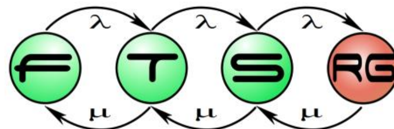
Code Generation

Ákos Horváth
Gábor Bergmann
Dániel Varró

Model Driven Systems Development

Lecture 8



Agenda

- Code Generation in general
- Approaches
- Advanced Text Generation Issues
- Example template languages
  - JET, Velocity, Xpand and XTend

Code Generation

(text synthesis)

Why?

- Let's shorten Development time!
- Use our **models/requirements/plans** to derive…
  - Documentation
  - Source code
  - Configuration descriptors
  - Communication messages
  - Object Serialization
  - …
- Need to support designing „text" synthesis

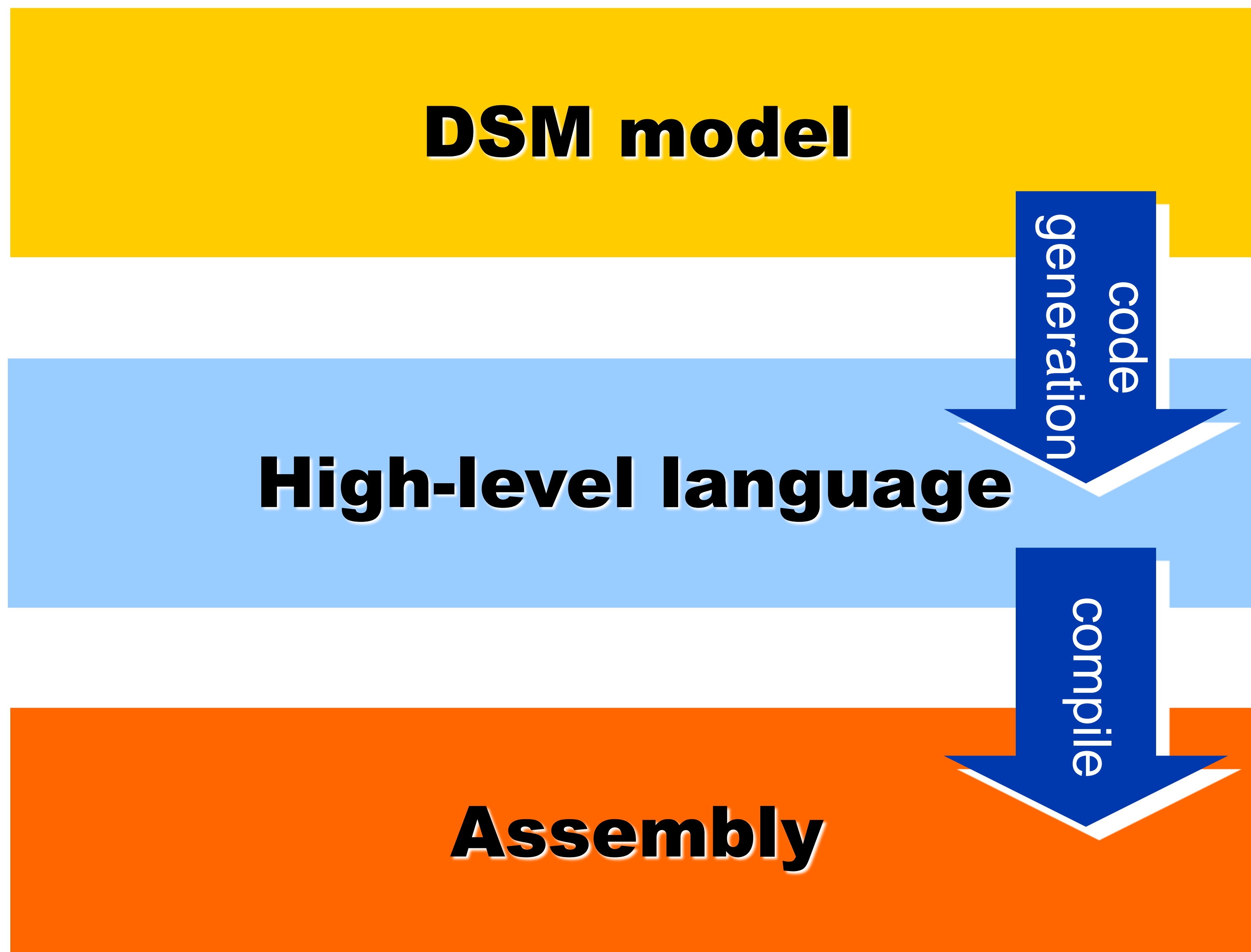
Text synthesis

- The realization of a high-level model on an implementation platform
- A choice between certain attributes – compromise between:
  - Compatibility
  - Performance
  - Maintainability
  - Reusability

Similarity with compilers

- Mapping between abstraction levels
  - e.g., From C to assembly
- Usage of design patterns
  - e.g., function calls in C
- Many similarities, NOT a strict separation
  - pl. C++ templates, automatically generated ctor+dtor
- Prediction:
  - yesterday's design pattern → today's code generation feature → tomorrow's language element
- Domain-specific instead of universal languages

