Model-Based Software Engineering

Lecture 06 – Concrete Syntax

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May 24, 2016

Leibniz Universität Hannover

Acknowledgment

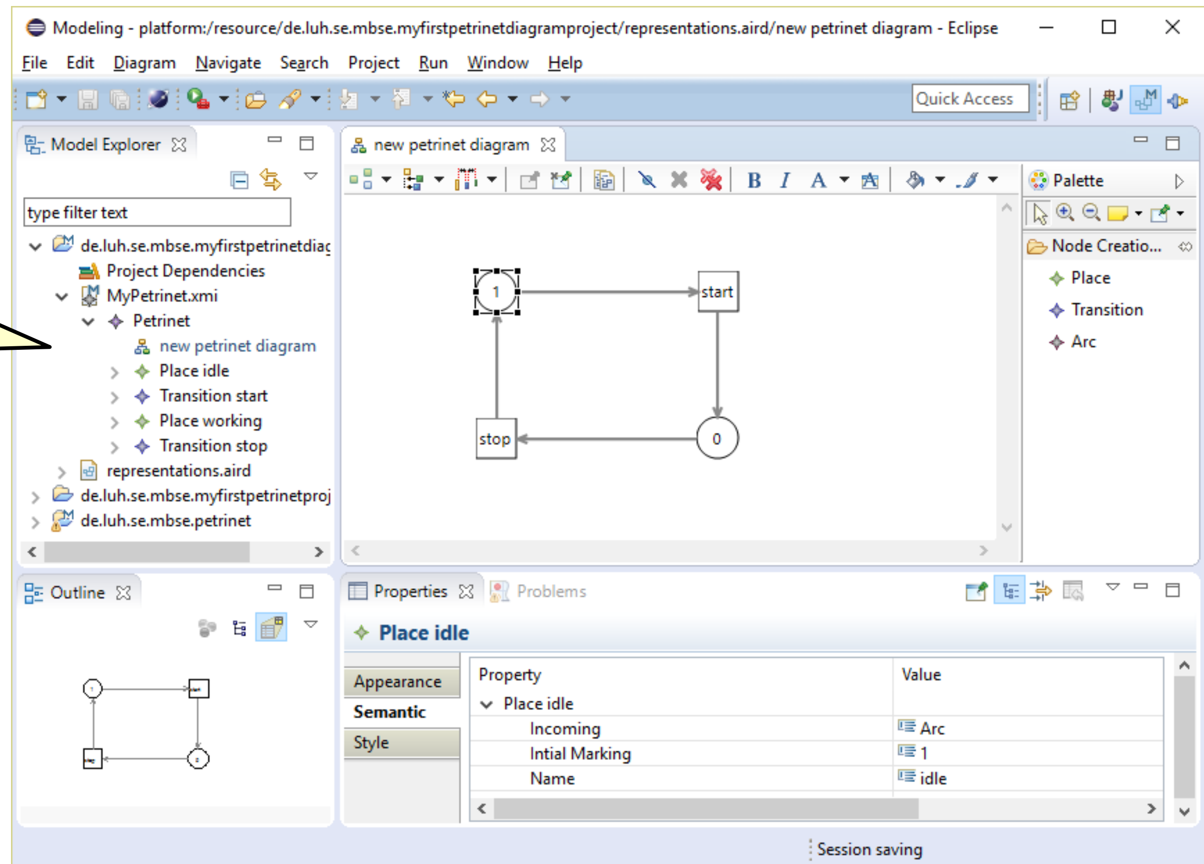
- The slides of this lecture are inspired by lecture slides from
  - *Ekkart Kindler*: Course on Advanced Topics in Software Engineering, DTU Compute, 2015.
    - http://www2.imm.dtu.dk/courses/02265/f15/schedule.shtml
  - *Ina Schäfer, Christoph Seidl*: Modellbasierte Software-entwicklung, TU Braunschweig, 2015.
  - *Steffen Becker*: Model-Driven Software Development, Universität Paderborn, 2013
  - The Eclipse Open Model CourseWare (OMCW) Project:
    - https://eclipse.org/gmt/omcw/

Eclipse Sirius

in the last lecture...

- Eclipse **Sirius** works by *interpreting* a graphical mapping of the model
  - no code generation required

example: Petri net editor created in 15 Minutes!



see https://eclipse.org/sirius/
and https://eclipse.org/sirius/getstarted.html

4.2. Textual syntax

Excursion on Compilers – Syntax Analysis

in the last lecture...

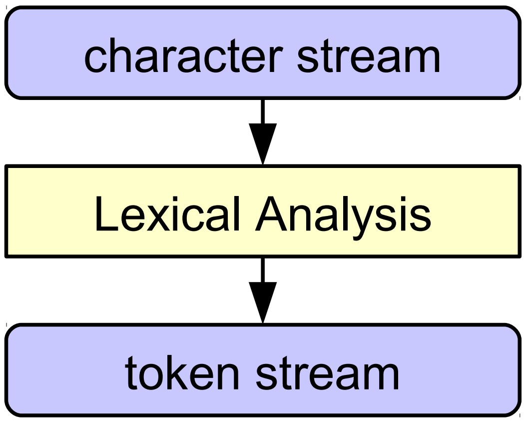
- Steps in the textual syntax analysis:

character stream

Excursion on Compilers – Syntax Analysis

in the last lecture...

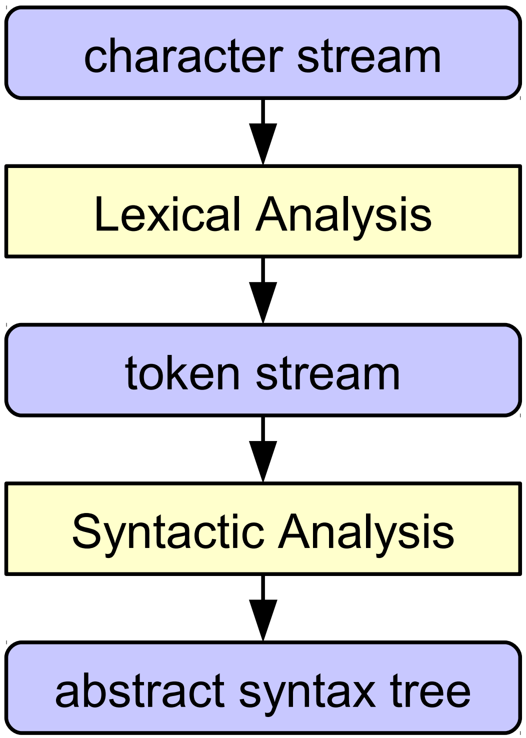
- Steps in the textual syntax analysis:
  - Lexical Analysis
    - partitions character stream into tokens (removes whitespaces, identifies keywords, identifiers, ...)



Excursion on Compilers – Syntax Analysis

in the last lecture...

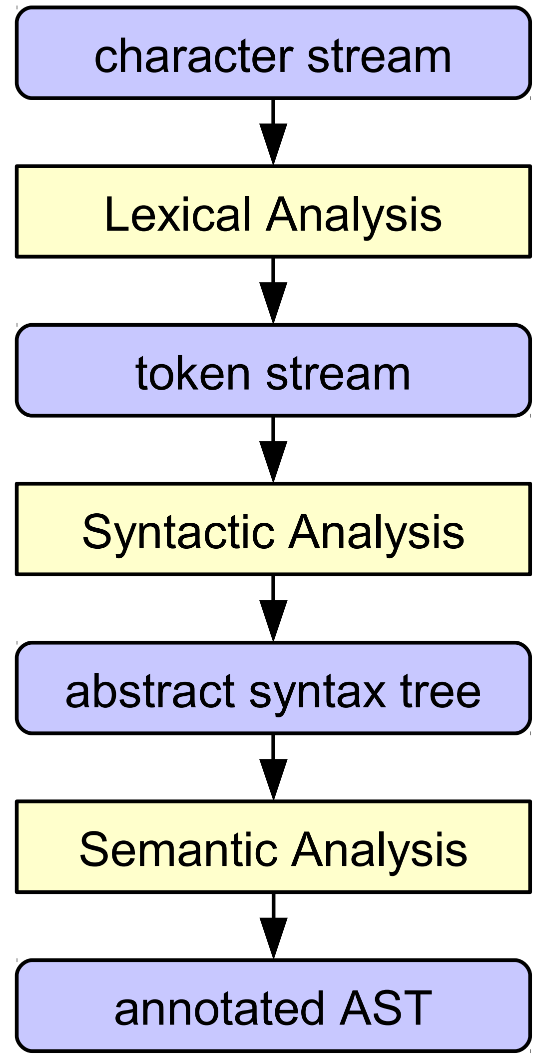
- Steps in the textual syntax analysis:
  - Lexical Analysis
    - partitions character stream into tokens (removes whitespaces, identifies keywords, identifiers, ...)
  - Syntax Analysis
    - context-free analysis identifies abstract syntax tree (AST) structure



Excursion on Compilers – Syntax Analysis

in the last lecture...

- Steps in the textual syntax analysis:
  - Lexical Analysis
    - partitions character stream into tokens (removes whitespaces, identifies keywords, identifiers, ...)
  - Syntax Analysis
    - context-free analysis identifies abstract syntax tree (AST) structure
  - Semantic Analysis
    - analyze cross-references of AST elements (variable scoping, type conformance, ...)



Parser generators – Example: ANTLR

in the last lecture...

