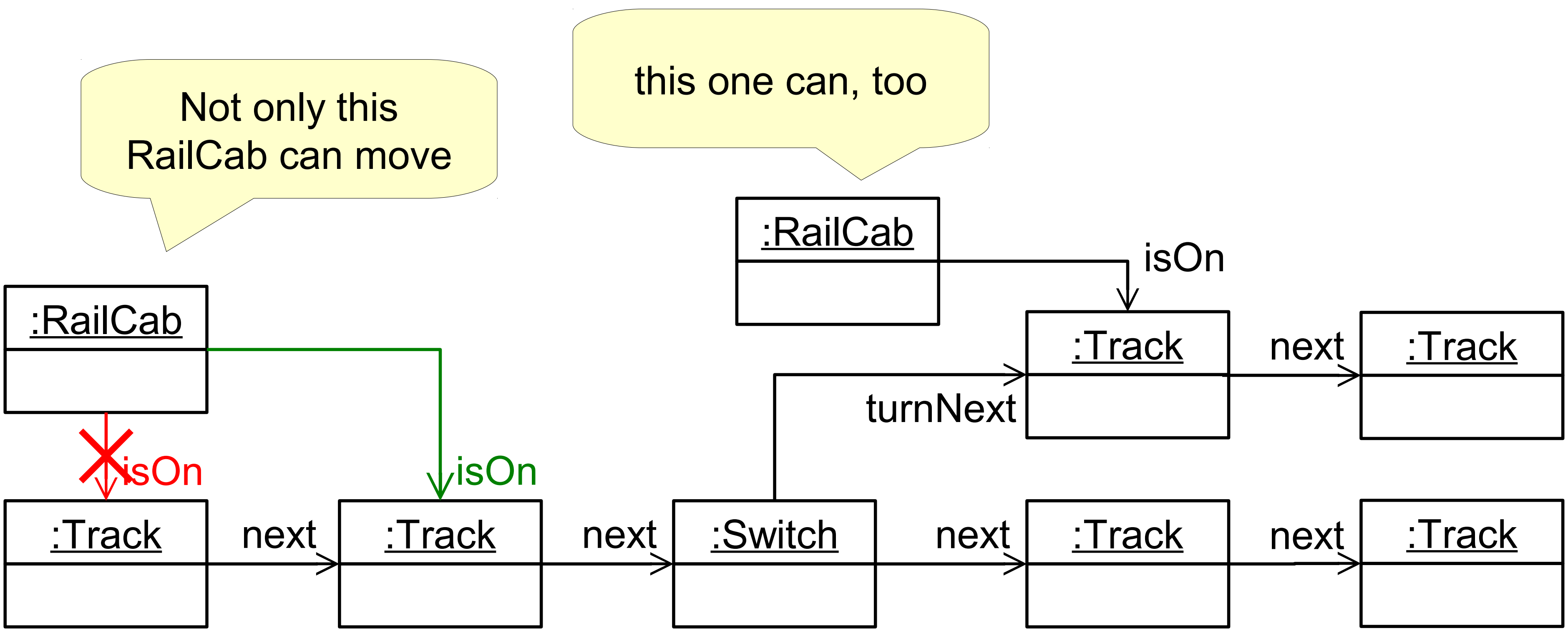
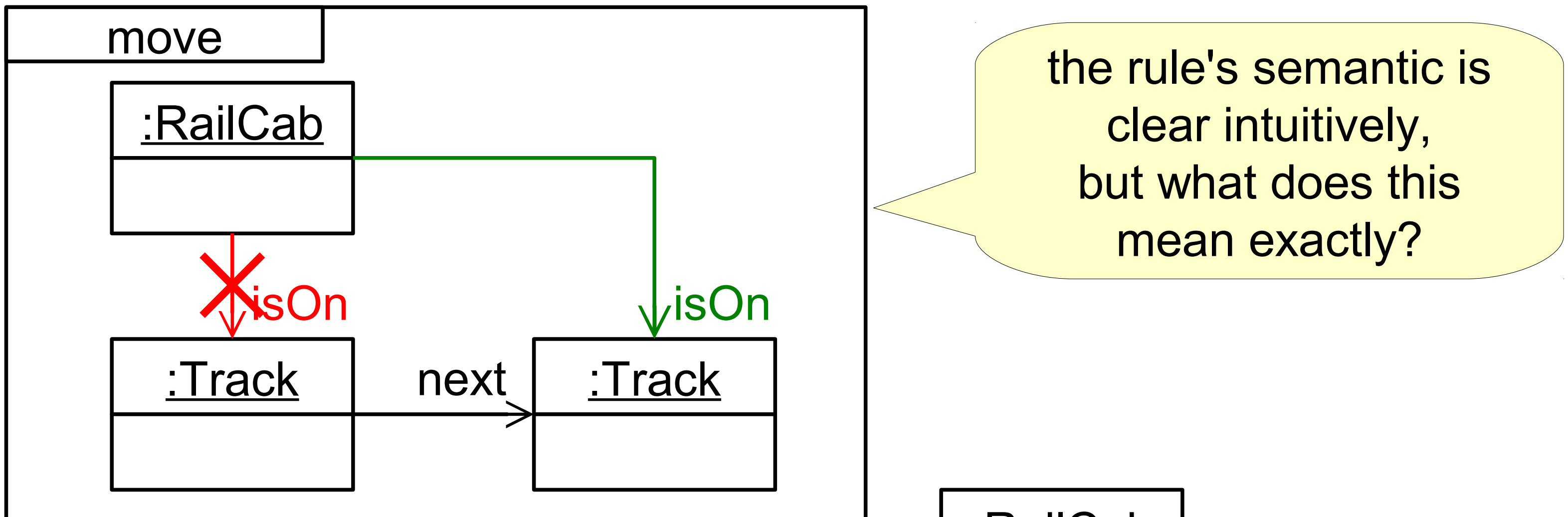
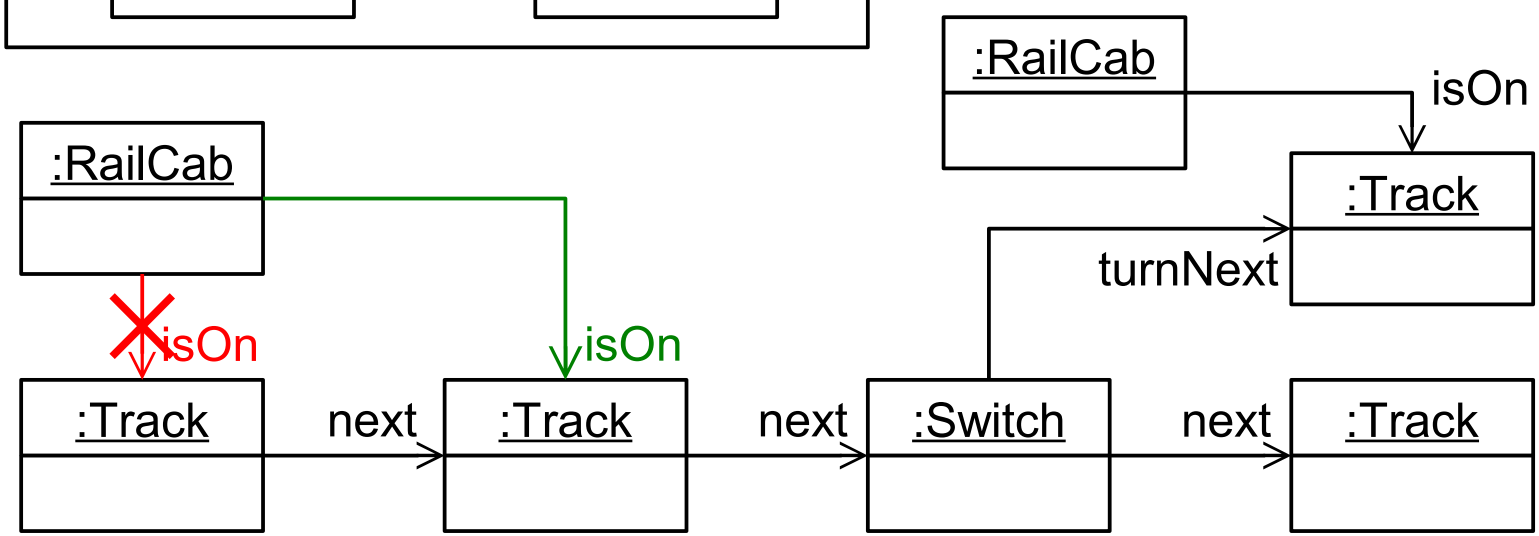