Example: Source Code generation in MDD



Approaches

Approaches

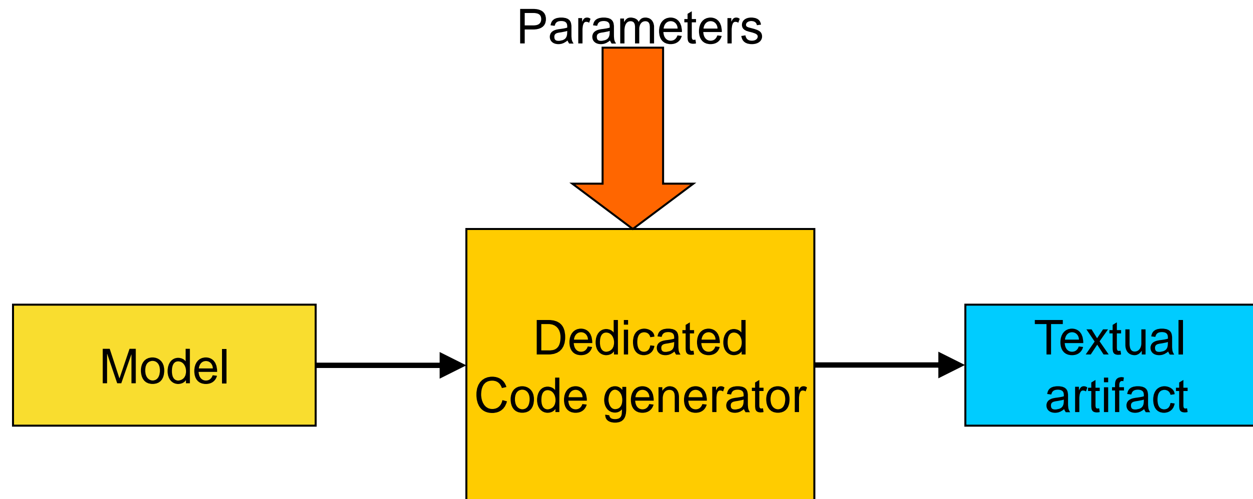
- Dedicated
  - Specific, ad-hoc
  - Using a dedicated code generator
- Template based

Specific, ad-hoc

```
sourceFile.write("    temp = ((AIDA_PARTITION_TYPE*) selfModule.partitions.elements);\n" )
i = 0
for partition in partitions:
 numPorts = getNumberOfAllCommPorts_Partition(currModuleComm, interPartitionComm, partition.partitionName)
 sourceFile.write("    temp[" + str(i) + "].partition_id = " + str(partition.partitionID) + ";\n" )
 sourceFile.write("    strcpy( &temp[" + str(i) + "].partition_name[0], \"" + str(partition.partitionName) + "\");\n")
 sourceFile.write("    temp[" + str(i) + "].ports.type = CONST_AIDA_PORTS_TYPE;\n")
 sourceFile.write("    temp[" + str(i) + "].ports.elements = &mem_ports_" + str(partition.partitionName) + "[0];\n")
 sourceFile.write("    temp[" + str(i) + "].ports.numOfElements = " + str(numPorts) + ";\n")
 sourceFile.write("\n")
 i = i + 1
## end for
sourceFile.write("\n")
```

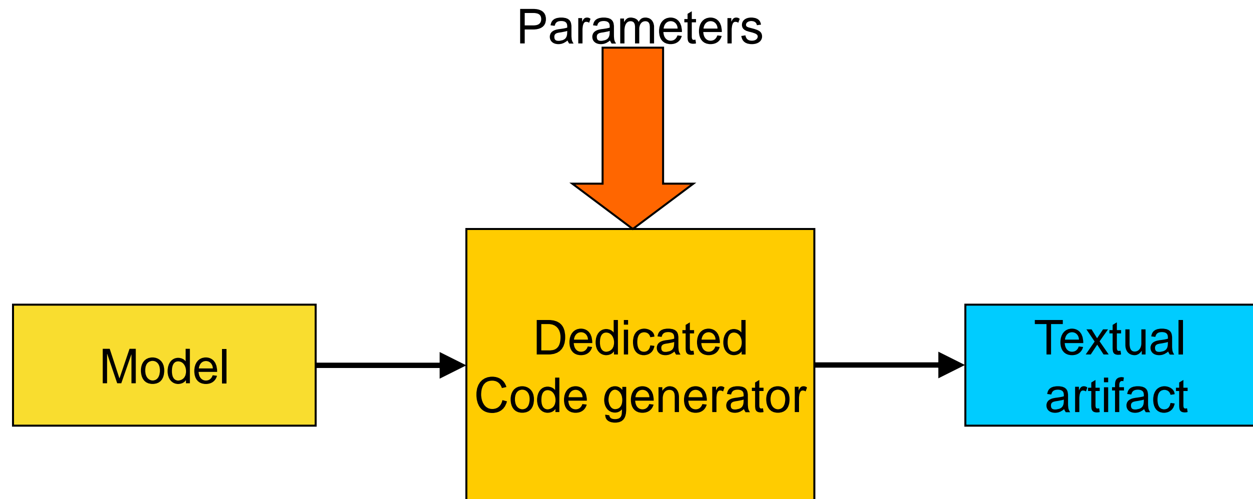
- Designed for the specific problem domain:
  - Best performance
  - Quick and dirty
  - Long development, hard maintainability
  - Zero reusability
  - Dedicated problem domains
    - Minimal changes during support cycle (safety critical embedded system, defense)
    - Certifiability
  - Example:
    - ARINC653 Multistatic configuration generator (python script)