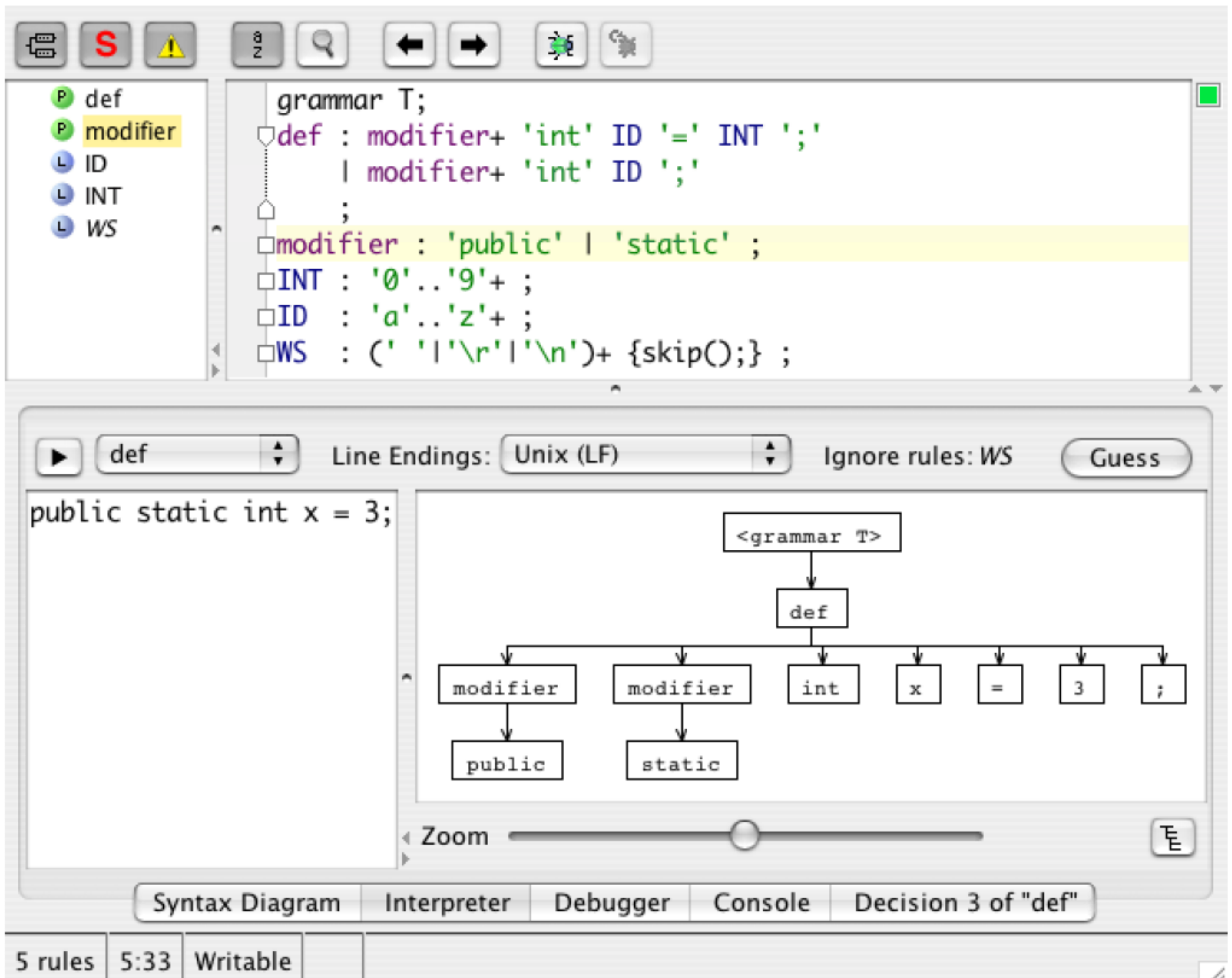
- There exist **frameworks for constructing compilers** that can generate lexer and parser components (and other things) from a language definition in the form of a grammar

- a popular example: **ANTLR**
  - takes as input a context-free grammar in Extended Backus–Naur Form (EBNF)

Parser generators – Example: ANTLR

in the last lecture...

- ANTLRWorks Interpreter visualizes the result of the syntactic analysis:



see http://www.antlr.org/papers/antlrworks-draft.pdf

Xtext – a Framework for Building Textual Languages in Eclipse

in the last lecture...

- **Xtext** is a framework for building textual languages and editors within Eclipse (also IntelliJ IDEA and web browser)
- The language is built based on a grammar definition similar to EBNF
  - but with extra features for referencing a corresponding Ecore metamodel
  - Generation of an Ecore metamodel from a grammar is also supported
- Xtext can create the Ecore metamodel, lexer/parser, and editor from the grammar definition
  - The editor supports syntax checking, highlighting, and code completion, renaming/refactoring, and has extensions for implementing quick-fixes, and other functionality

Xtext – Simple Example: Company

in the last lecture...

```
// automatically generated by Xtext
grammar de.luh.se.mbse.company.cml.CML with org.eclipse.xtext.common.Terminals

import "platform:/resource/de.luh.se.mbse.company/model/company.ecore"
import "http://www.eclipse.org/emf/2002/Ecore" as ecore

Company returns Company:
    {Company}
    'Company'
    name=EString
    '{'
        ('department' '{' department+=Department ( "," department+=Department)* '}' )?
    '}';

EString returns ecore::EString:
    STRING | ID;

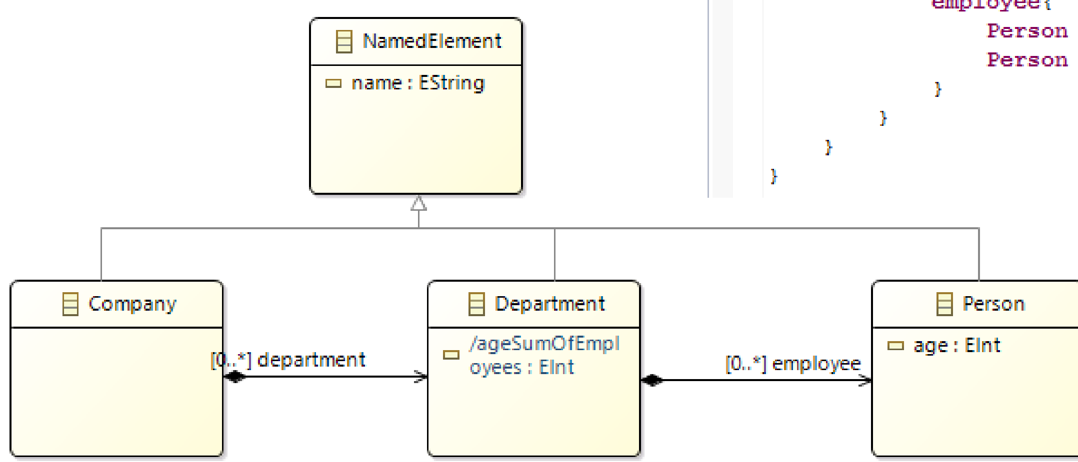
Department returns Department:
    {Department}
    'Department'
    name=EString
    '{'
        ('employee' '{' employee+=Person ( "," employee+=Person)* '}' )?
    '}';

Person returns Person:
    {Person}
    'Person'
    name=EString
    '{'
        ('age' age=EInt)?
    '}';

EInt returns ecore::EInt:
    '-'? INT;
```

mycompany.cml

```
Company MyCompany{
    department {
        Department Finance{
            employee{
                Person Alison {age 21},
                Person Beverly {age 34}
            }
        },
        Department Marketing{
            employee{
                Person Charlie {age 43},
                Person Dave {age 39}
            }
        }
    }
}
```



4.3. Xtext

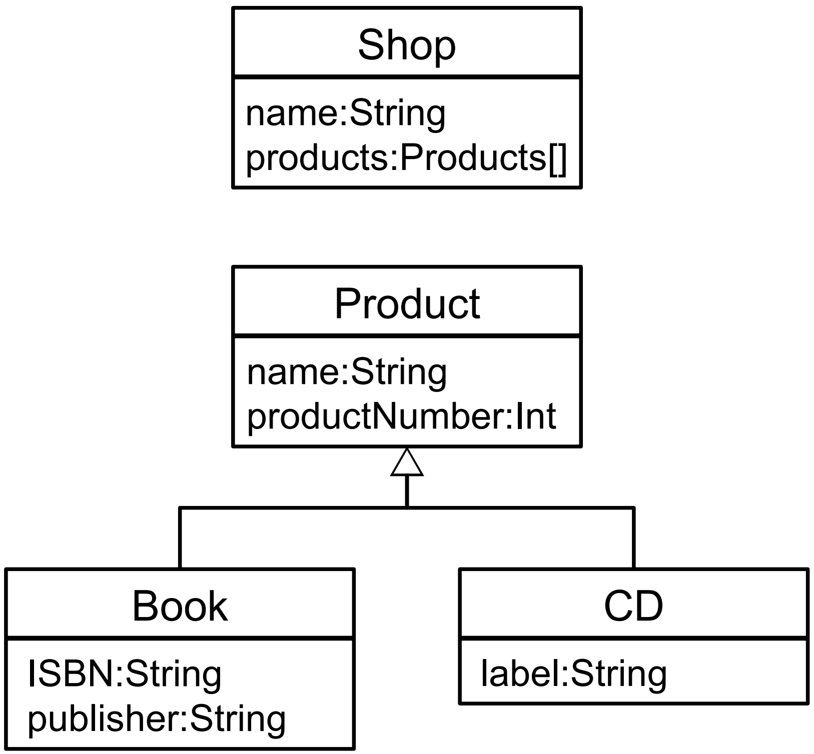
Literature

- Bettini, Lorenzo: Implementing Domain-Specific Languages with Xtext and Xtend. Packt Publishing, 2013.

- The *Entities* example (coming next) is taken from this book.

Example: Defining a Language for Entities

- Entities: A simple class-model-like DSL




```
entity Shop{
        String name;
        Product[] product;
}

entity Product{
        String name;
        Int productNumber;
}

entity Book extends Product{
        String ISBN;
        String publisher;
}

entity CD extends Product{
        String label;
}
```

graphical syntax

textual syntax
(this is what we are going to define)

Example: Defining a Language for Entities

- We start with a very simple version of the language

```
grammar de.luh.se.mbse.entities.Entities
with org.eclipse.xtext.common.Terminals

generate entities "http://www.luh.de/se/mbse/entities/Entities"

Model:
	entities+=Entity*;

Entity:
	'entity' name=ID;
```

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Model:
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Entity:
       'entity' name=ID;
```

name of the grammar / language

Example: Defining a Language for Entities

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grammar de.luh.se.mbse.entities.Entities
with org.eclipse.xtext.common.Terminals

generate entities "http://www.luh.de/se/mbse

Model:
	entities+=Entity*;

Entity:
	'entity' name=ID;
```

reuses the grammar **`Terminals`**, which defines strings, numbers, comments

Example: Defining a Language for Entities

- We start with a very simple version of the language

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generate entities "http://www.luh.de/se/mbse/entities/Entities"

Model:
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Entity:
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```

Will generate a corresponding Ecore model with the given nsURI

Example: Defining a Language for Entities

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a **rule**: when a rule is applied in the parsing process, a corresponding EObject is created

Example: Defining a Language for Entities

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generate entities "http://www.luh.de/se/mbse/entities/Entities"

Model:
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Entity:
	'entity' name=ID;
```

a **rule**: when a rule is applied in the parsing process, a corresponding EObject is created

the first rule is the **start rule**

Example: Defining a Language for Entities

- We start with a very simple version of the language

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Model:
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Entity:
      'entity' name=ID;
```

an **assignment**: assigns the parsed information to a feature of the currently produced object

Example: Defining a Language for Entities

- We start with a very simple version of the language

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generate entities "http://www.luh.de/se/mbse/entities/Entities"

Model:
	entities+=Entity*;

Entity:
	'entity' name=ID;
```

First rule:

- `Model` is the type of the root element of the AST model (Every Xtext rule corresponds to an EClass in the corresponding Ecore model)
- `Model` contains a collection `entities` of zero or many `Entity` elements.

Example: Defining a Language for Entities

- We start with a very simple version of the language

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grammar de.luh.se.mbse.entities.Entities
with org.eclipse.xtext.common.Terminals

generate entities "http://www.luh.de/se/mbse/entities/Entities"

Model:
        entities+=Entity*;

Entity:
```

+= operator:
entities is a collection (many-valued EReference)

First rule:

- Model is the type of the root element of the AST model (Every Xtext rule corresponds to an EClass in the corresponding Ecore model)
- Model contains a collection entities of zero or many Entity elements.