Graph Transformation Rule

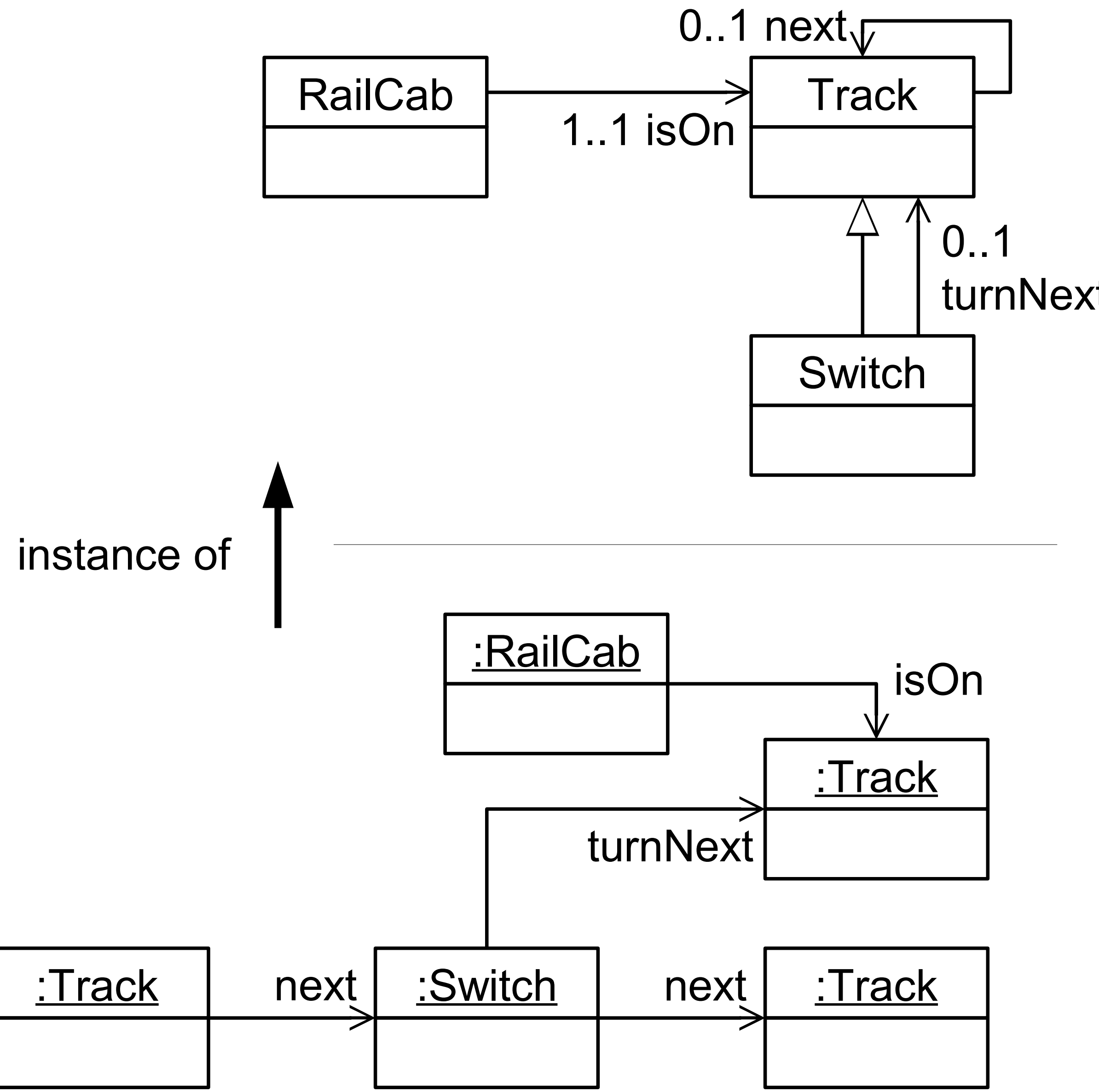
- Describe the necessary **context of the change** and the **change itself** in a **graph transformation rule**





