L4. DDD and MDE

S2. Metamodelling with MOF

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Metamodel-Centric Language Design

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- Model validation: models are validated against constraints defined in the metamodel
  - OCL as the language of choice for defining constraints
- Metamodels are employed
  - constructively by using the metamodel as a set of production rules for building models
  - analytically by using the metamodel as a set of constraints that need to be satisfied by a model in order to conform to its metamodel

Benefits of Metamodelling

- Precise language definition
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- Metamodelling frameworks:
  - exchange formats: support to serialize/deserialize models into XML format to support metadata exchange
  - model repositories: models may be stored to and retrieved from a model repository
  - model editors for defining and validating models

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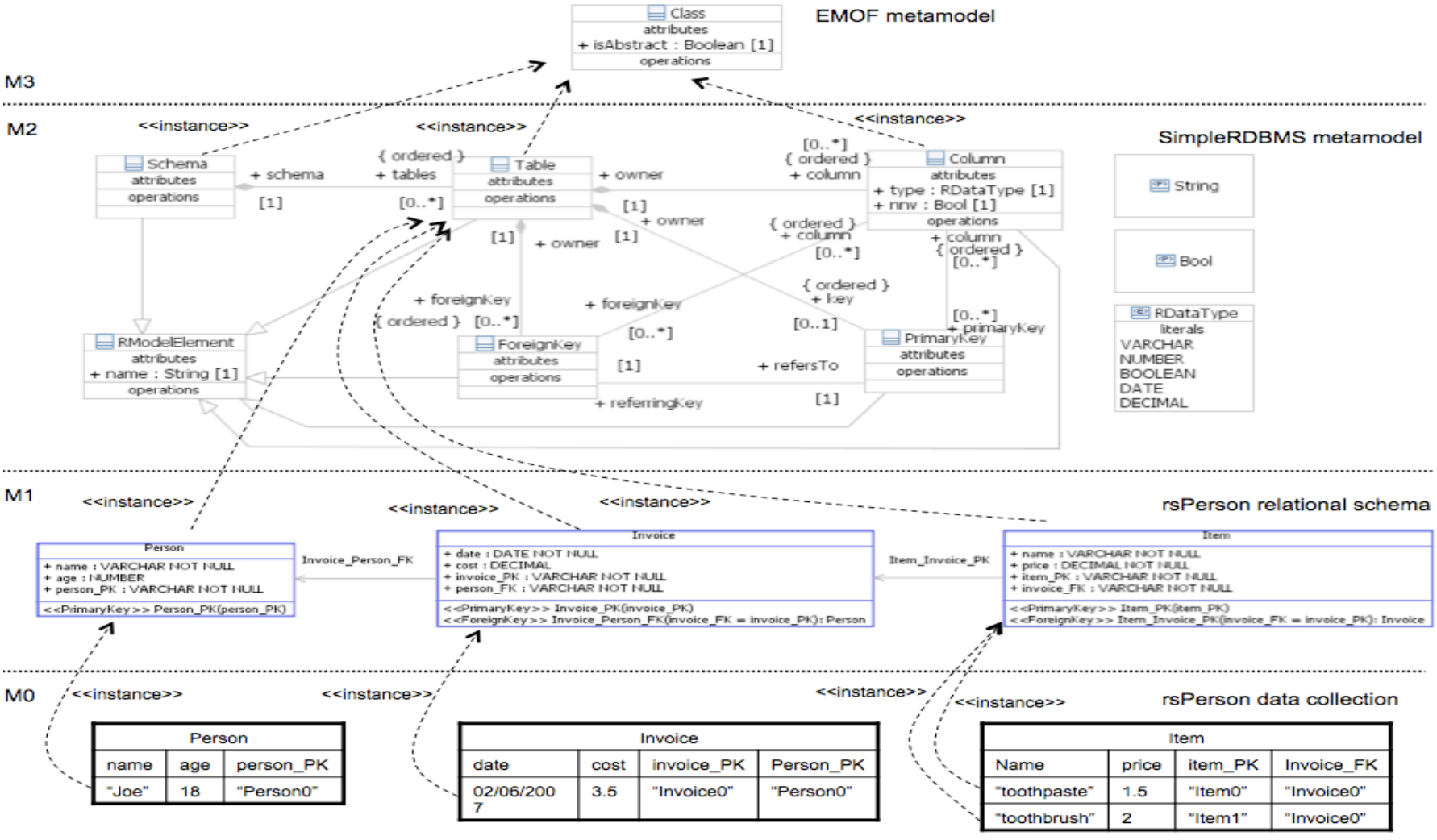
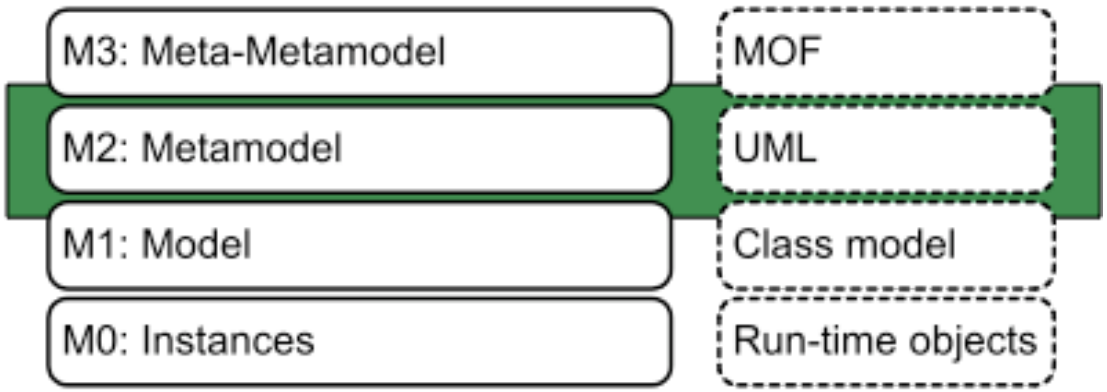
- Similarly to EBNF, MOF is defined in MOF.