Example: Defining a Language for Entities

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Model:
	entities+=Entity*;

Entity:
	'entity' name=ID;
```

An `Entity` statement starts with the keyword “entity”, followed by a name

IDs from
`org.eclipse.xtext.common.Terminals`

- ID is defined in `org.eclipse.xtext.common.Terminals`

```
Entity:
        'entity' name=ID ;
```

IDs from `org.eclipse.xtext.common.Terminals`

- `ID` is defined in `org.eclipse.xtext.common.Terminals`

```
Entity:
        'entity' name=ID ;
```

- A look into `Terminals` shows what valid `ID`s are:

IDs from `org.eclipse.xtext.common.Terminals`

- `ID` is defined in `org.eclipse.xtext.common.Terminals`

```
Entity:
        'entity' name=ID ;
```

- A look into `Terminals` shows what valid `ID`s are:

```
terminal ID:
```

IDs from `org.eclipse.xtext.common.Terminals`

- `ID` is defined in `org.eclipse.xtext.common.Terminals`

```
Entity:
        'entity' name=ID ;
```

- A look into `Terminals` shows what valid `ID`s are:

```
terminal ID:
        '^'?('a'..'z'|'A'..'Z'|'_')('a'..'z'|'A'..'Z'|'_'|'0'..'9')*;
```

IDs from `org.eclipse.xtext.common.Terminals`

- `ID` is defined in `org.eclipse.xtext.common.Terminals`

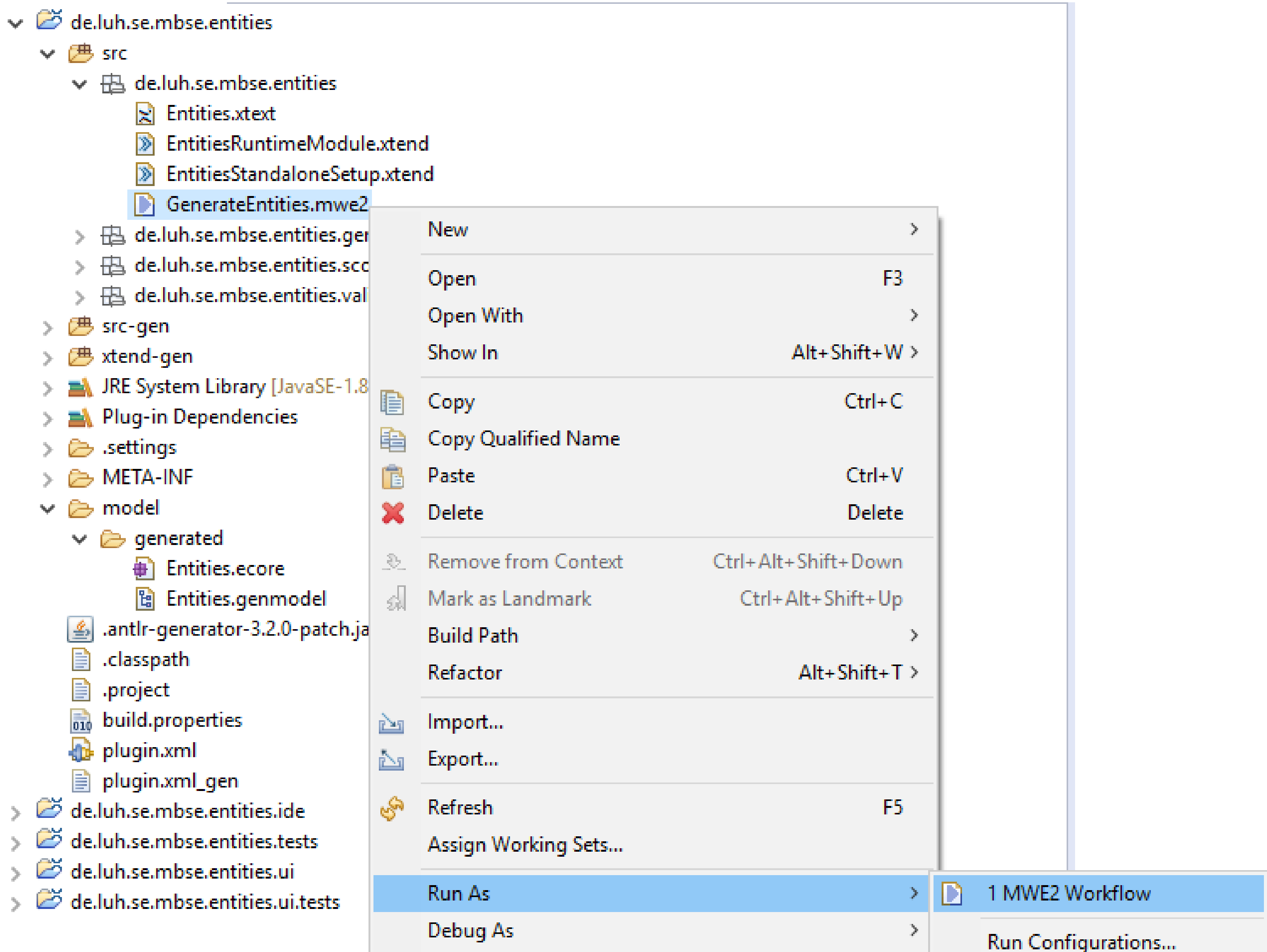
```
Entity:
        'entity' name=ID ;
```

- A look into `Terminals` shows what valid `ID`s are:

```
terminal ID:
        '^'?('a'..'z'|'A'..'Z'|'_')('a'..'z'|'A'..'Z'|'_'|'0'..'9')*;
```

Any sequence of lower- and upper-case letters, underscores, and digits
- but no leading digits
- leading '^' possible

Example: Defining a Language for Entities (tool-specific: generate code)



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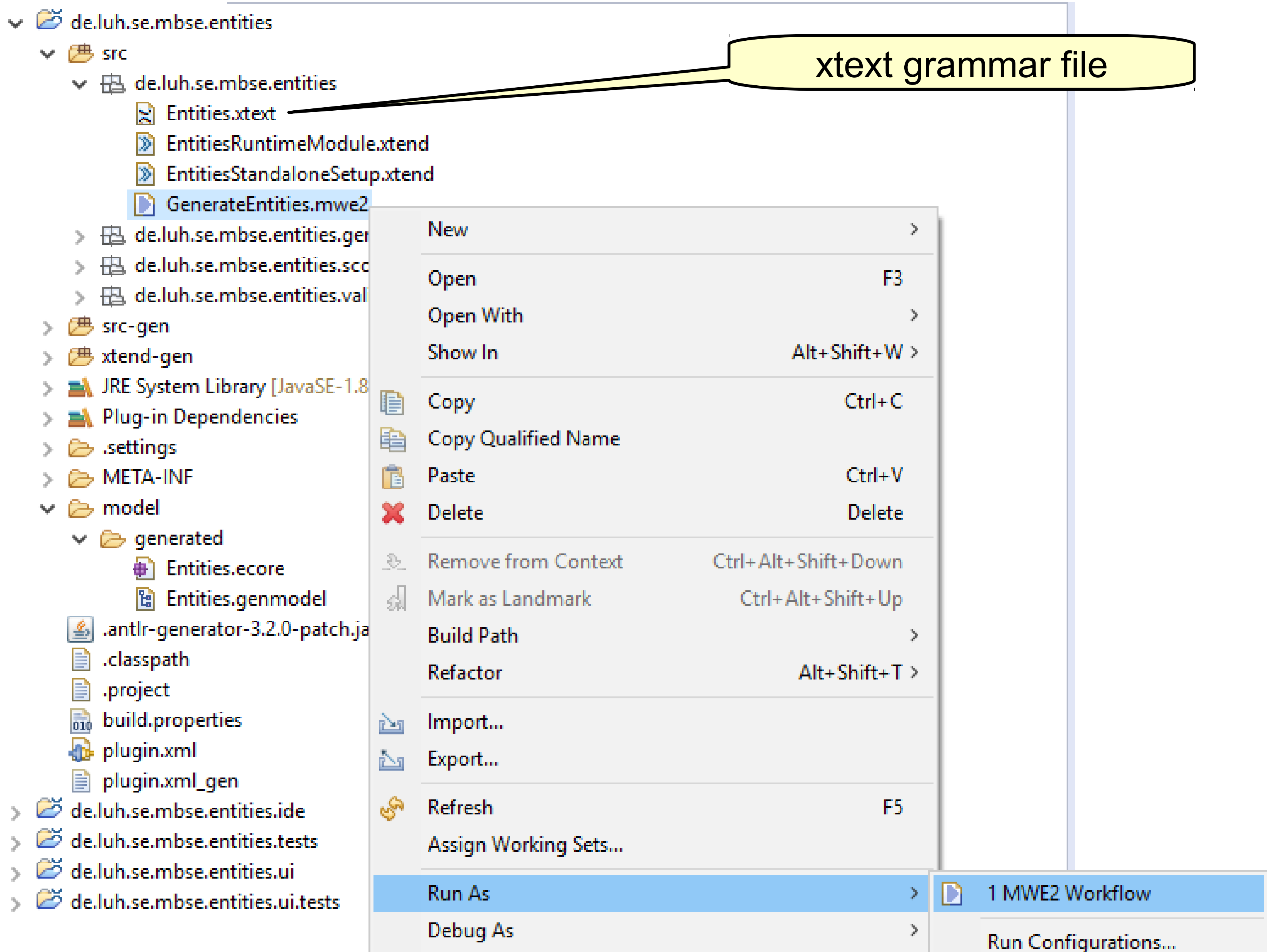

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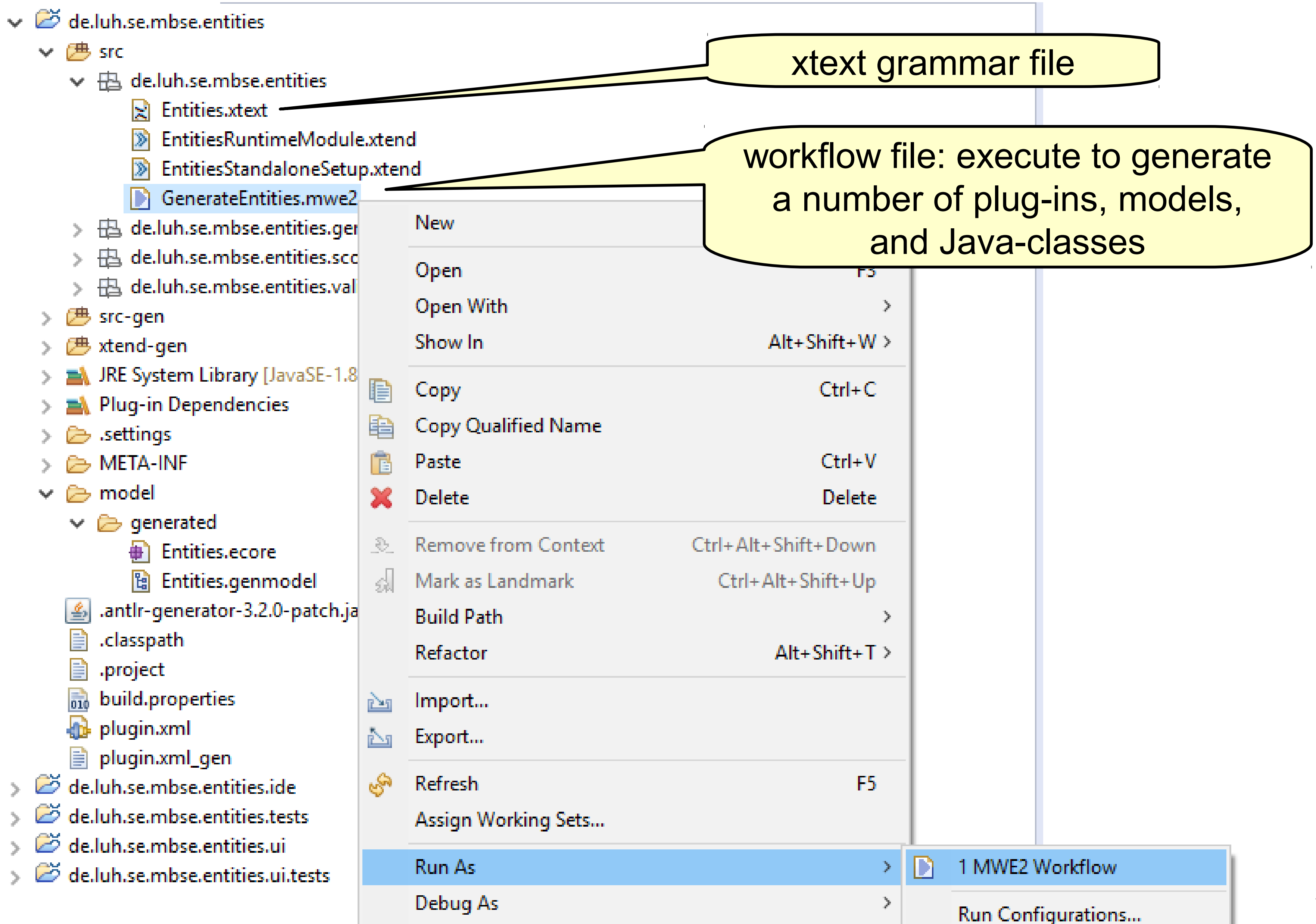

Example: Defining a Language for Entities

- How does the Ecore model look that is generated by Xtext?

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generate entities
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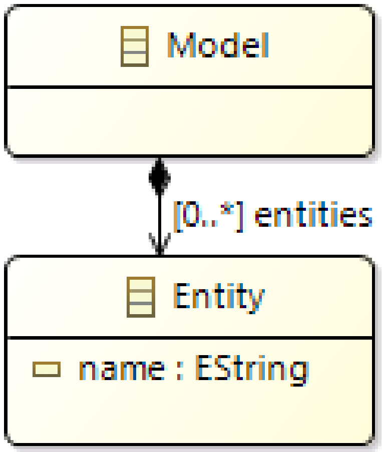

Example: Defining a Language for Entities

- Let's extend the language to allow attributes of entities and entities that extend other entities:

```
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generate entities "http://www.luh.de/se/mbse/entities/Entities"

Model:
	entities+=Entity*;

Entity:
	'entity' name=ID ('extends' supertype=[Entity])? '{'
	attributes+=Attribute*
	'}';

Attribute:
	type=[Entity] (array?='[]')? name=ID ';';
```

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An `Entity` statement starts with the keyword “entity”, followed by a name

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	'}';

Attribute:
	type=[Entity] (array?=
```

An Entity statement starts with the keyword “entity”, followed by a name

It can be followed by the keyword “extends” and a reference called supertype to an existing element of type Entity

- optionality is denoted by ?
- referring to a type in square brackets [] expresses a cross reference to an existing element of the given type

Example: Defining a Language for Entities

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Model:
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Entity:
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```

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It can be followed by the keyword “extends” and a reference called `supertype` to an existing element of type `Entity`

- optionality is denoted by ?
- referring to a type in square brackets [ ] expresses a cross reference to an existing element of the given type

Then, enclosed in the keywords/symbols “{” and “}”, follows a collection of attributes.

Example: Defining a Language for Entities

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```
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Entity:
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cross reference to an existing entity (as above)

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	'}';

Attribute:
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```

cross reference to an existing entity (as above)

attribute `array`, `?` defines it as EBoolean. If optional `'[]'` is provided, set `array` to true.

Example: Defining a Language for Entities

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Entity:
	'entity' name=ID ('extends' supertype=[Entity])? '{'
	attributes+=Attribute*
	'}';