Dedicated code generator



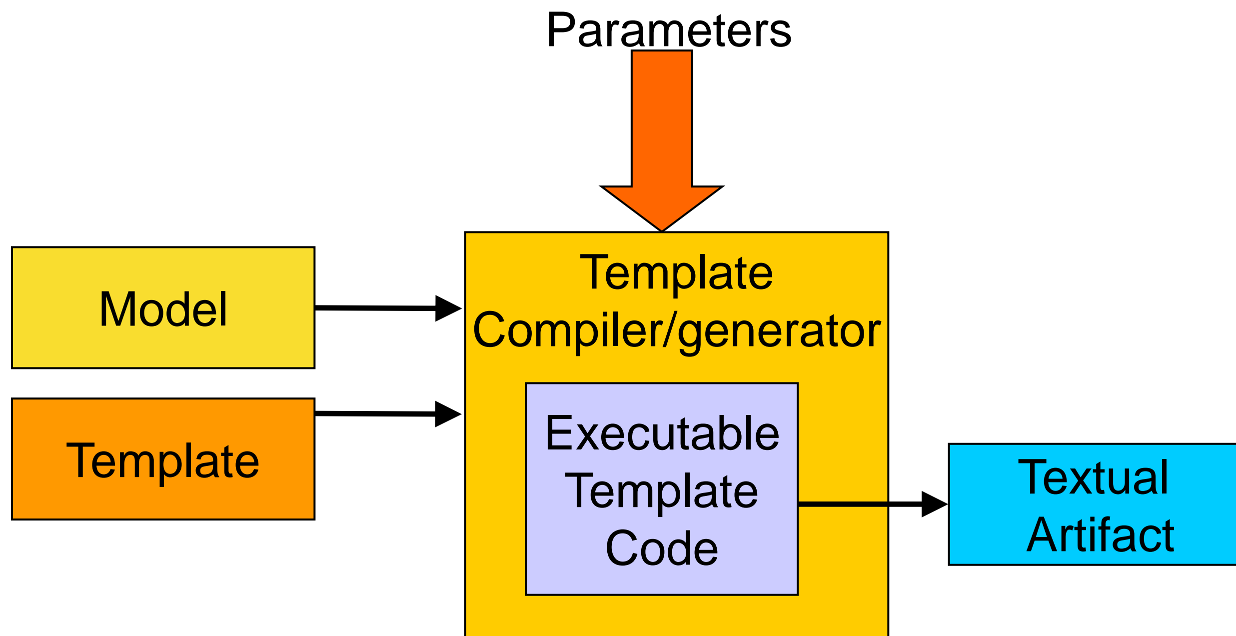
- Based on a framework:
  - Faster development time
  - Slower performance, better reusability
  - Embedded systems, moderate changes during project lifecycle

Dedicated code generator

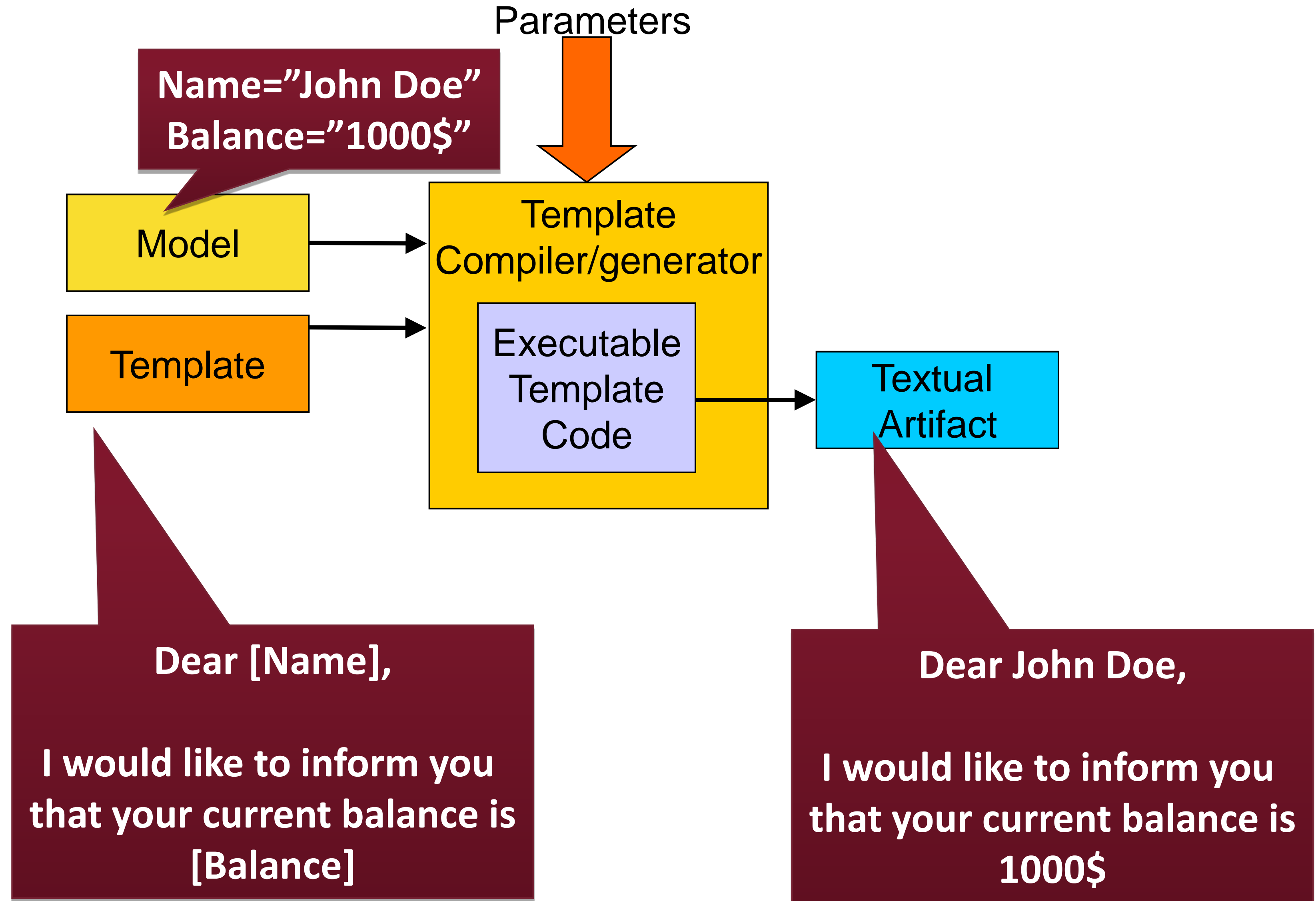


- Examples:
  - IBM Rational Software Architect
  - VASP (DO-178B Level A) Display graphics in avionics
  - Mathworks
  - Matlab Simulink
  - Esterel Scade suite