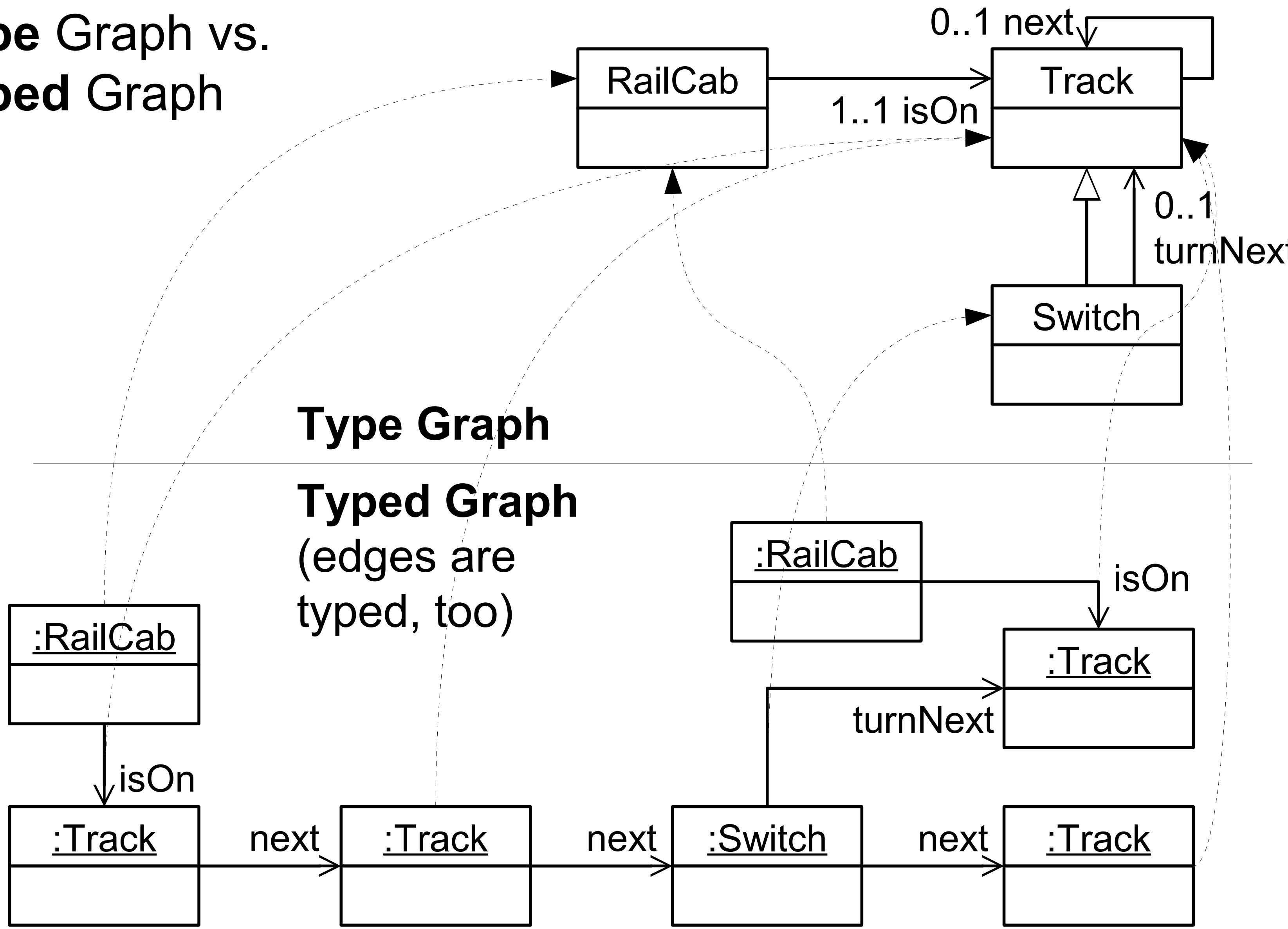
Model vs. Metamodel

- See chapter on metamodeling



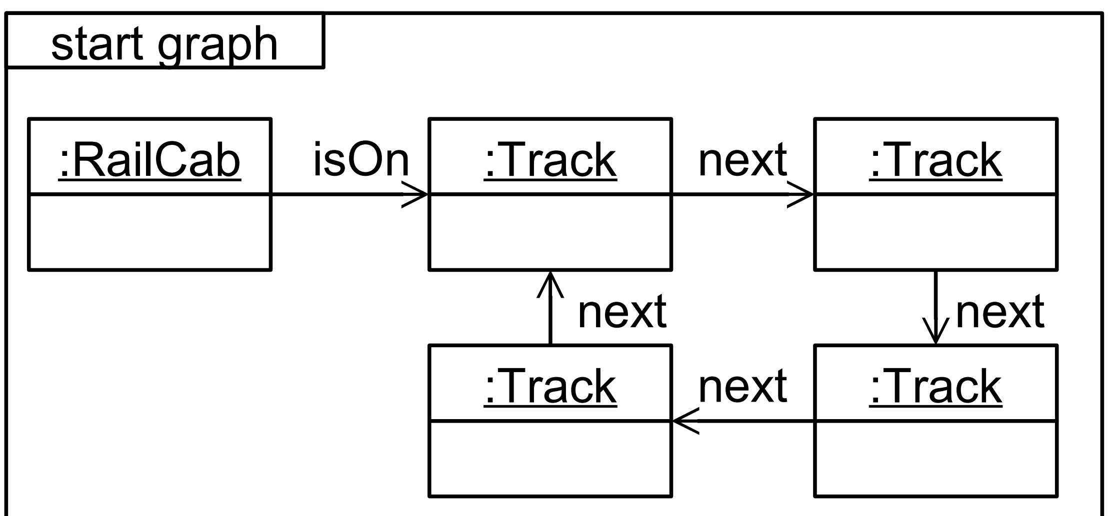
Models are Typed Graphs

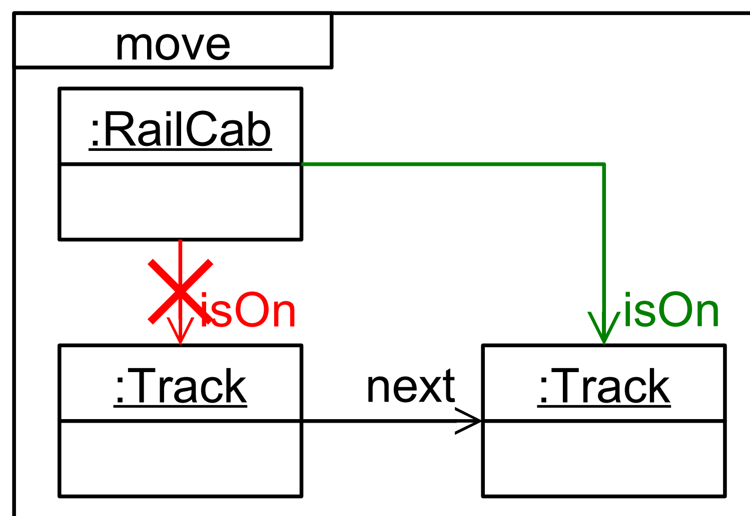
- **Type** Graph vs. **Typed** Graph



Graph Grammars

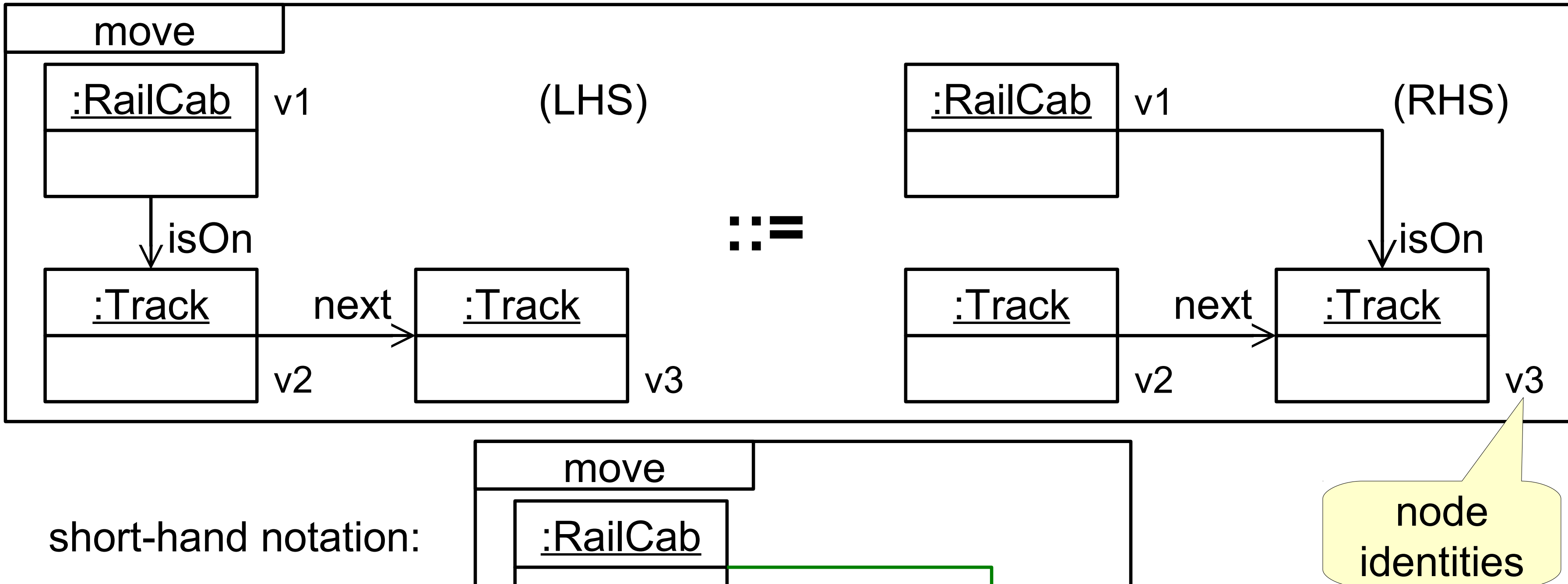
- A **graph grammar** consists of
  - a set of **graph grammar rules**
  - a **start graph** (also called **host graph**)
  - a **type graph**
- A graph grammar describes a (possibly infinite) set of graphs
  - those that can be constructed from the start graph by applying the graph grammar rules in all possible orders
- Graph grammars are also called **Graph Transformation Systems**