MOF Framework



Where do we find metamodels?

- Metamodelling happens on the M2 Metamodel layer of the MOF framework



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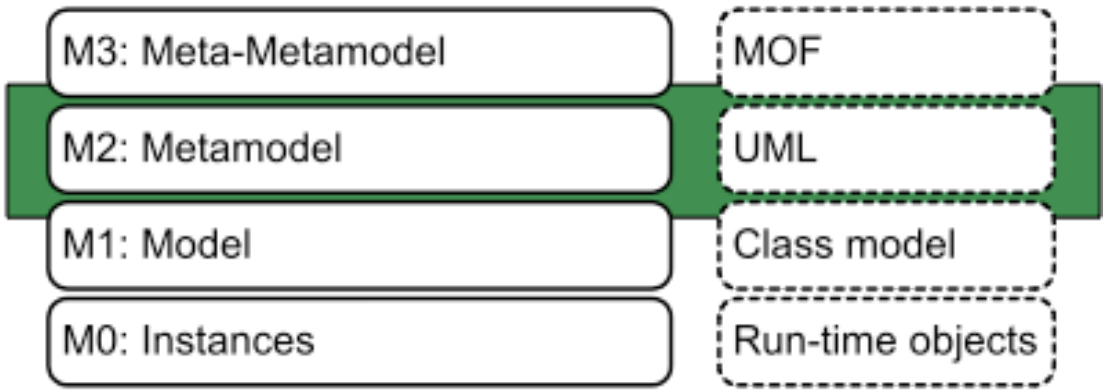

- The four-layer metamodelling stack assumes that a model on layer M conforms to a model on layer $M + 1$:
  - Models (M1) are represented as a collections of instances of classes defined in a metamodel (M2)
  - Changes to the metamodel have an impact on representation of the instances of this metamodel (i.e. the model itself)

MOF Modelling Primitives: classes

- A class is an abstraction modelling an entity in the application or solution domain
  - the class name is the only mandatory information
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- Multiplicity: to indicate the number of separate values that an attribute could hold

n..m : n is the lowest value, m is the greatest value. middlename: String[0..2]
n : to indicate a fixed number of attributes
{ordered} : the different values are ordered address: String[1..*]{ordered}
{unique} : no duplicate values phoneNumber: Integer[1..*]{unique}