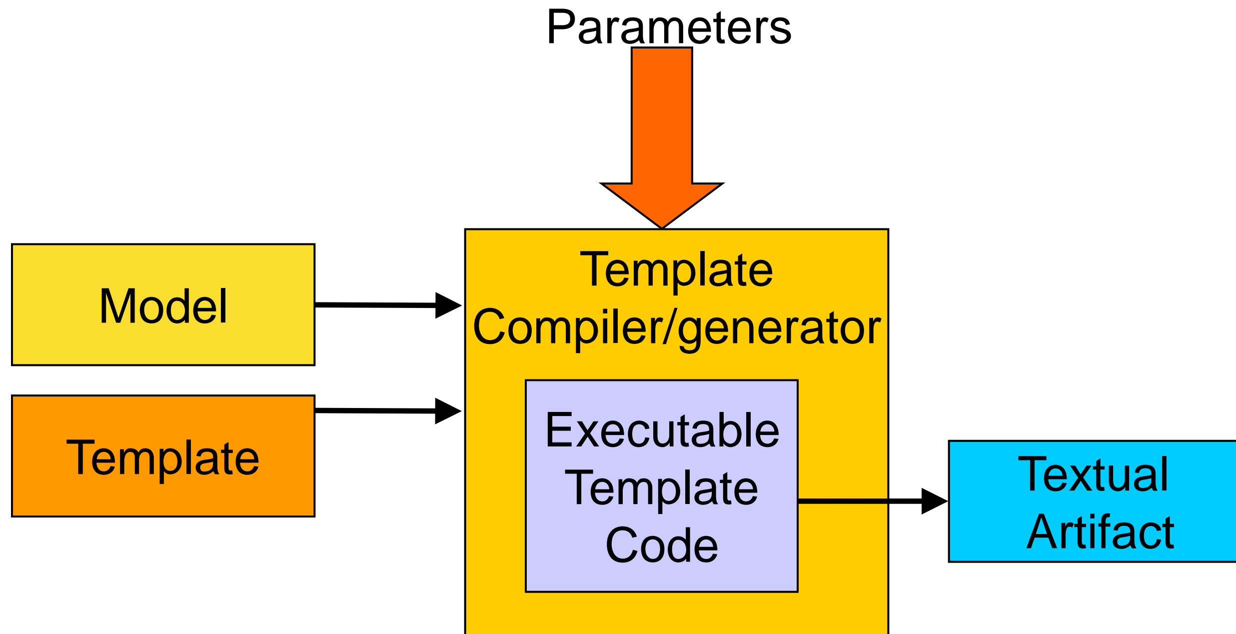
Template Based



Template Based

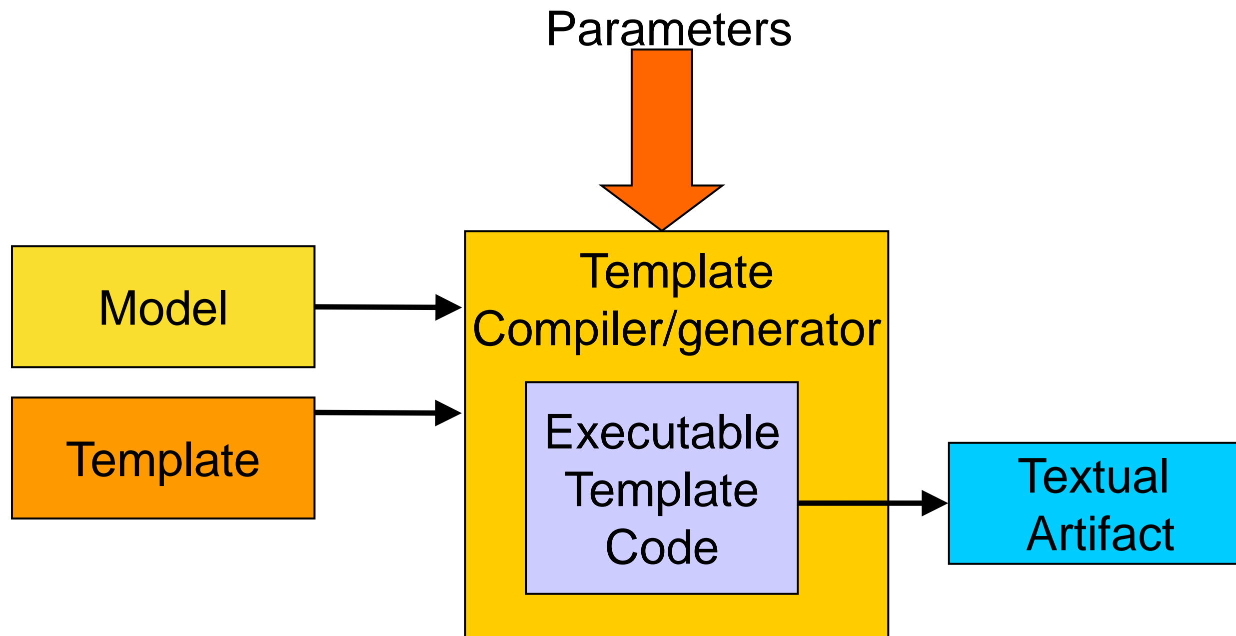


Template Based



- Fastest development time
- „Slowest" performance, highest reusability
- Fast changing environments (e.g., web based technologies)
- Complex changes during project lifecycle
  - Models and templates can be changed independently

Template Based



- Examples:
  - JET (for EMF models)
  - Velocity (/JSP)
  - OpenArchitectureWare/ XPand (MDD approach)
  - AutoFilter (Kalman filters)
  - Smarty (php)