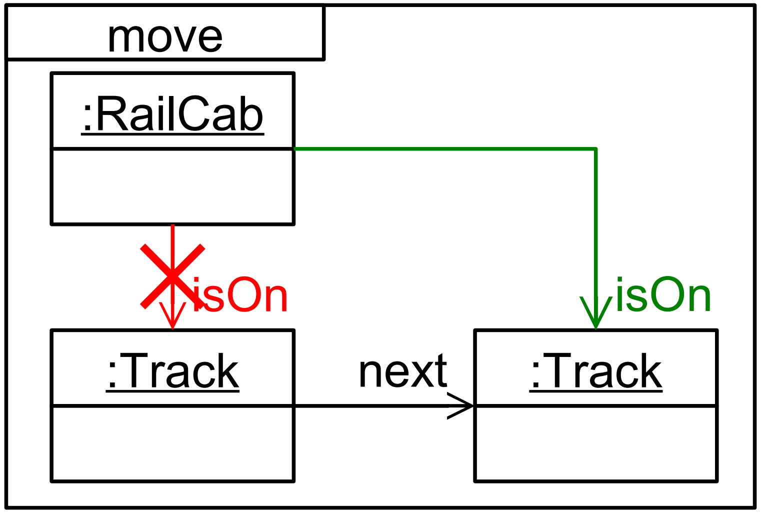


Graph Grammar Rule

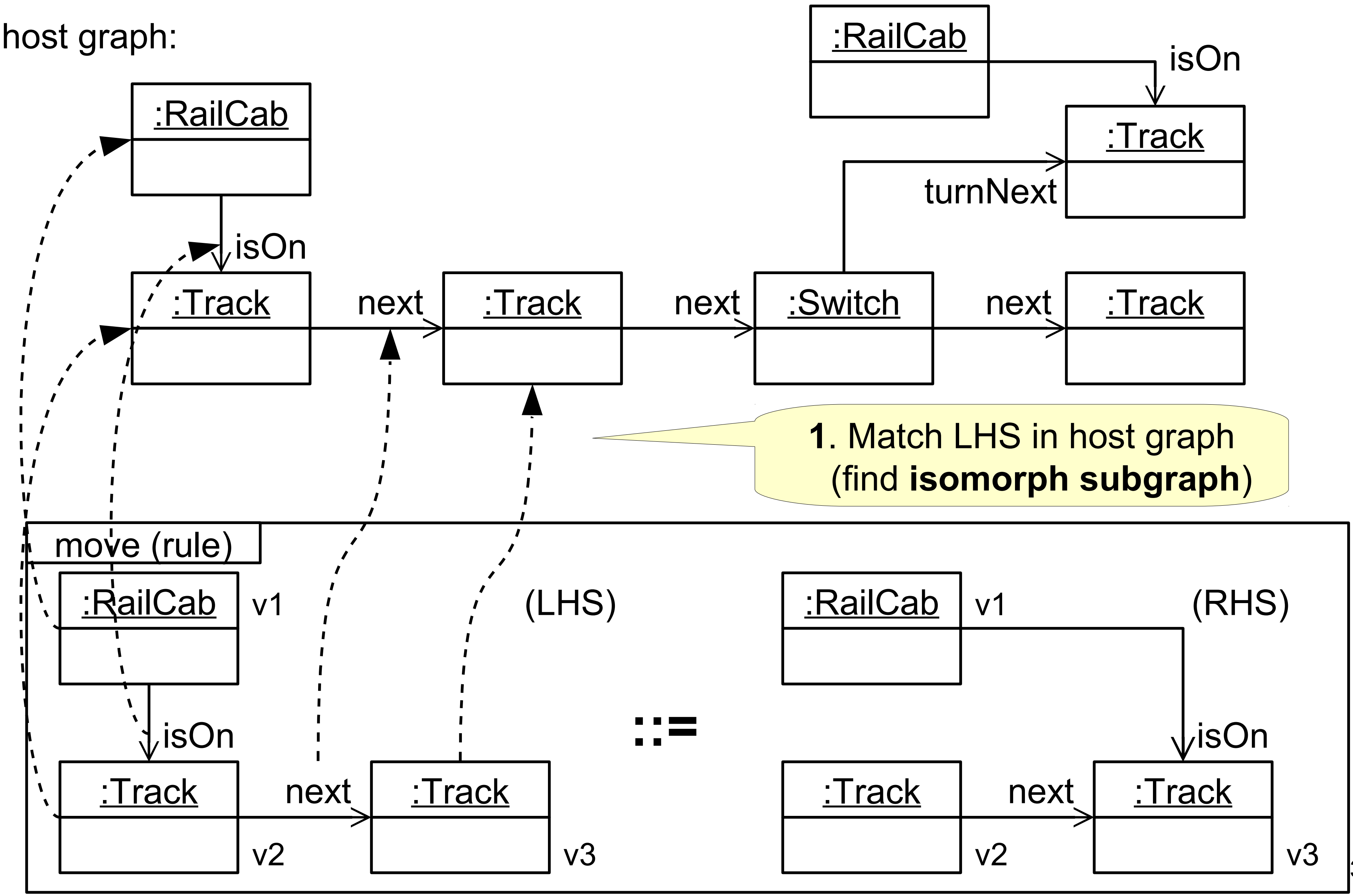
- A graph grammar rule consists of two typed graphs
  - called **left-hand side** (LHS) and **right-hand side** (RHS)



short-hand notation:

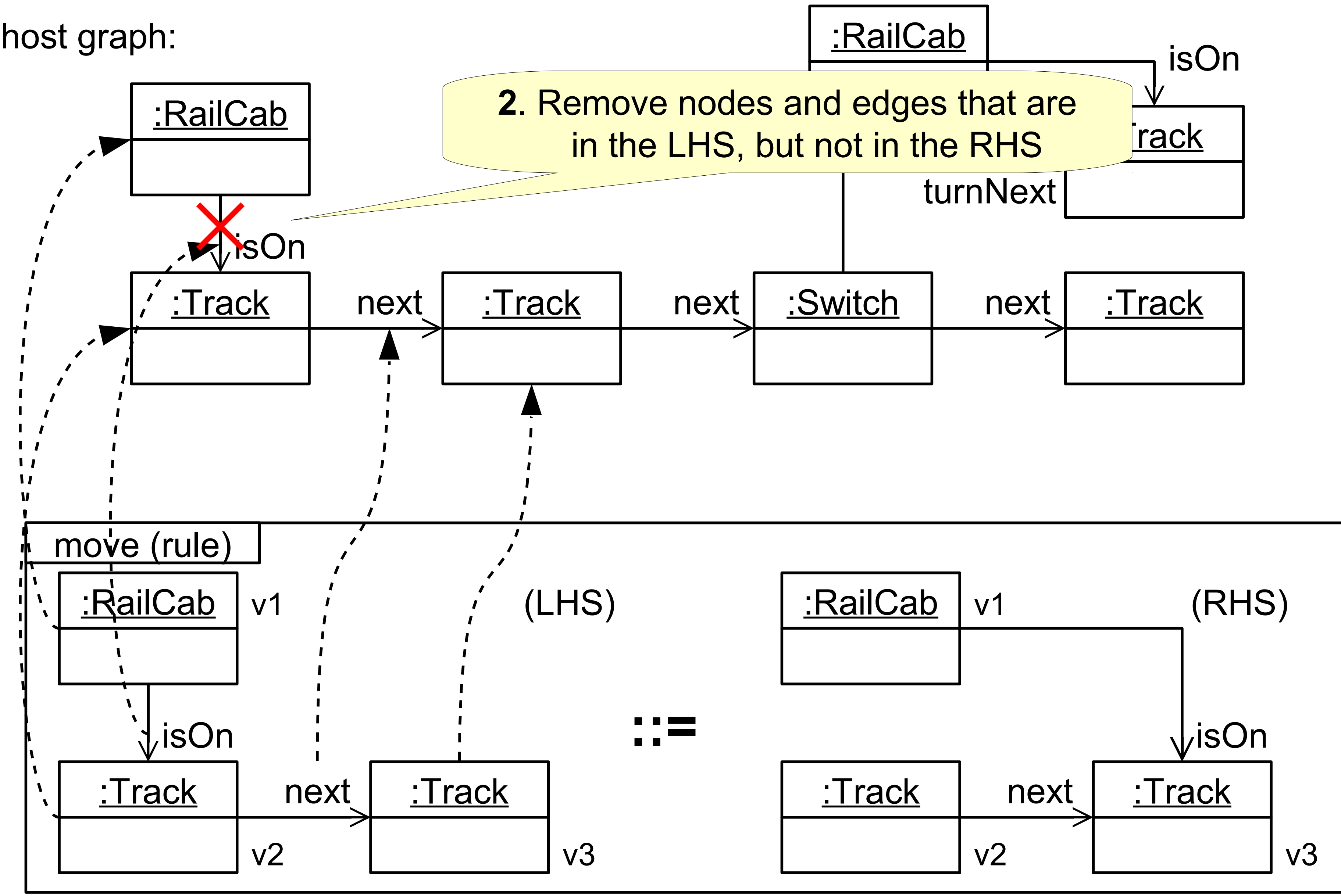


Graph Grammar Rule Application

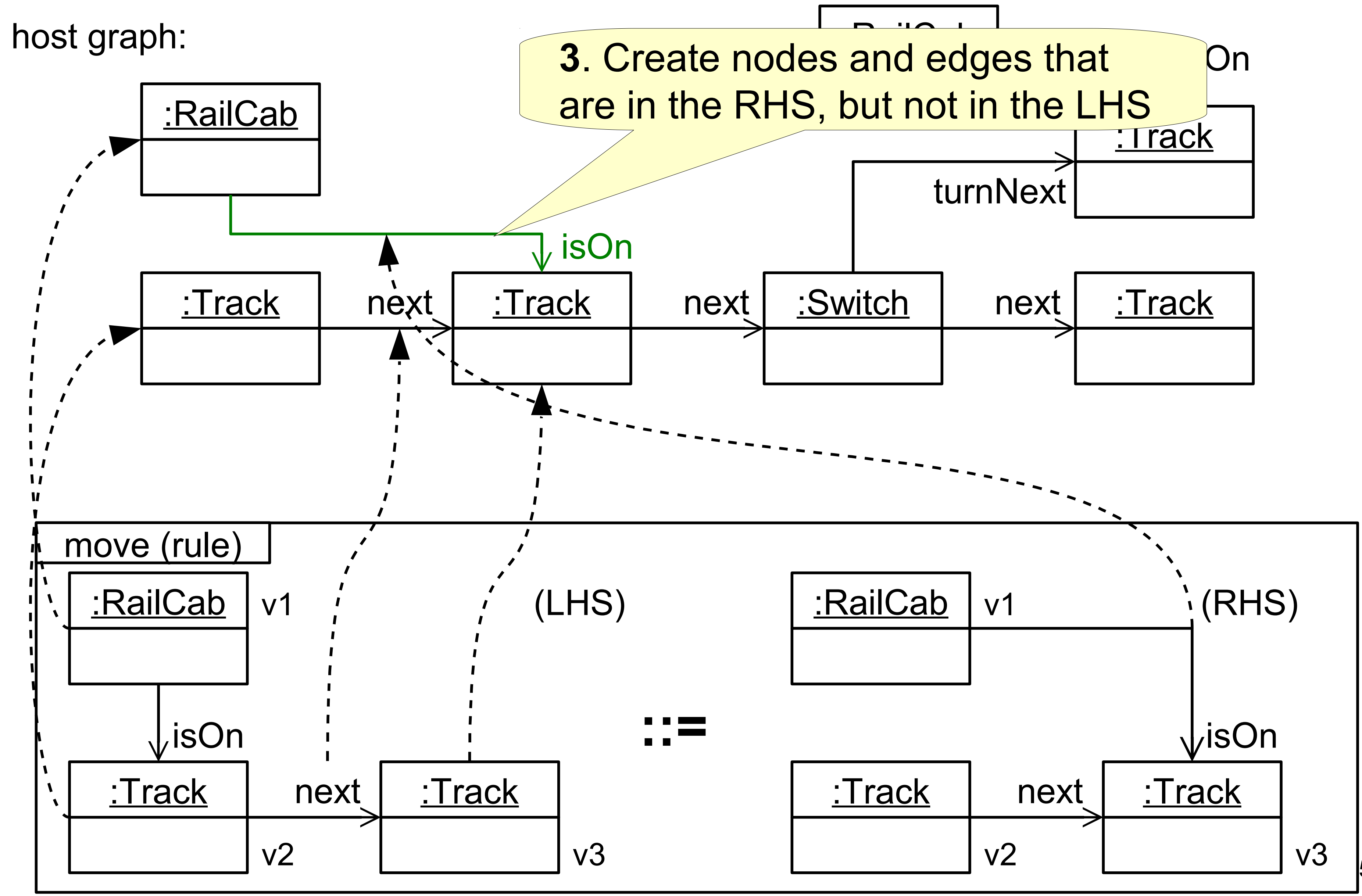


Graph Grammar Rule Application

host graph:

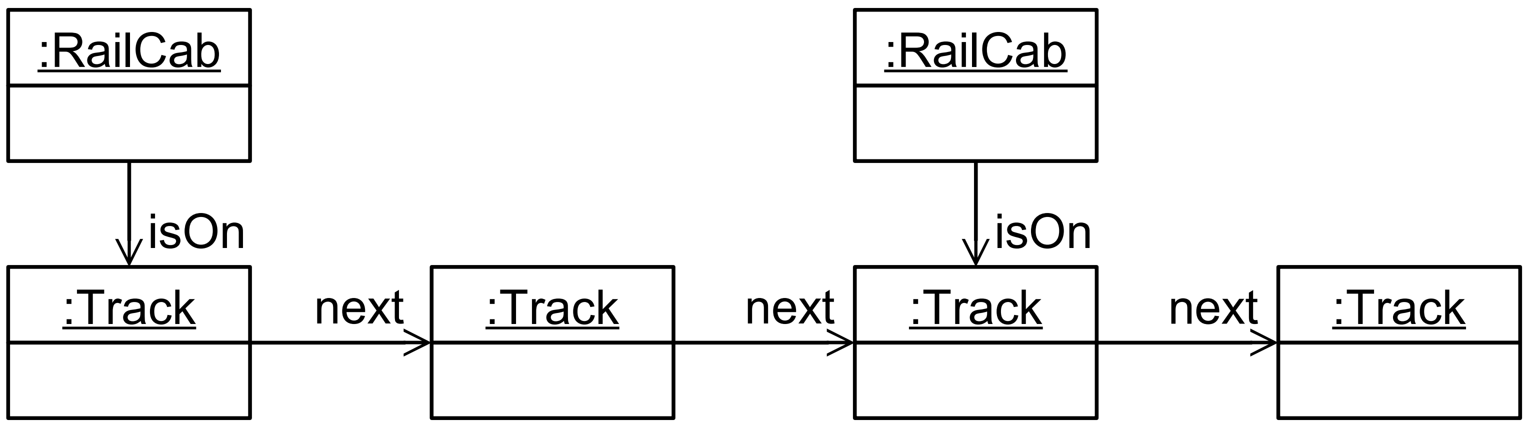


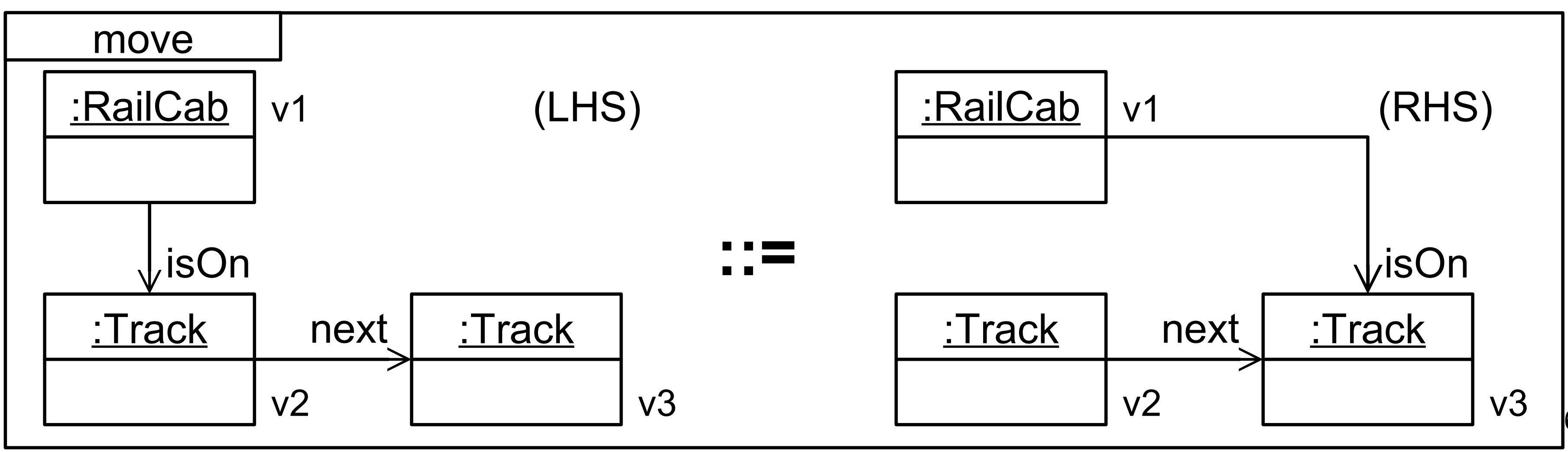
Graph Grammar Rule Application



Graph Grammar Rule Application

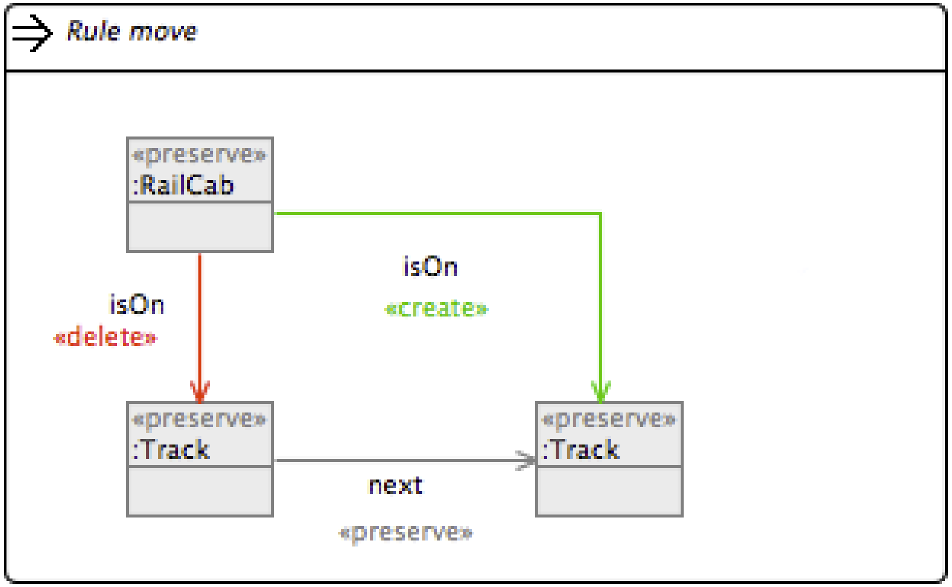
- When to move which RailCab?
  - here we have a non-deterministic choice





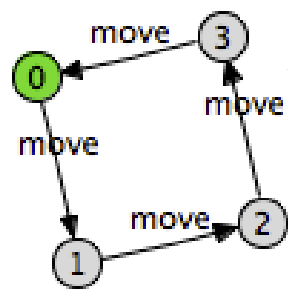
Eclipse Henshin

- An Eclipse project that supports the modeling, execution, and analysis of EMF-based graph transformation systems
  - https://www.eclipse.org/henshin/