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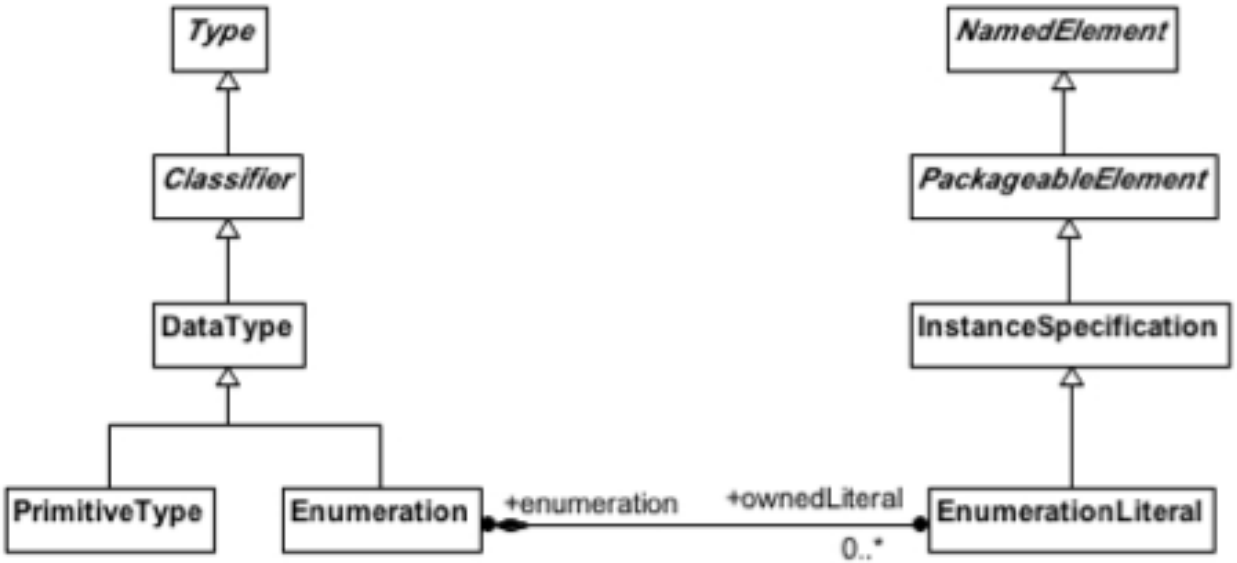
  - opposite:
    - to define bidirectional associations