Advanced Code/Text Generation Issues

Direct source code generation

- Direct source code generation
  - Simple structure
  - Low complexity
  - Fast development
  - Linear output generation (single pass)
  - Problematic formatting
  - Problematic M2C synchronization

Output:

```
package hu.bme.mit.pimpsm.diana.editors;

import hu.bme.mit.pimpsm.api.editors.PimPsmEditor;

/**
 * @author Akos Horvath
 *
 */
public class DianaPimPsmEditor extends PimPsmEditor
{

    public static final String PLUGIN_ID = "hu.mit.bme.pimp

    /* (non-Javadoc)
     * @see hu.bme.mit.pimpsm.api.editors.PimPsmEditor#crea
     */
    @Override
    public PimPsmModelManager createModelManager() {
        // TODO Auto-generated method stub
        return new DianaPimPsmModelManager(this);
    }

    /** Have to return the exact id of the project for the
     * in order to be able to include the icons
```

AST generation

Output:

```
⊞ PACKAGE
⊟ IMPORTS (2)
  ⊟ ImportDeclaration [59, 50]
    ⊞ > type binding: hu.bme.mit.pimpsm.api.editors.PimPsmEditor
      STATIC: 'false'
    ⊞ NAME
      ON_DEMAND: 'false'
  ⊞ ImportDeclaration [111, 57]
⊟ TYPES (1)
  ⊟ TypeDeclaration [172, 817]
    ⊞ > type binding: hu.bme.mit.pimpsm.diana.editors.DianaPimPsmEditor
    ⊞ JAVADOC
    ⊟ MODIFIERS (1)
      ⊟ Modifier [211, 6]
          KEYWORD: 'public'
      INTERFACE: 'false'
    ⊞ NAME
      TYPE_PARAMETERS (0)
    ⊟ SUPERCLASS_TYPE
      ⊟ SimpleType [250, 12]
        ⊞ > type binding: hu.bme.mit.pimpsm.api.editors.PimPsmEditor
        ⊞ NAME
      SUPER_INTERFACE_TYPES (0)
    ⊟ BODY_DECLARATIONS (4)
      ⊟ FieldDeclaration [270, 65]
          JAVADOC: null
```

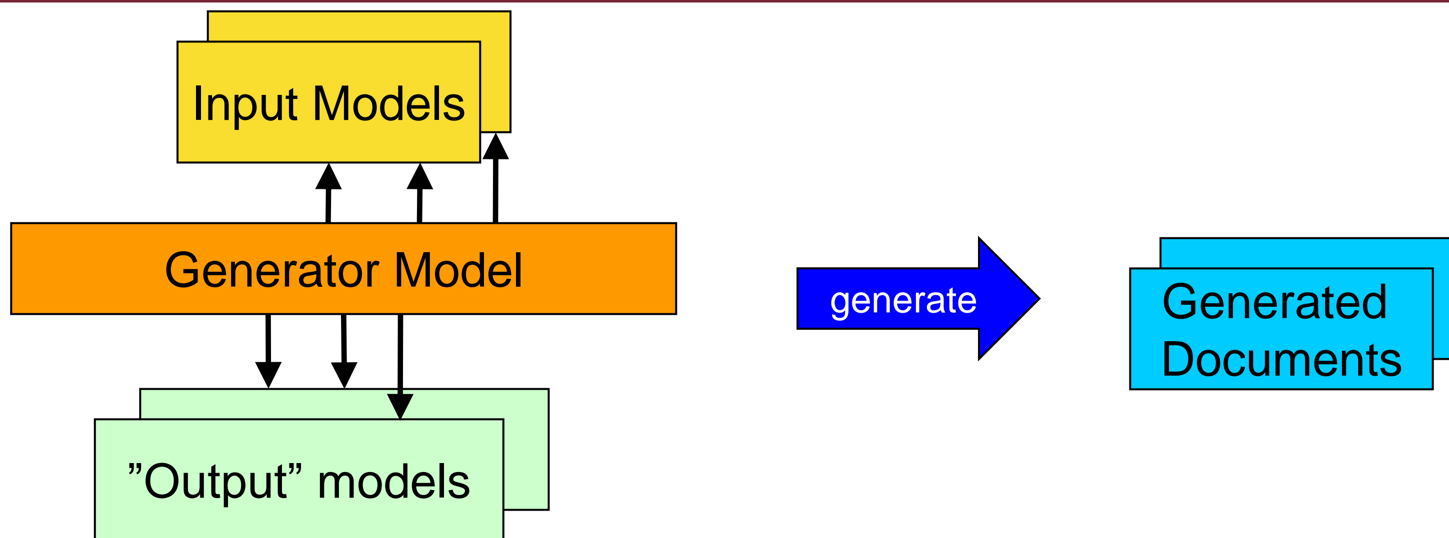
- AST generation
  - Represents the program structure (PSM)
  - Can be very complex
  - Slower development
  - Non-linear generation process
  - Support for M2C synchronization
  - Incremental output generation
  - ”pretty formatting”
  - E.g., Eclipse JDT

Direct source code generation vs. AST

- Direct source code generation
  - Simple structure
  - Low complexity
  - Fast development
  - Linear output generation (single pass)
  - Problematic formatting
  - Problematic M2C synchronization

- AST generation
  - Represents the program structure (PSM)
  - Can be very complex
  - Slower development
  - Non-linear generation process
  - Support for M2C synchronization
  - Incremental output generation
  - ”pretty formatting”
  - E.g., Eclipse JDT

Generator model



- Multiple source models → **"generator" model**
- Stores all additional information
- References to both Input Models and „Outputs" (prettyprintable)
- Helps code generation by
  - Multiple output streams
  - Traceability between models → cross references
  - Support for Non-linear **"Multi Pass"** traversals and model build
  - Support for complex model hierarchies (multiple AST-s, packages etc.)