Attribute:
	type=[Entity] (array?='[]')? name=ID ';';
```

Then a name, and finally a semicolon ';'

cross reference to an existing entity (as above)

attribute array, ? defines it as EBoolean. If optional '[]' is provided, set array to true.

Example: Defining a Language for Entities

- How does the Ecore model look that is generated by Xtext?

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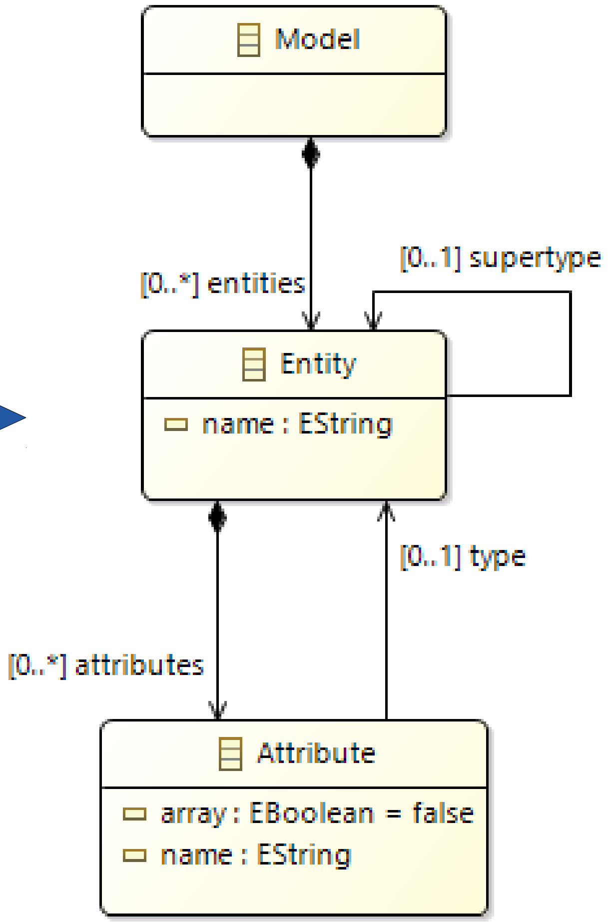
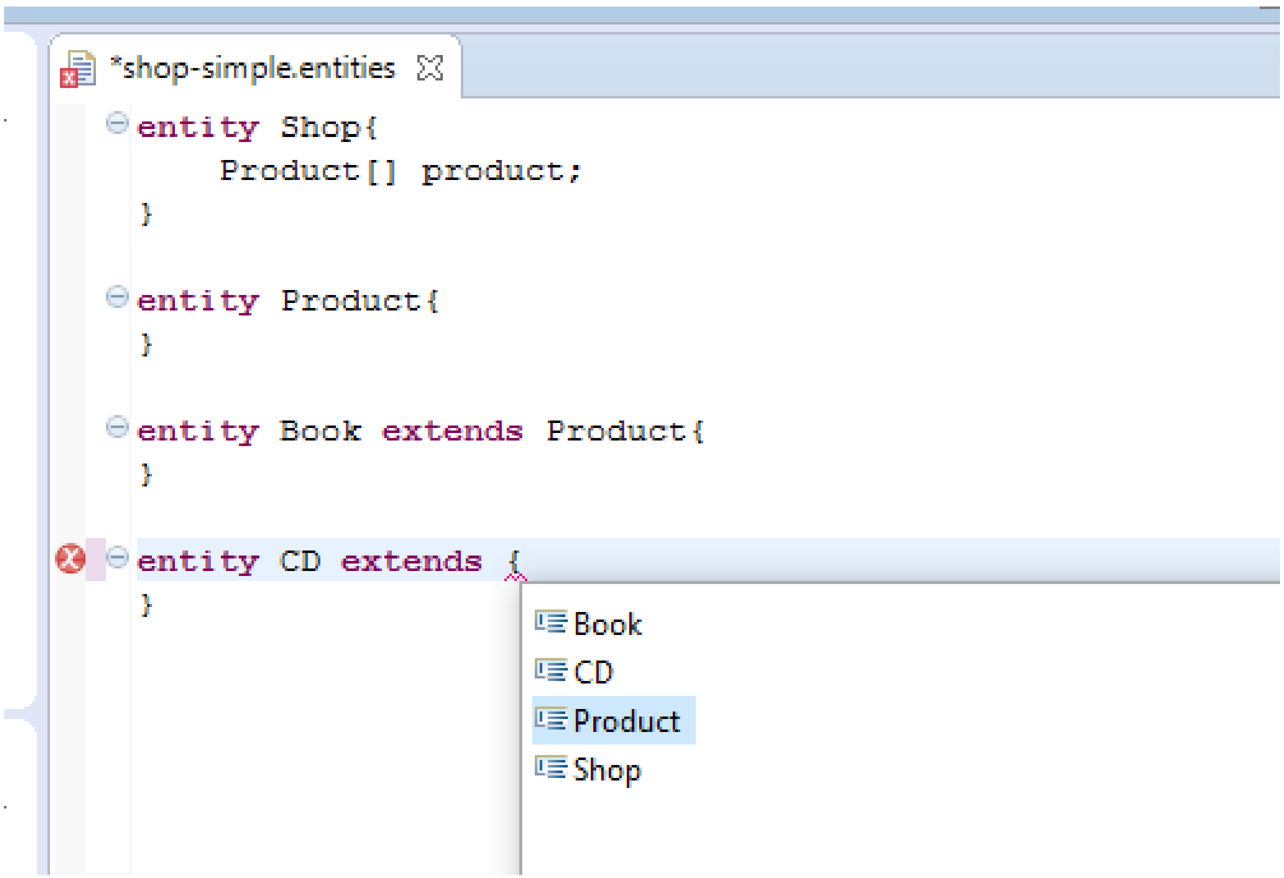


Example: Defining a Language for Entities

- Let's try the editor:



Example: Defining a Language for Entities

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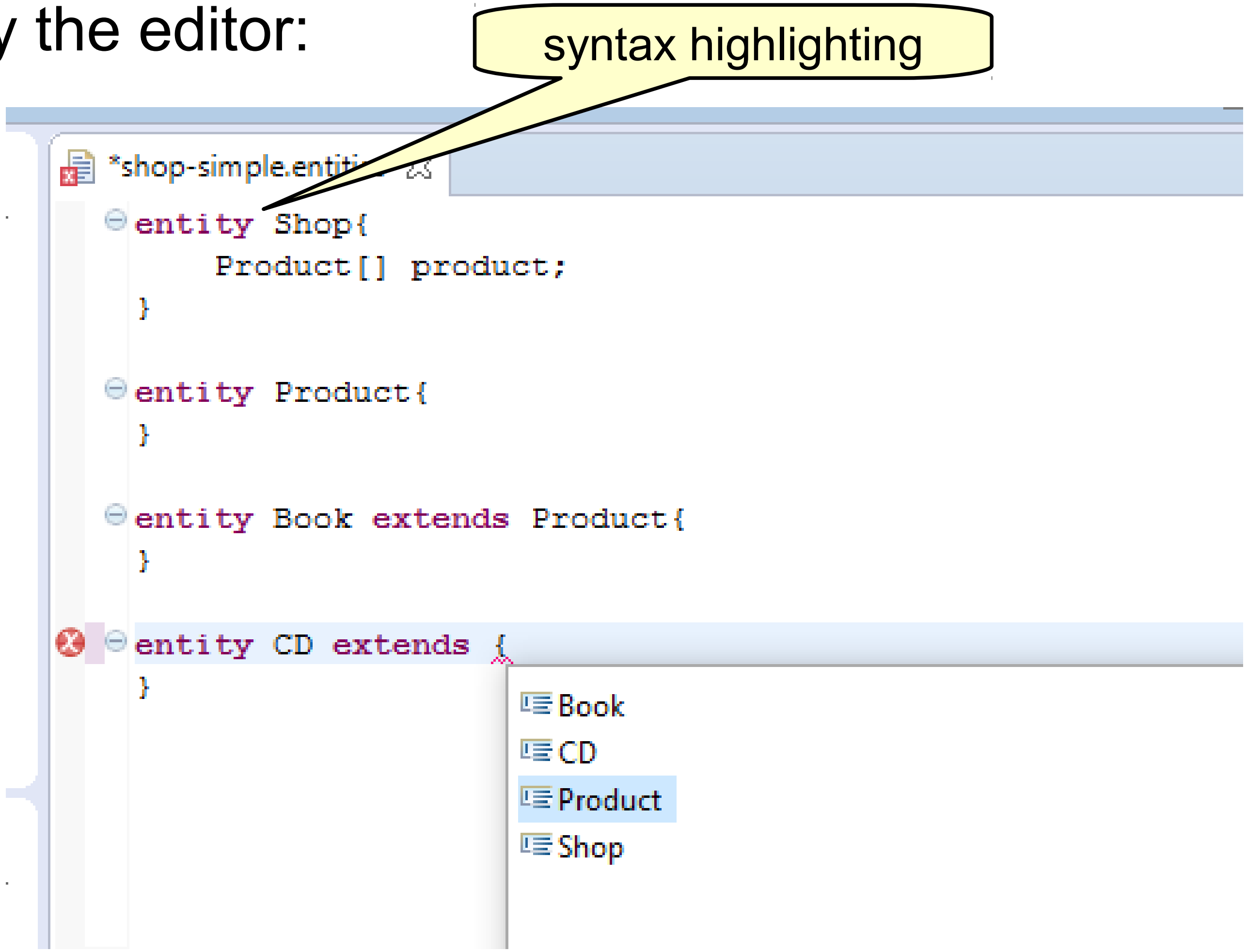