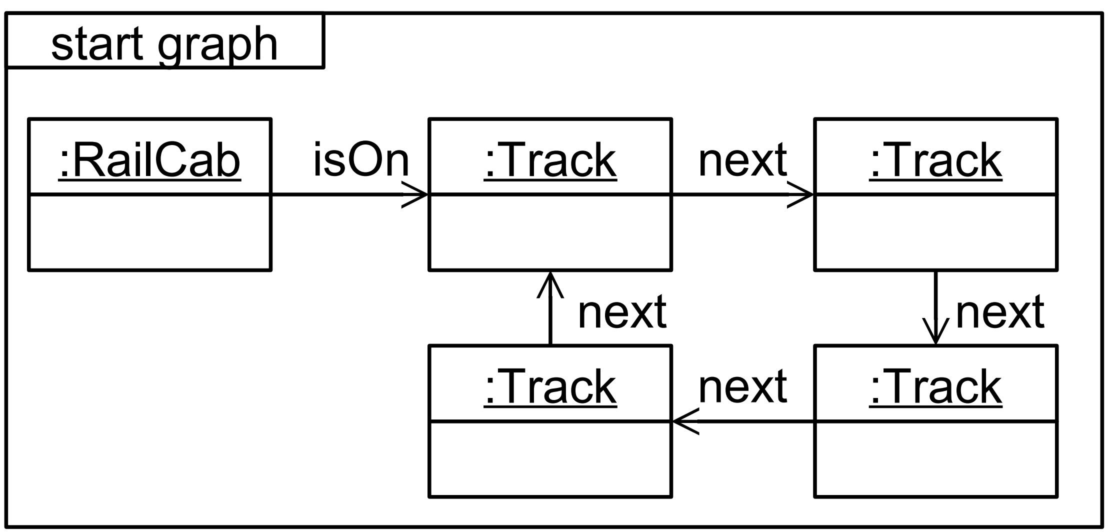


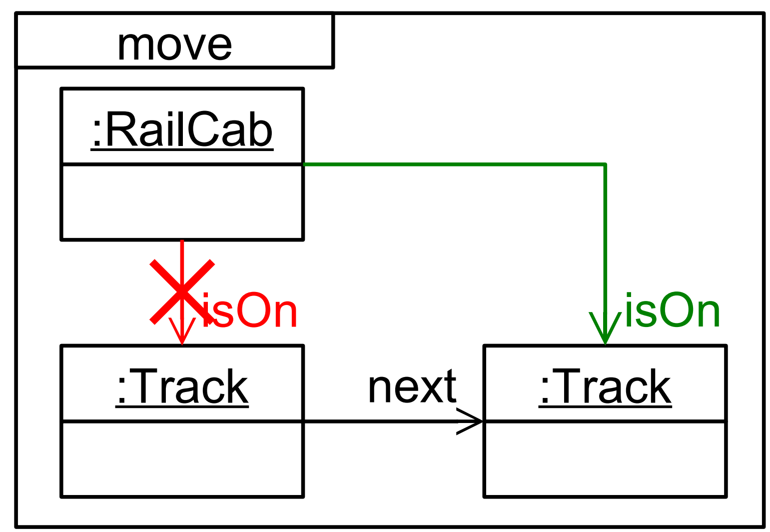
Exploring the State Space

- A rule application can be considered a transition in a Labeled Transition System
  - source state: host graph before the rule application
  - transition: rule application
  - target state: host graph after the rule application



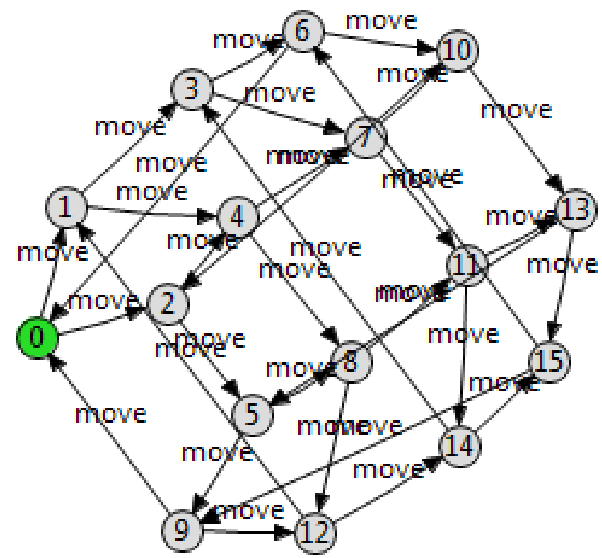
state space explored with Henshin: 4 different graphs; (graph after 4 applications of move rule is isomorphic⇒equal to the first)