MOF Modelling Primitives: data types



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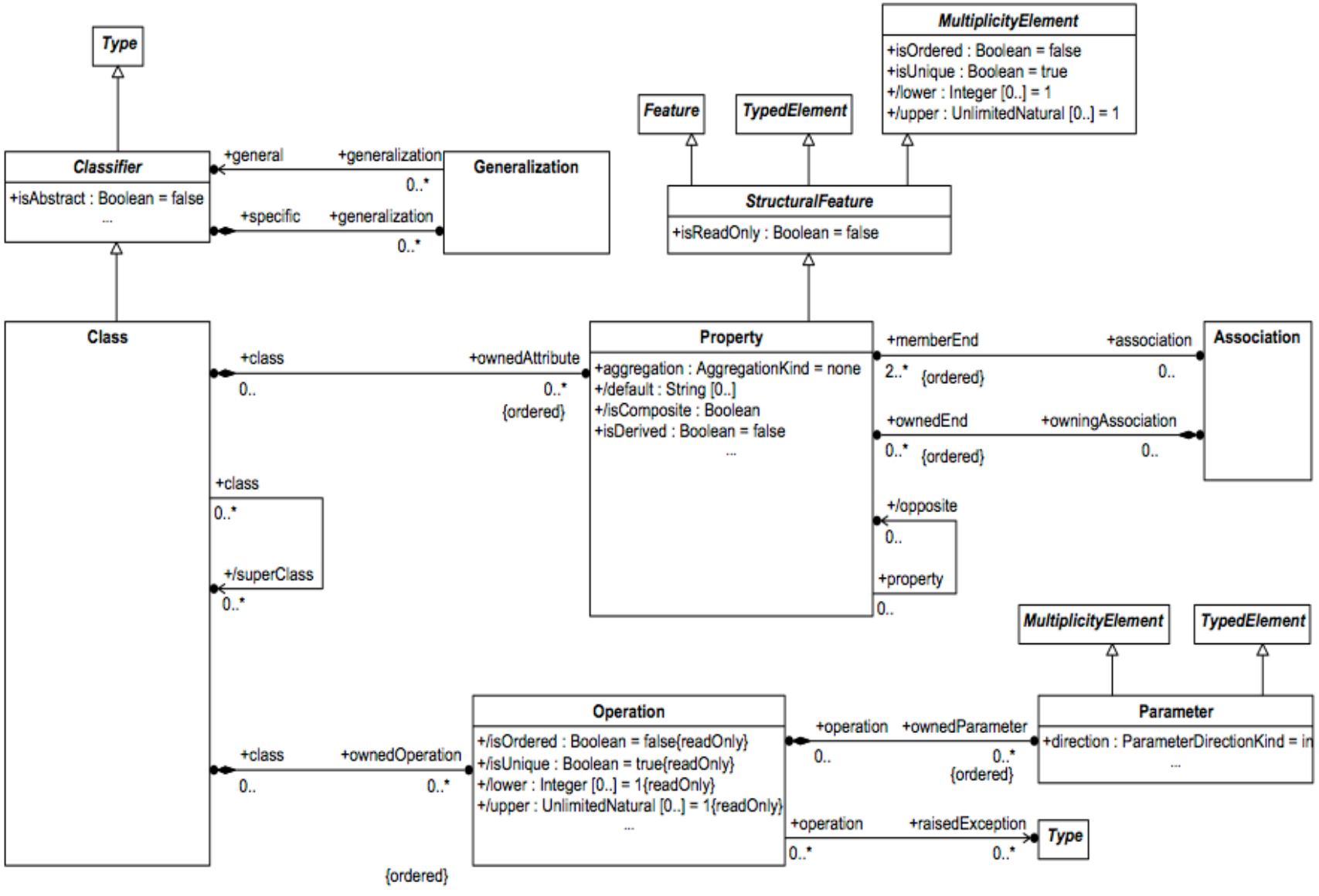

DSL Design: Domain Analysis

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4. Define a model using the metamodel
5. Refine the metamodel

Exercise

- Model the abstract syntax for defining state machines as follows:
  - A state machine consists of states and transitions, both labelled with a name.
  - A state machine has one initial and it may have many final states.
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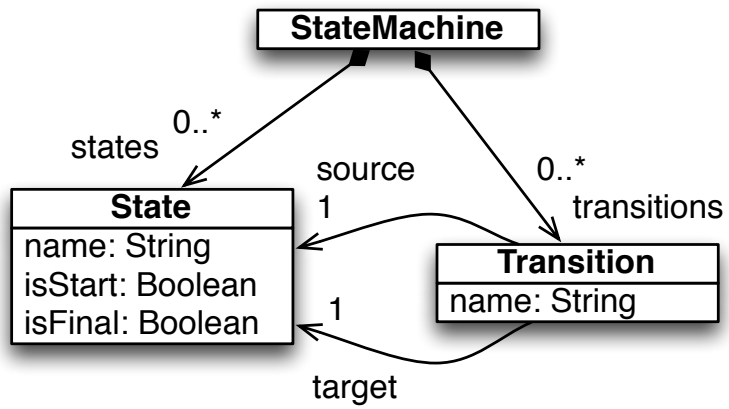

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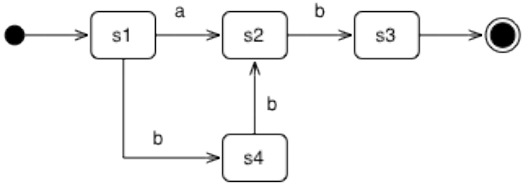
  - Models can be represented as object diagrams
  - Models can be viewed as graphs: objects are nodes and references are unidirectional edges
- A model conforms to a metamodel iff it is syntactically well-formed, i.e. if
  - it is defined by means of the modelling primitives (types) that are provided in the metamodel
  - it satisfies the metamodel constraints