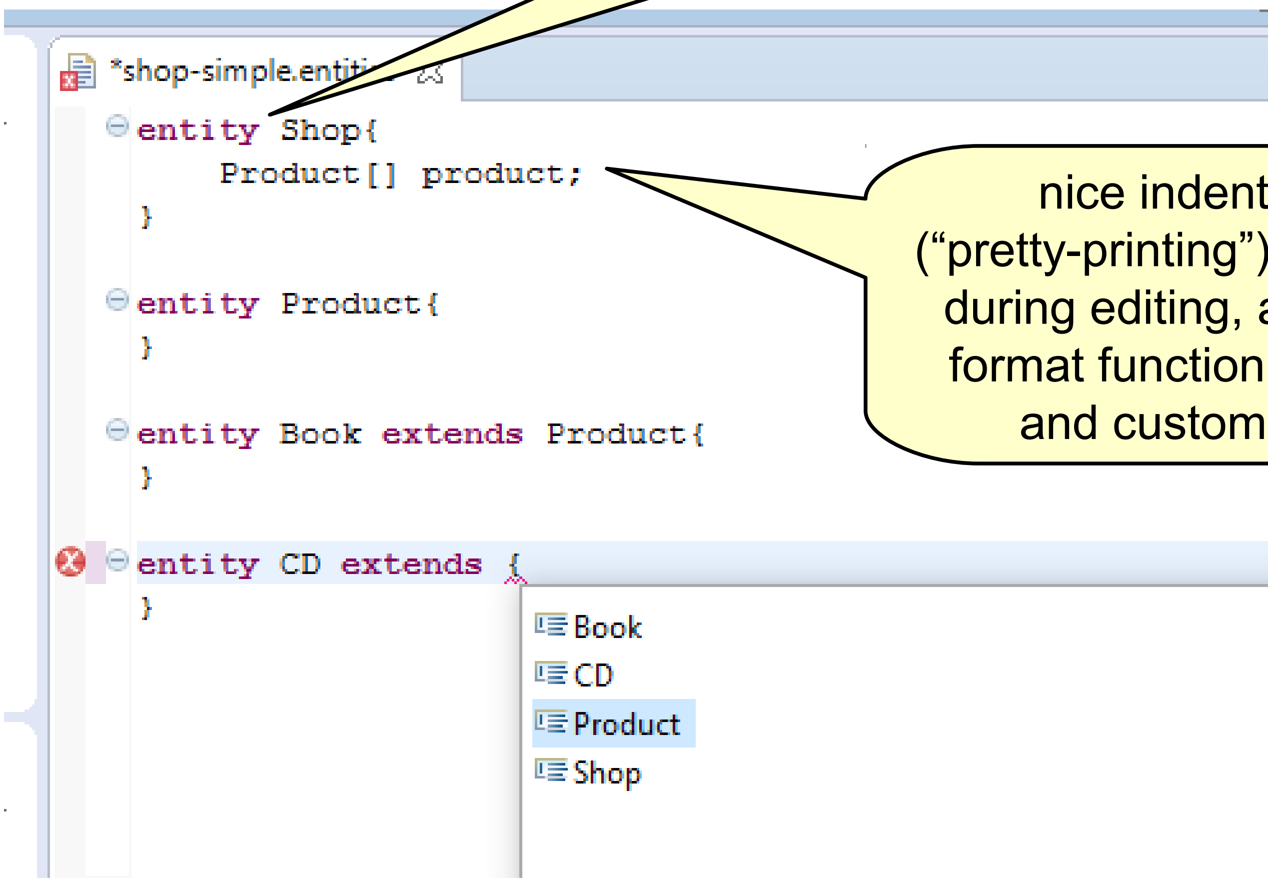


Example: Defining a Language for Entities

- Let's try the editor:

syntax highlighting



nice indentation (“pretty-printing”) supported during editing, also auto-format function provided and customizable

Example: Defining a Language for Entities

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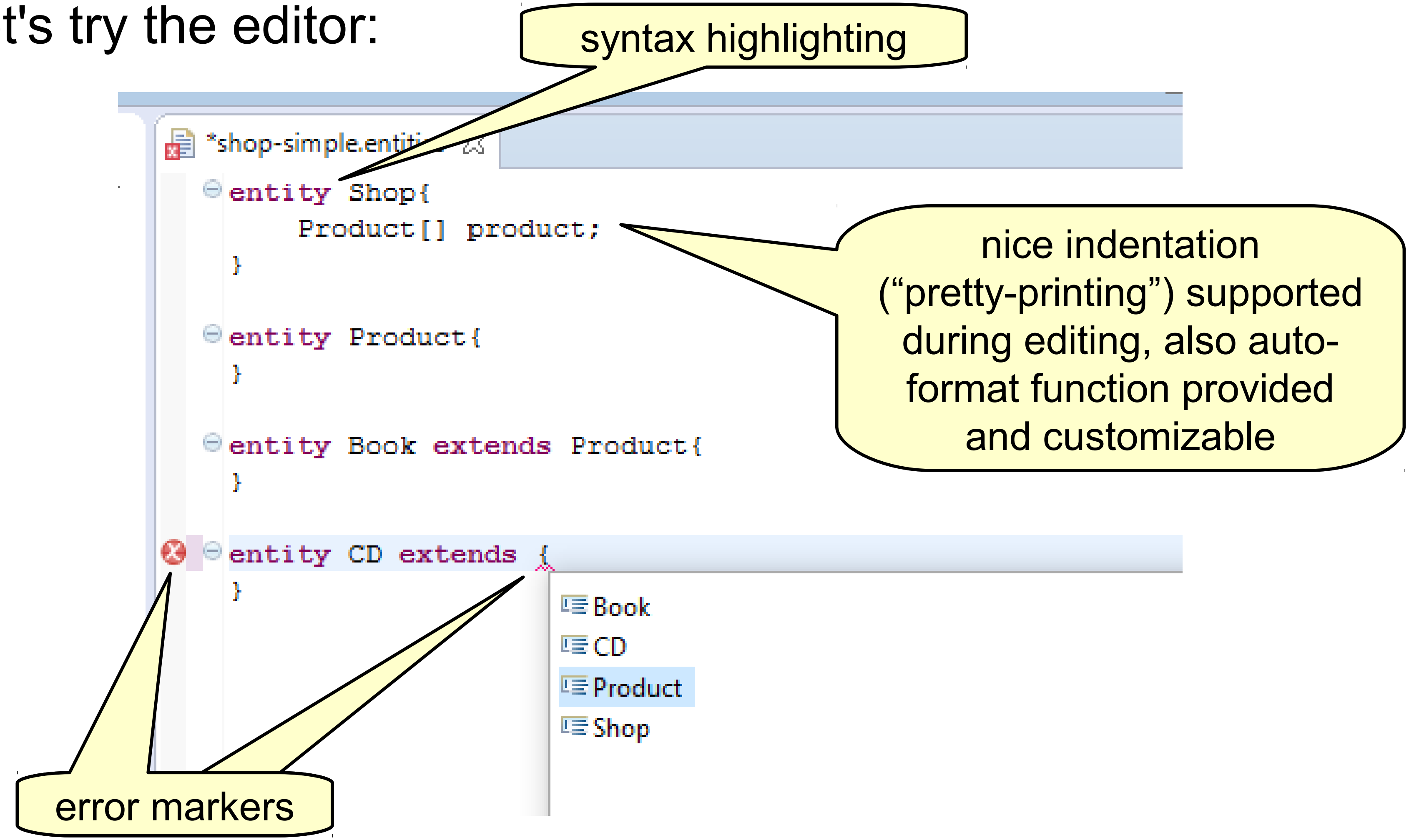

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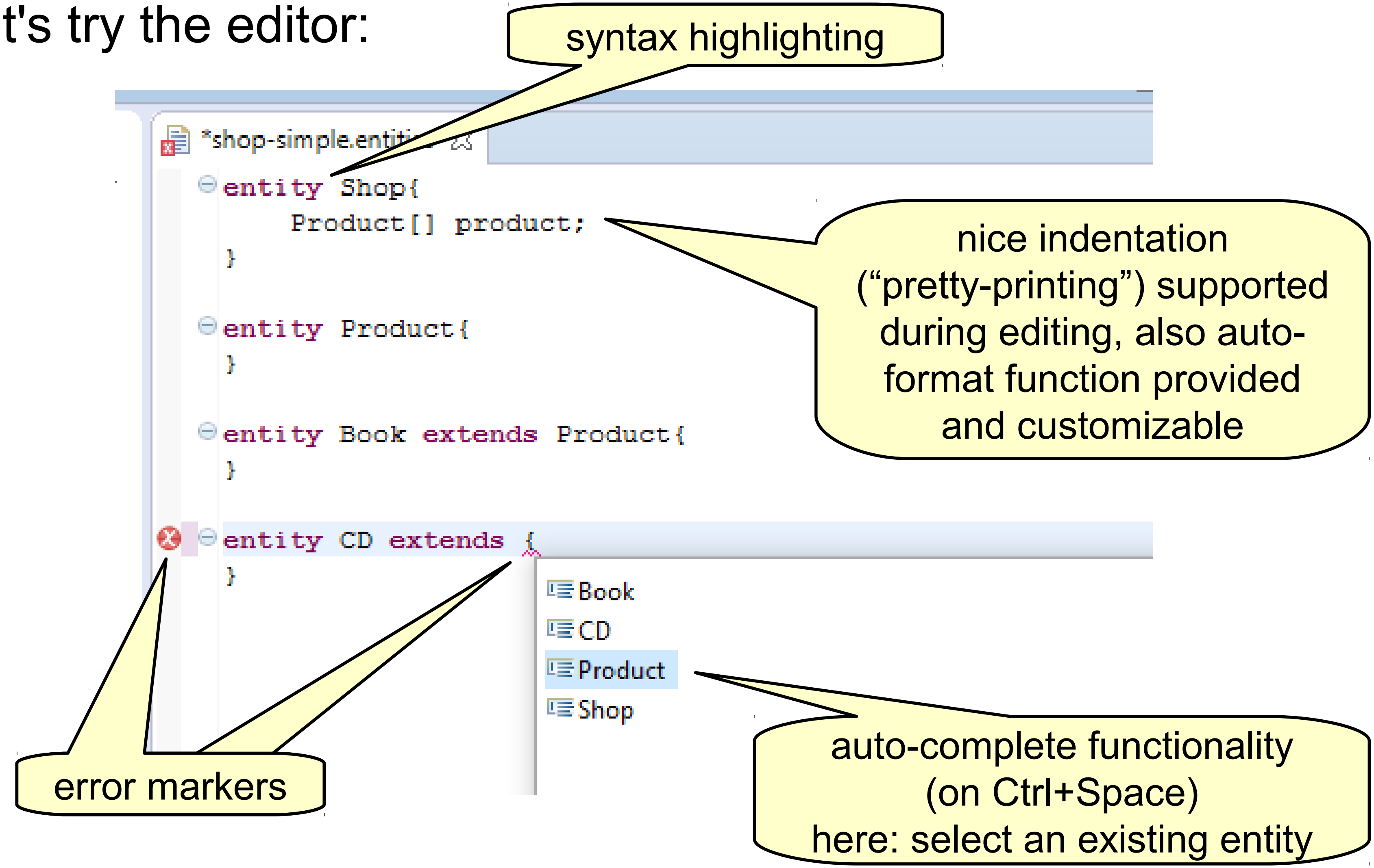

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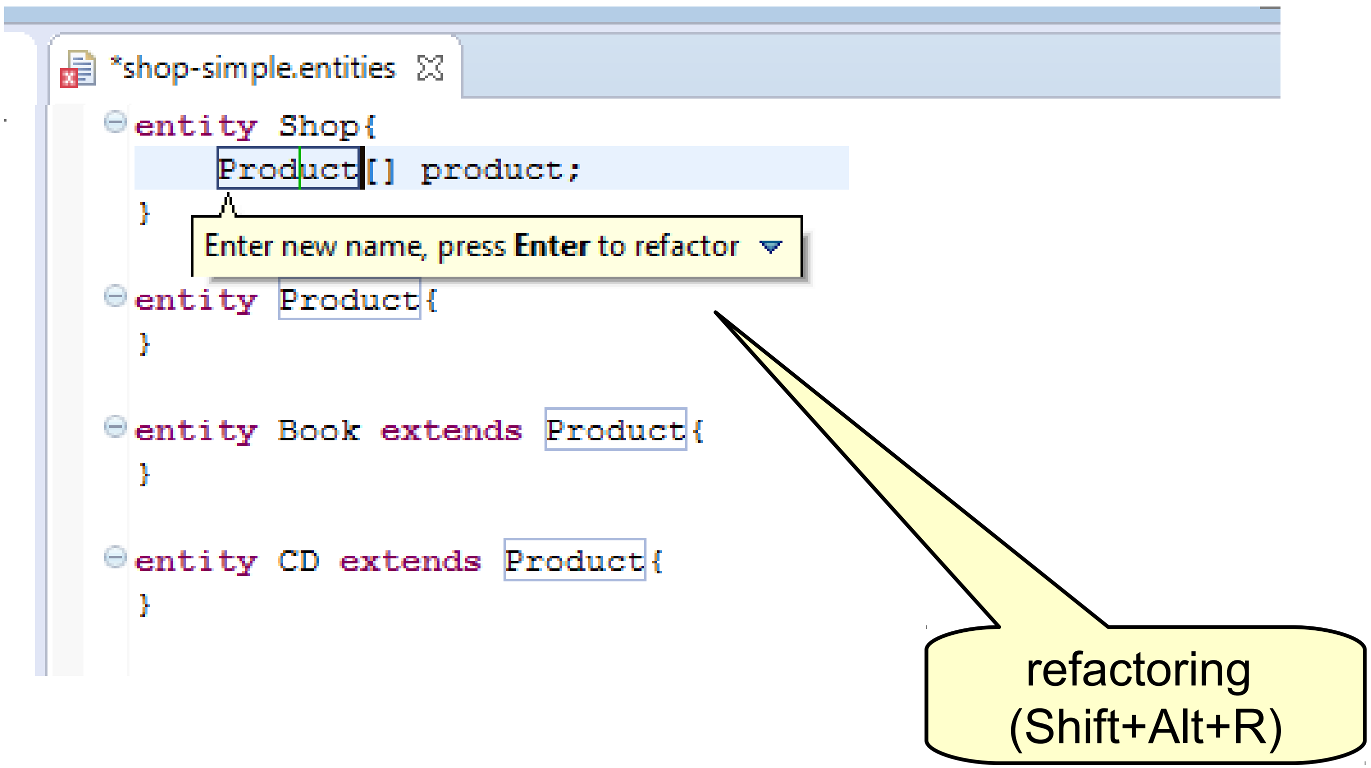

Example: Defining a Language for Entities (extending the language)

- What about String and Integer attributes?