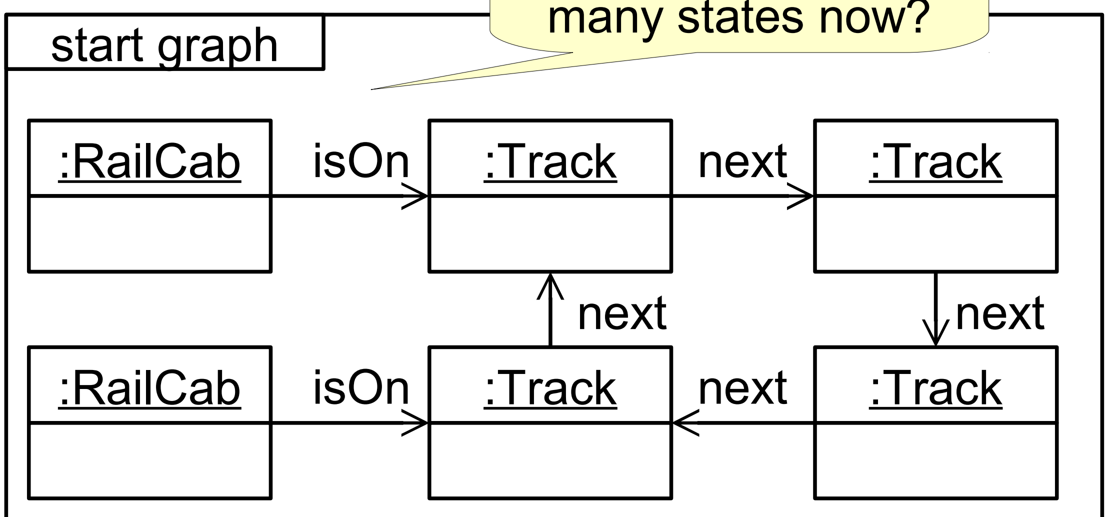


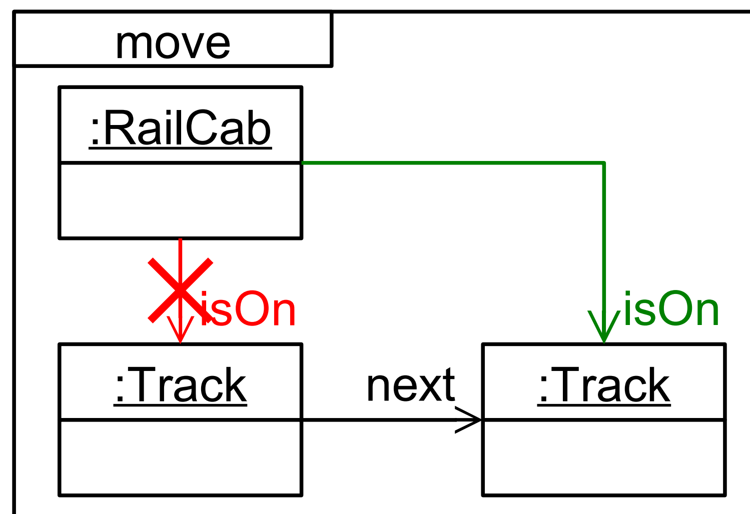
Exploring the State Space

16 states

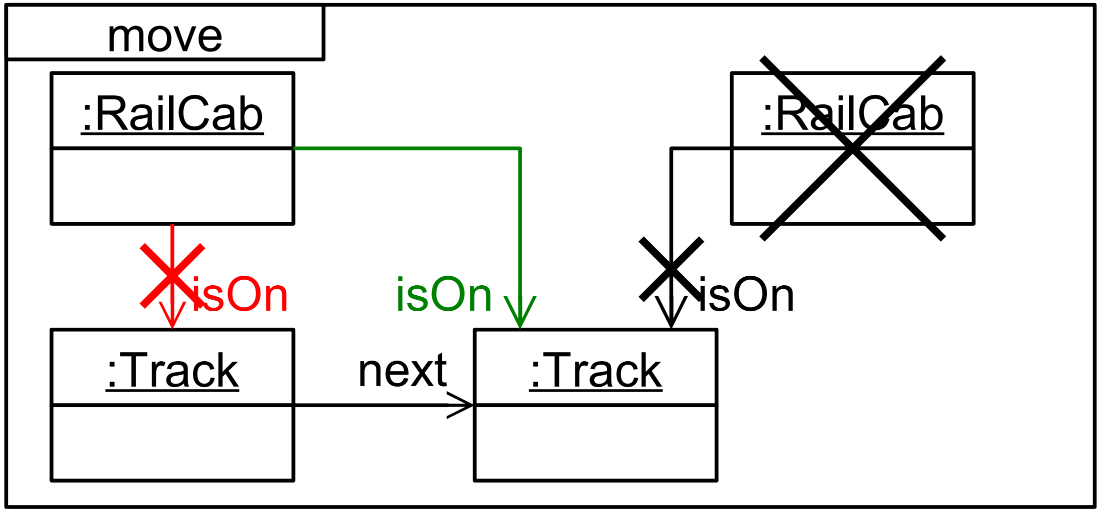


two RailCabs – how many states now?



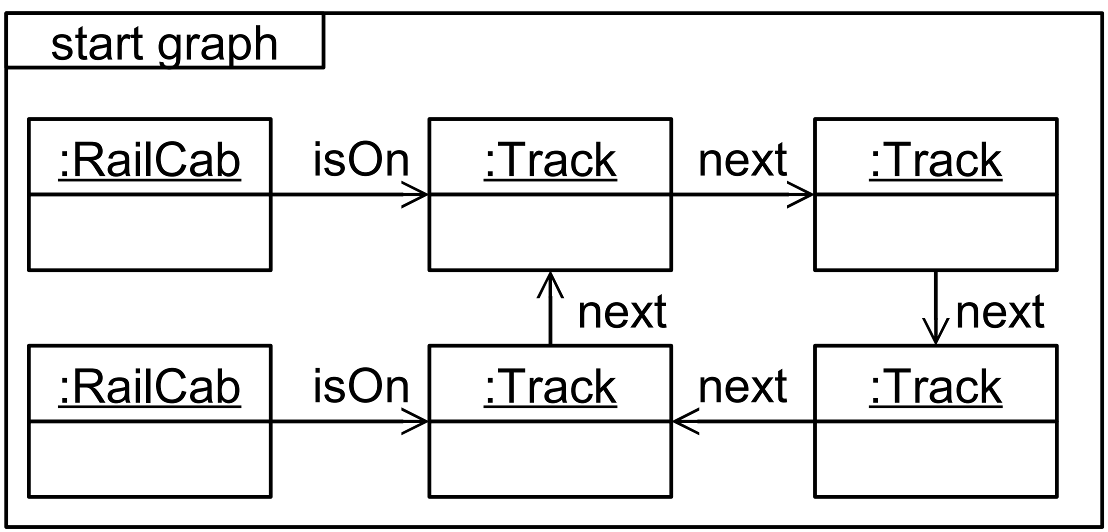


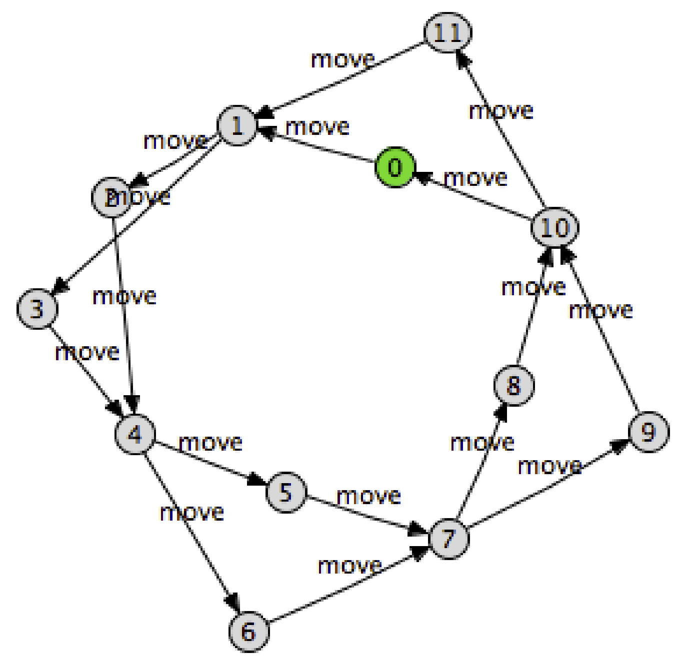
Exploring the State Space



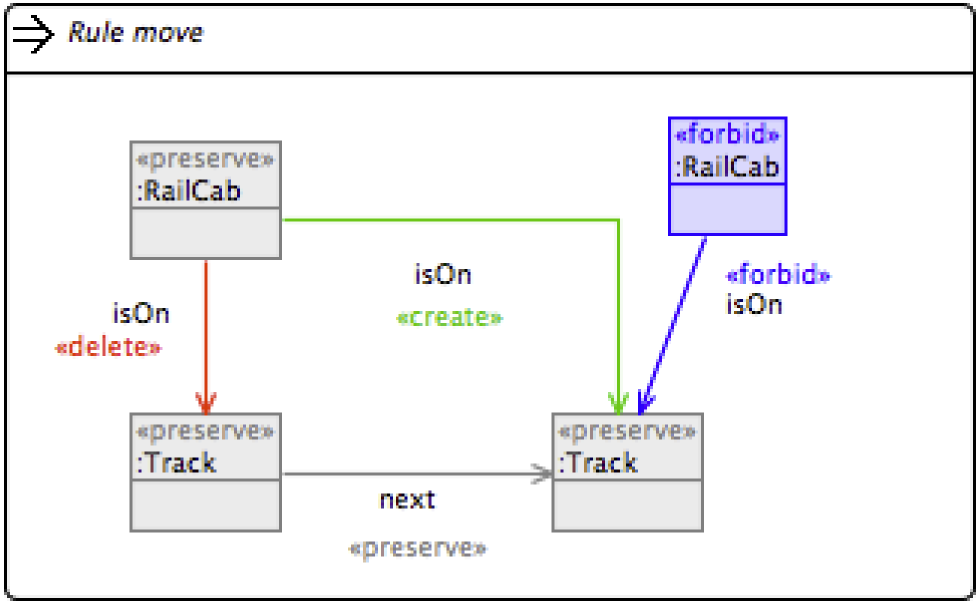
two RailCabs and not a RailCab moving on a track if another RailCab is already on it – how many states?

16-4 = 12 states





Exploring the State Space



rule as specified in Henshin