Model to code synchronization

- What if the output text is changed? → M2C synchronization
- Works only with AST based approaches
- Requires
  - Traceability between model and text
  - Model compare
  - Change localization
- Incremental model building for better performance
- Example
  - Eclipse JDT: java source and its AST
  - EMF: model generator

Manual and generated parts

- Don't overwrite manual extensions upon re-generation
- Where to put non-changing parts
  - Model
    - Allows better reusability
    - Increases complexity
  - Template
    - Works well for simple cases
  - AST
    - Manual markings in AST → the rest is generated
  - Directly to code
    - Java → no support ☹
      - Use generalization
    - C# partial classes ☺

Code formatting

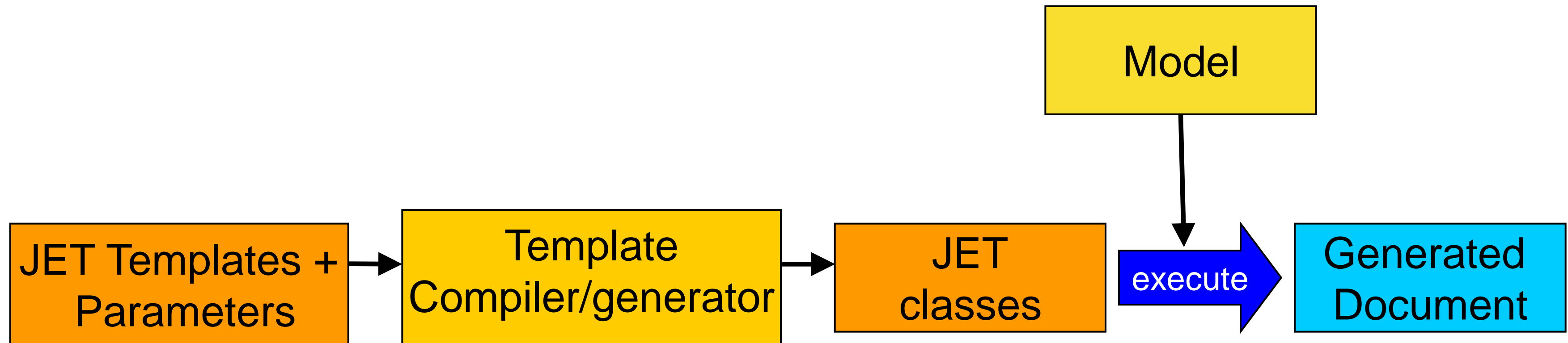
- Where to include?
  - Model
    - Does not follow typical MVC design paradigm
  - Templates
    - Simple formatting element
  - AST
    - Can store all relevant information
    - Makes it very complex
- Best solution: Code formatting as **separate step**
  - a new step in the generation workflow
  - Can be handled with 3rd party code formatters
    - Eclipse JDT formatter
    - XML DOM serializer

Keywords and special characters

- Restricted keywords in the target language
  - Java: abstract, class
  - XML: ‘<‘ , ‘>’
  - etc.
- Needs to validate the model before generation
  - Can be very complex → separate step before code generation
  - Example
    - Java simple support: isJavaIdentifierStart() (in Character)
    - EMF validation
- Escaping
  - On the model (in separate generator model?)
  - Only at code generation time

Java Emitter Templates (JET)
Velocity, Xpand, Xtend

Java Emitter Templates



- Java Emitting Templates (JET)
  - JSP-like template language using Java as its control sequence
  - **Compiled** to Java
  - Open output format (Text)
  - Parameters as Java objects
  - Part of EMF
  - Eclipse uses JET as its own template language

JET example

```
<%@ jet package="hello"  imports="java.util.*"
class="XMLDemoTemplate" %>
<% List elementList = (List) argument; %>

<?xml version="1.0" encoding="UTF-8"?>
<demo>

<% for (Iterator i = elementList.iterator();
i.hasNext(); ) { %>
<element><%=i.next().toString()%></element>

<% } %>

</demo>
```

JET example

```
<%@ jet package="hello"  imports="java.util.*"
class="XMLDemoTemplate"   >
<% List elementList = (L     argument; %>

<?x  l version=    .0" encoding="UTF-8"?>
<de   >

<% for (Ite                  tList.iterator();
i.hasNext()
<element><%=i.next().toString()%></element>

<% } %>

</demo>
```

Package of representing class

Packages to import

Jet Header

Name of the Class representing the Template

JET example

```
<%@ jet package="hello"  imports="java.util.*"
class="XMLDemoTemplate" %>
<% List elementList = (List) argument; %>

<?x… version="1.0" encod…?>
<c…

<% for (Iterator i = elementList.ite…or();
i.hasNext(); ) { %>
<element><%=i.next().toString()%></element>

<% } %>

</demo>
```

Start of code section

Input parameter

End of code section

JET example

```
<%@ jet package="hello"  imports="java.util.*"
class="XMLDemoTemplate" %>
<% List elementList = (List) argument; %>

<?xml version="1.0" encoding="UTF-8"?>
<demo>

<% for (Iterator i   elementList.iterator();
i.hasNext(); ) { %>
<element><%=i.next                          </element>

<% } %>

</demo>
```