```
entity Shop{
        String name;
        Product[] product;
}

entity Product{
        String name;
        Int productNumber;
}

entity Book extends Product{
        String ISBN;
        String publisher;
}

entity CD extends Product{
        String label;
}
```

Example: Defining a Language for Entities (extending the language)

```
…

Model:
     entities+=Entity*;

Entity:
     'entity' name=ID ('extends' supertype=[Entity])? '{'
     attributes+=Attribute*
     '}';

Attribute:
     type=AttributeType name=ID ';';

AttributeType:
     elementType=ElementType (array?='[' (length=INT)? ']')?;

ElementType:
     EntityType | BasicType;

EntityType:
     entity=[Entity];

BasicType:
     typename=('String'|'Boolean'|'Int');
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Example: Defining a Language for Entities (extending the language)

```
…

Model:
     entities+=Entity*;

Entity:
     'entity' name=ID ('extends' supertype=[Entity])? '{'
     attributes+=Attribute*
     '}';

Attribute:
     type=AttributeType name=ID ';';

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The `AttributeType` specifies and element type and whether it is an array of a specific length

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a basic type has a string attribute `typename`, which can be either "String", "Boolean" or "Int"

Example: Defining a Language for Entities

- How does the Ecore model look?

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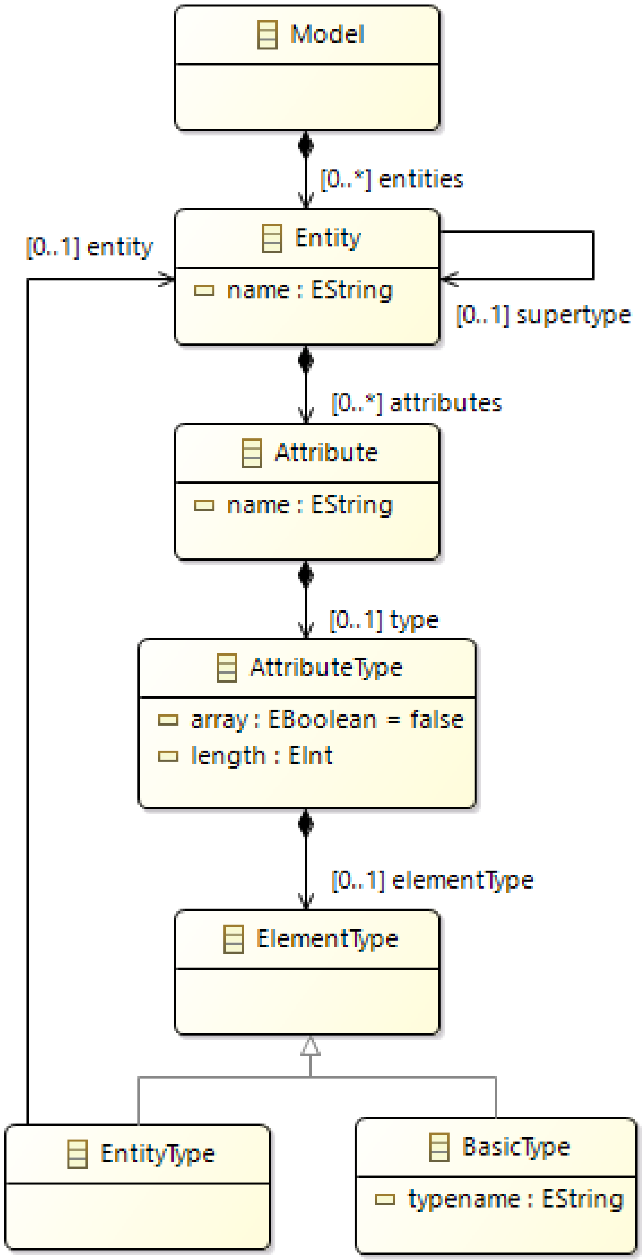

Example: Defining a Language for Entities

- We can use Enums, too.

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BasicType:
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enum BasicTypeEnum:
        String | Boolean | Int;
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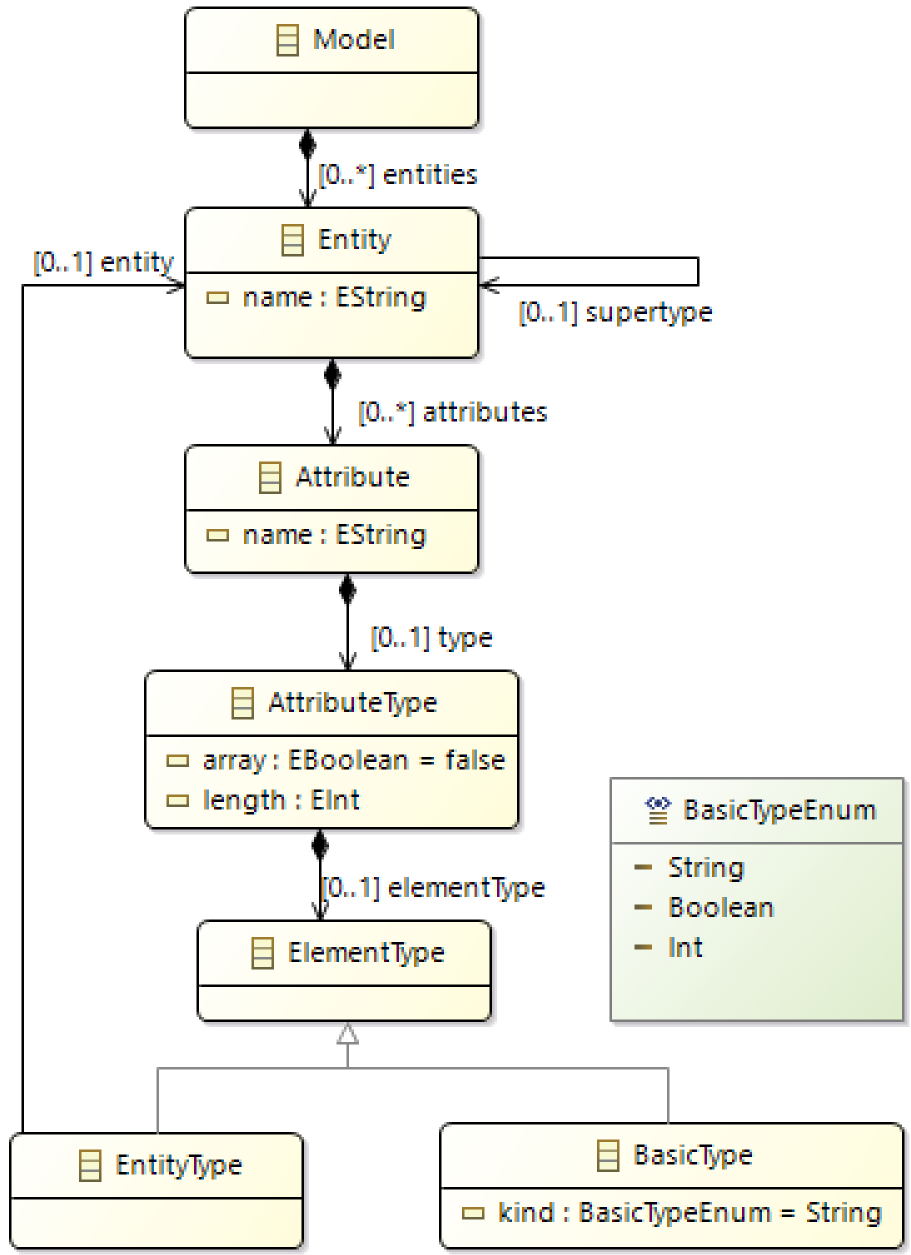

Referencing an Existing Ecore Model

- An Xtext grammar can also refer to an existing Ecore model:

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grammar de.luh.se.mbse.petrinet.pnl.PNL
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Petrinet:
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NetElement:
      Node | Arc;

Node:
      Place | Transition;

Place:
      'Place' name=ID;

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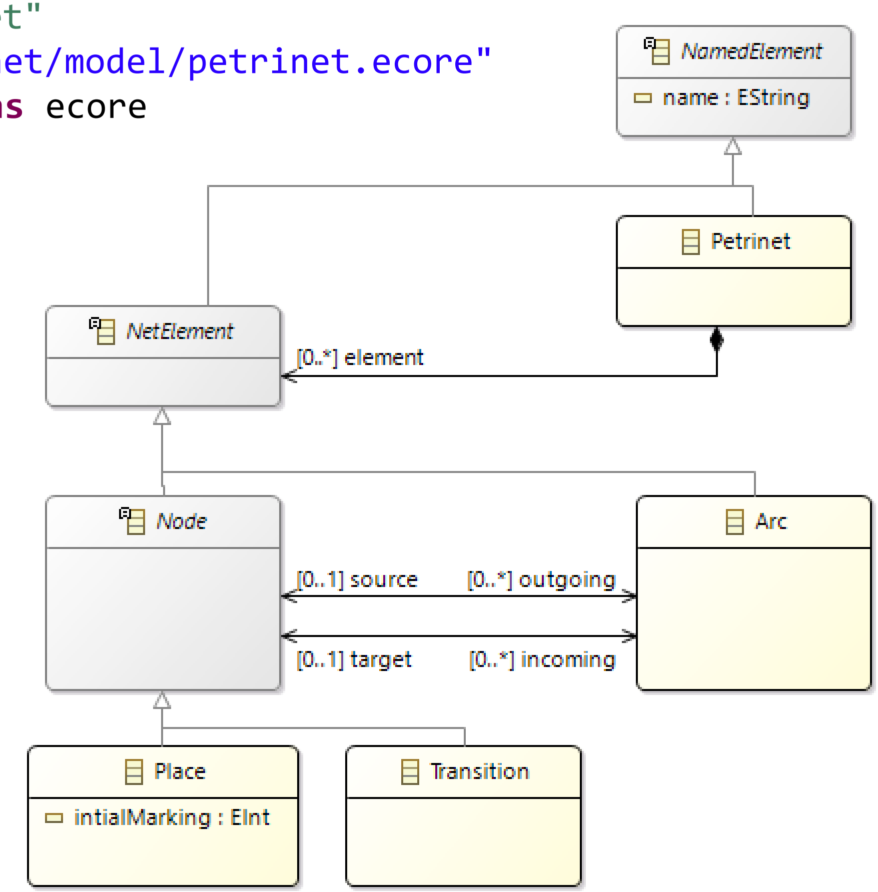

Some common Xtext issues

- “...may consume non empty input without object instantiation”

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Petrinet:
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The entry rule 'Petrinet' may consume non empty input without object instantiation. Add an action to ensure object creation, e.g. '{Petrinet}'.

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```
Arc:
    'Arc' source=[Place] '->' target=[Transition]
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Idea: use Xtext grammar to constrain valid Petri net edges

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```
Arc: // solution 1: add keywords
    'Arc' 'pl' source=[Place] '->' 'tr' target=[Transition]
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```
Arc: // solution 1: add keywords
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    | 'Arc' 'tr' source=[Transition] '->' 'pl' target=[Place] ;
```

Integration with OCL constraints on the Ecore metamodel

```
Arc:
      'Arc' source=[Place] '->' target=[Transition]
      | 'Arc' source=[Transition] '->' target=[Place] ;
```

```
Arc: // solution 2: use OCL constraint in the Ecore metamodel
      'Arc' source=[Node] '->' target=[Node];
```

```
Petri net DayAndNight {
     Place day
     Transition sunset
     Place night
     Transition sunrise
     Arc day -> night
}
```

The 'NoArcsBetweenNodesOfTheSameKind' constraint is violated on 'de.luh.se.mbse.petrinet.impl.ArcImpl@60cefcf8{platform:/resource/de.luh.se.mbse.myfirstpetrinetproject/myfirstpetrinet2.pnl#//@element.4}'