Exercise

Define the abstract syntax of the following diagram



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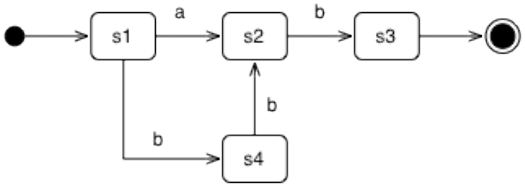

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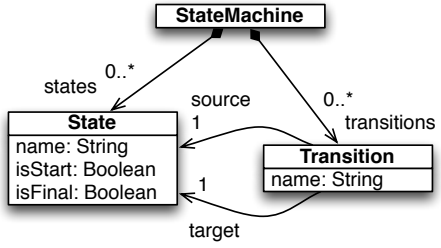

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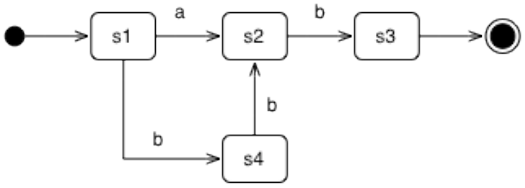

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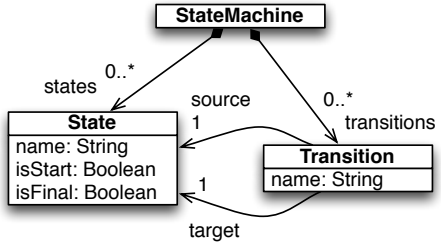
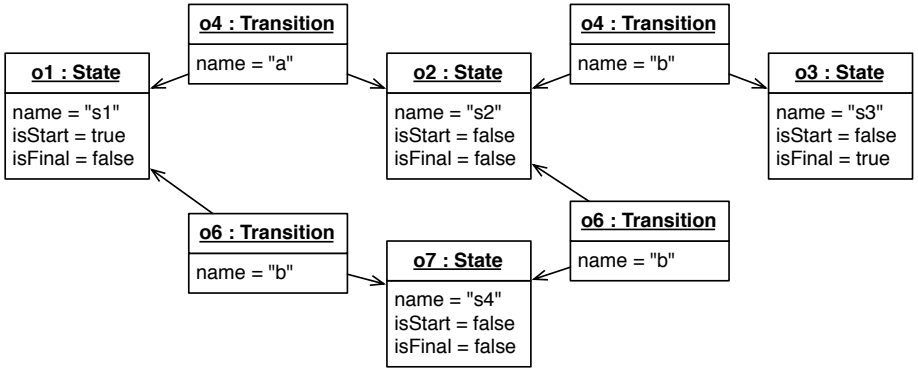
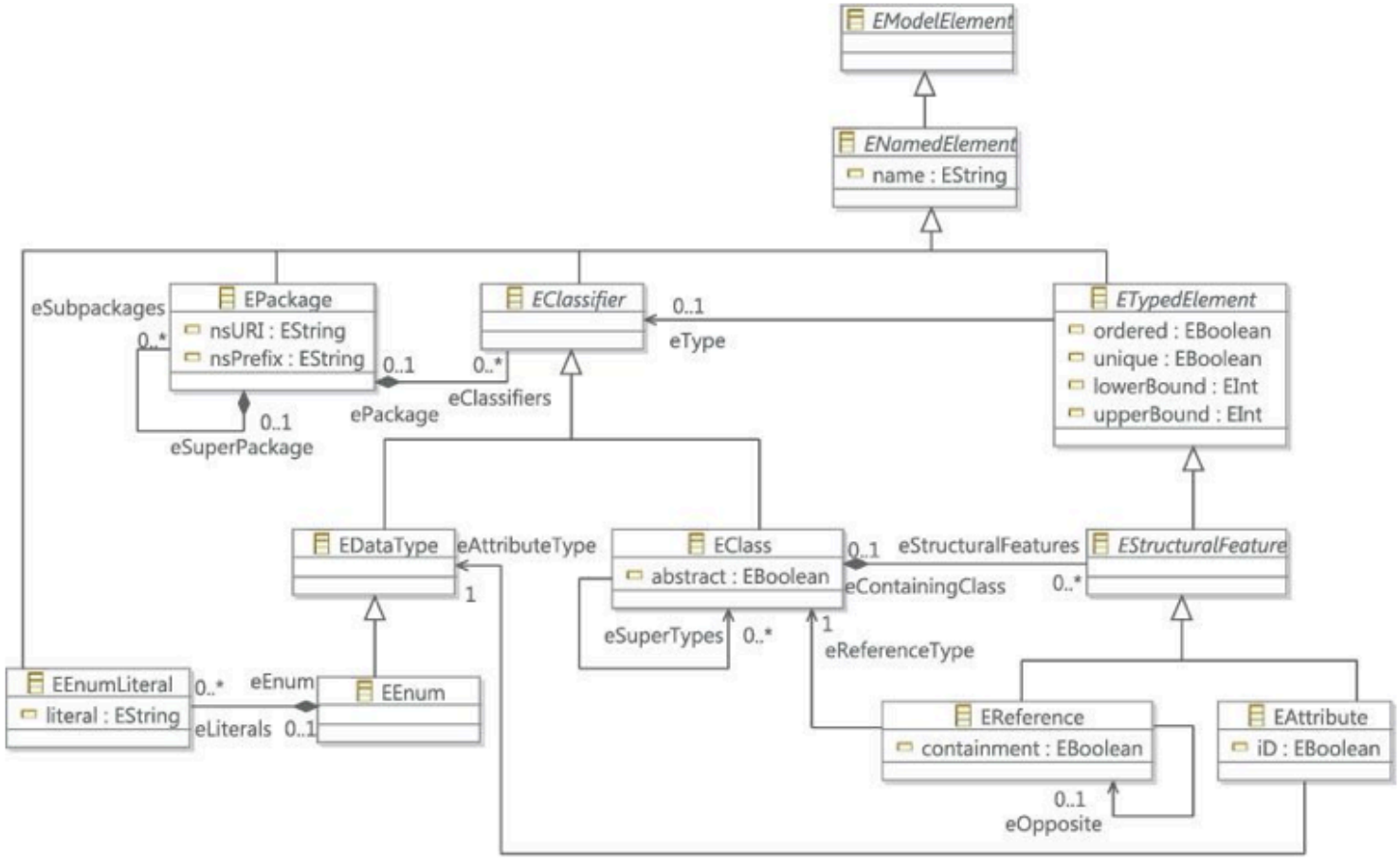