Start of target document

JET example

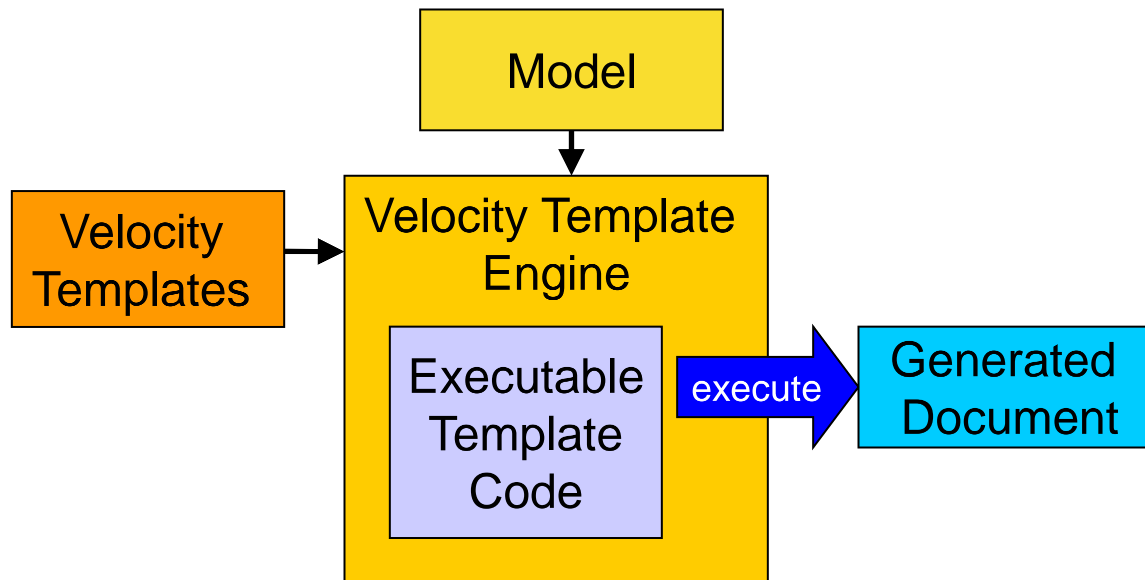
```
<%@ jet package="hello"  imports="java.util.*"
class="XMLDemoTemplate" %>
<% List elementList = (List) argument; %>

<?xml version="1.0" encoding="UTF-8"?>
<demo>

<% for (Iterator i = elementList.iterator();
i.hasNext(); ) { %>
<element><%=i.next().toString()%></element>

<% } %>

</demo>
```

Loop with the input parameter

Loop body

Returns value of the argument

Apache Velocity



- Apache Velocity
  - JSP like template language with limited control sequence
  - **Interpreted**
  - Open output format (Text)
  - Parameters as a Map

Velocity example

```
<?xml version="1.0" encoding="UTF-8"?>
<demo>
#set( $tempString = " Element")
#foreach( $element in $elementList)
     <element> ${element.toString()} <element>
#end

</demo>
```

Velocity example

Start of target document

```
<?xml version="1.0" encoding="UTF-8"?>
<demo>
#set( $tempString = "Element")
#foreach( $element in $elementList)
     <element> ${element.toString()} <element>
#end

</demo>
```

New value of tempString

Setting values

New variable

Velocity example

```
<?xml version="1.0" encoding="UTF-8"?>
<demo>
#set( $tempString = "Element")
#foreach( $element in $elementList)
      <element> ${element.toString()} <element>
#end

</demo>
```