Custom Validation

```
Arc:
     'Arc' source=[Place] '->' target=[Transition]
     | 'Arc' source=[Transition] '->' target=[Place] ;
```

```
Arc: // solution 3: implement a custom Xtext validation function
     'Arc' source=[Node] '->' target=[Node];
```

```
Petri net DayAndNight {
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An arc can only connect a place to transition or a transition to a place

Custom Validation

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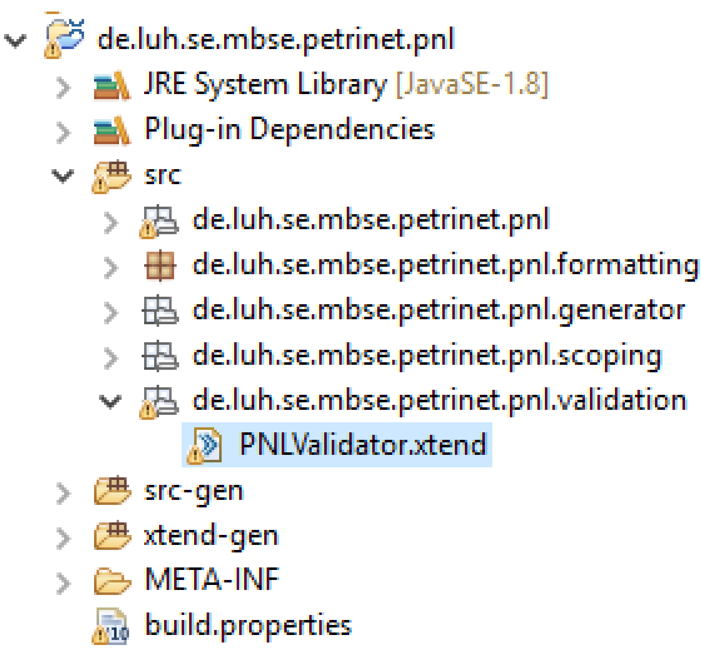

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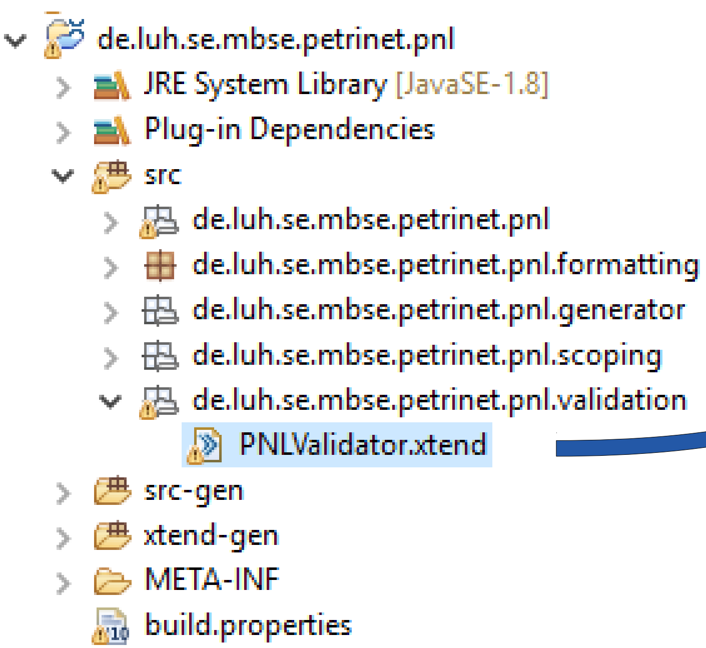


```
@Check
def checkValidArc(Arc arc){
    if(
        !( arc.source instanceof Place
            && arc.target instanceof Transition
        || arc.source instanceof Transition
            && arc.target instanceof Place)
    ){
        error('An arc can only connect ...',
            PetrinetPackage.Literals.ARC__SOURCE
        )
    }
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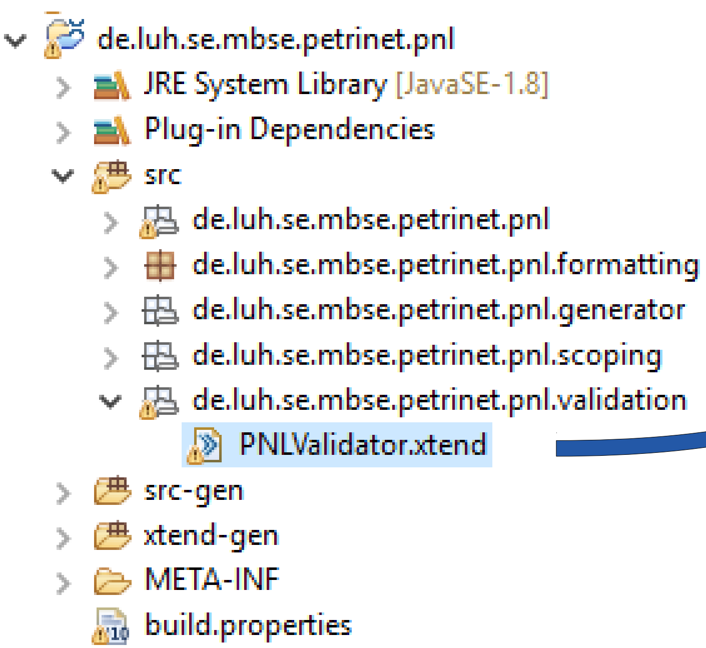
  - implementation in Xtend, a Java-like programming language

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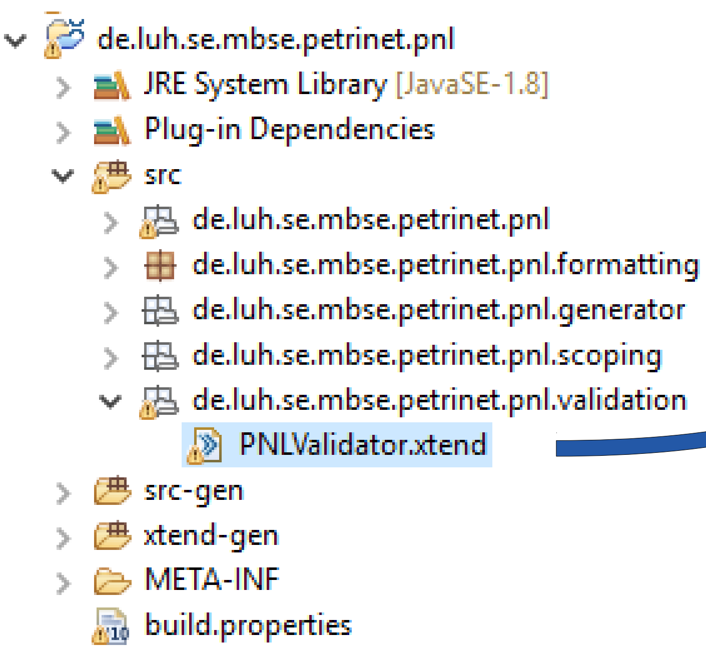
  - Xtend: less verbose than Java, easy to learn if you know Java

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- allows extensions:
  - validation
  - quick fixes
  - scoping
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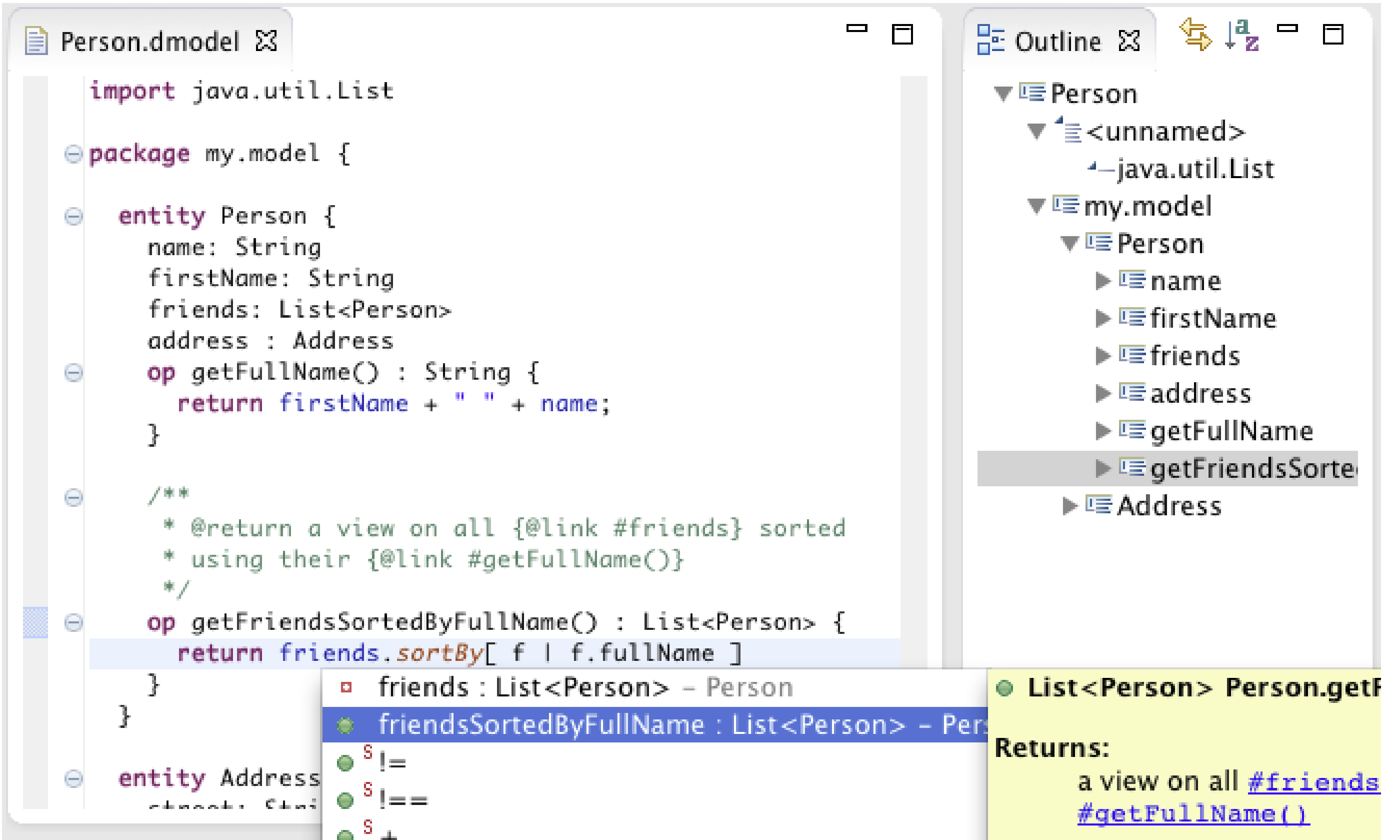
- supports importing other grammars: combine an existing language into your DSL

Summary Xtext

- Supports easy development of JVM-compatible languages using Xbase, including compiler-support
  - grammar needs to map DSL-concepts to JVM concepts
  - see extended Entities example: https://eclipse.org/Xtext/documentation/104_jvmdomainmodel.html



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  - Building a language is hard or impossible if the Ecore model does not fit the structure of the grammar

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- textual vs. graphical: different advantages and disadvantages
- rich frameworks exist for building graphical and textual languages
- Important principle: separate abstract and concrete syntax!

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  - Infer Ecore model from a given Xtext grammar