solution (you may also include the root object containing all states and transitions):



Eclipse Modelling Framework

- Metamodeling framework atop the Eclipse platform.
- Ecore metamodel is the realization of the MOF meta-modeling language:



OCL and Metamodelling

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- An OCL constraint is a rule attached to a UML element restricting its semantics.
  - In a modelling language, OCL constraints restrict what can be modelled with the metamodel.
  - An invariant is a property that must remain true for all the instances of a particular classifier
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  - An invariant is a property that must remain true for all the instances of a particular classifier
    - restrict the semantics of a particular class in the metamodel
- OCL constraints are:
  - declarative: they specify what must be true, not what must be done
  - have no side effects: evaluating an OCL expression does not change the model under study
  - have formal syntax and semantics: their interpretation is unambiguous

Types of Constraints

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- The context of a constraint defines the link between an entity in the metamodel and an OCL expression.
- The contextual type is the type (e.g. a class, component, interface, data type...) of the object for which the expression will be evaluated:
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- Constraint expression:

  `context <contextual-type>`
  `<constraint-type>: <OCL expr>`
  - `<contextual-type>`: model element that is constrained
  - `<constraint-type>`:
    - `inv`: (invariant, contextual type is a classifier)
  - `<OCL-expression>`: boolean OCL expression
- OCL expressions that share the same context can be combined under the same `context` clause.

Example

- Given the following model

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  - Direct loops are not allowed.

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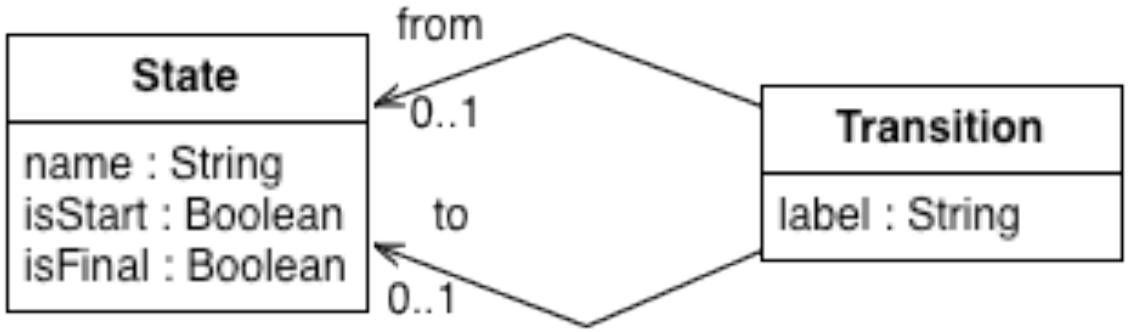

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  - A state cannot be initial and final in a state machine.
    ```
    context State
    inv:not(self . isStart = true and self . isFinal = true)
    ```
  - Loops are not allowed.
    ```
    context Transition
    inv: from <> to
    ```

Collection Types

- When the multiplicity of an association end (reference) denotes more than one object, an object is linked to a collection of objects of the associated class
  - Traversing the association results in a collection of objects
- OCL has a number of collection operations to write expressions in such situations
  - Notation `c->f()`: apply the OCL operation f to the collection c as a whole (as opposed to each member of the collection)

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- Sequence
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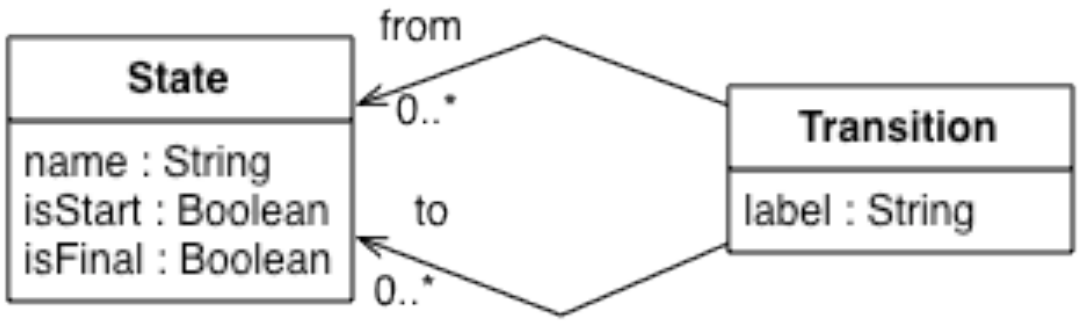
Examples



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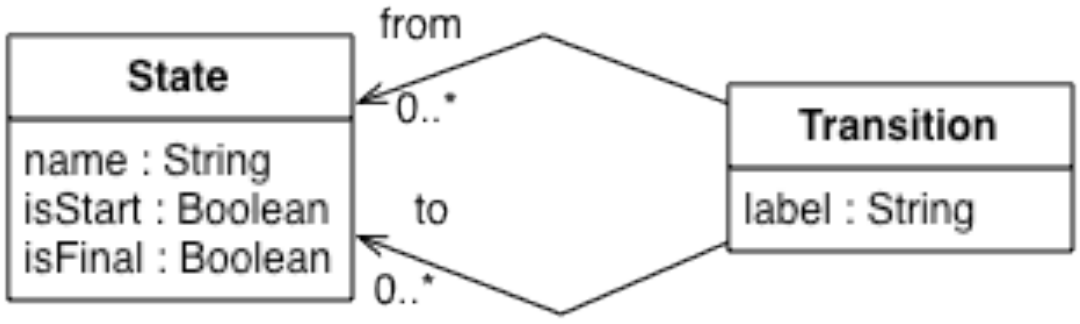

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```
context Transition
inv:  to -> size() = 1 and from -> notEmpty()
```

- All transitions with label ‘done’ lead to final states.

```
context Transition
inv:  label = ‘done’ implies to -> forAll( isFinal = true )
```

Concluding Remarks and Best Practices

- A DSL is a communication tool between developers and domain practitioners.
- The abstract syntax of a DSL captures the main constructs that can be used to specify knowledge in a domain.
- Design metamodels by considering the models that should be defined with it.
- DSL design is always iterative.