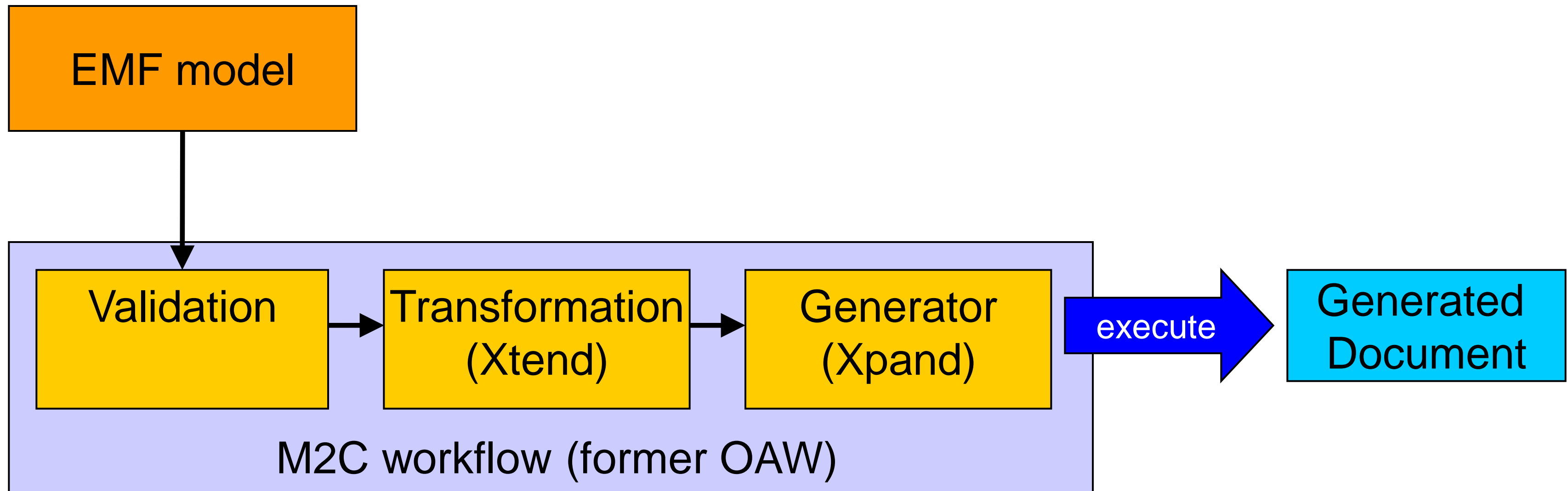
Input parameter

For loop

New running variable

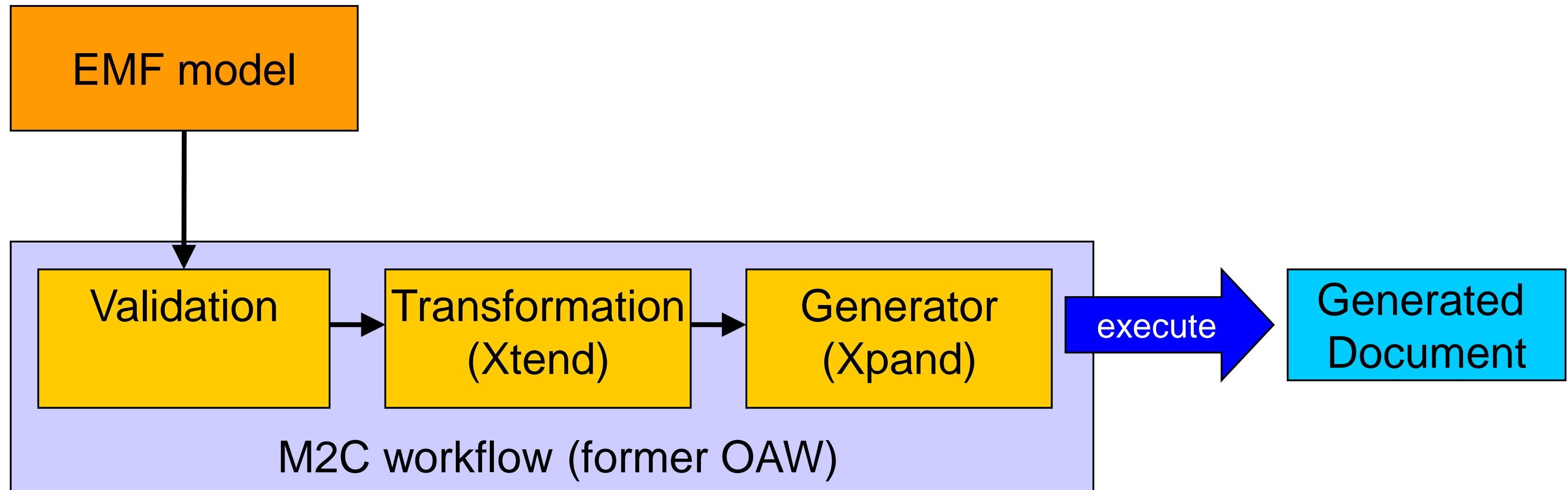
Arbitrary Java method call

Xtend



- Eclipse M2C (former OAW)
  - Complete M2C workflow
    - Validation
    - Transformation (Xtend language)
    - Code generation (Xpand language)
- Mainly for EMF model based transformation
- Flexible workflow definition

Xtend



- **Interpreted**
- Statically-typed template language
- Polymorphic template invocation
- Support for AOP programming
- Error handling
- Support for whitespace generation/definition ☺

Xpand

```
«IMPORT XMLmetamodel»
«DEFINE main FOR Model»
   «FILE this.name + ".myxml"»
   <?xml version="1.0" encoding="UTF-8"?>
   <demo>
   «EXPAND listElement FOREACH elements»
   </demo>
   «ENDFILE»
«ENDDEFINE»

«DEFINE listElement FOR Element»
<element> «this.toString()»</element>
«ENDDEFINE»
```

Xpand

```
«IMPORT XMLmetamodel»
«DEFINE main FOR Model»
   «FILE this.name + ".myxml"»
   <?xml version="1.0" encoding="UTF-8"?>
   <demo>
   «EXPAND listElement FOREACH elements»
   </demo>
   «ENDFILE»
«ENDDEFINE»

«DEFINE listElement FOR Element»
<element> «this.toString()»</element>
«ENDDEFINE»
```

Import EMF metamodel

Define template for specific type

Xpand

```
«IMPORT XMLmetamodel»
«DEFINE main FOR Model»
   «FILE this.name + ".myxml"»
   <?xml version="1.0" encoding="UTF-8"?>
   <demo>
   «EXPAND listElement FOREACH elements»
   </demo>
   «ENDFILE»
«ENDDEFINE»

«DEFINE listElement FOR Element»
<element> «this.toString()»</element>
«ENDDEFINE»
```

Output file definition

Start of target document

Xpand

```
«IMPORT XMLmetamodel»
«DEFINE main FOR Model»
   «FILE this.name + ".myxml"»
   <?xml version="1.0" encoding="UTF-8"?>
   <demo>
   «EXPAND listElement FOREACH elements»
   </demo>
   «ENDFILE»
«ENDDEFINE»

«DEFINE listElement FOR Element»
<element> «this.toString()»</element>
«ENDDEFINE»
```

EReference holding the elements

Invoke other template with type definition

Xtend overview

- Foundation of Xtext2
  - Original purpose: compile Xtext2 DSLs to Java
- A JVM-based language
  - Imperative, statically typed, compiles to Java
  - Incorporates functional programming constructs
- Advanced features
  - Type inference
  - Properties
  - Everything is an expression
  - Operator overloading
  - Power switch
  - Lambda expressions
  - Templates

Xtend example

```
import com.google.inject.Inject

class DomainmodelGenerator implements IGenerator {

  @Inject extension IQualifiedNameProvider nameProvider

  override void doGenerate(Resource resource, IFileSystemAccess fsa) {
    for(e: resource.allContentsIterable.filter(typeof(Entity))) {
      fsa.generateFile(
        e.fullyQualifiedName.toString.replace(".", "/") + ".java",
        e.compile)
    }
  }
  def compile(Entity e) '''
    «IF e.eContainer != null»
      package «e.eContainer.fullyQualifiedName»;
    «ENDIF»

    public class «e.name» «IF e.superType != null
            » extends «e.superType.fullyQualifiedName» «ENDIF»{
      «FOR f:e.features»
        «f.compile»
      «ENDFOR»
    }
```

Summary

Code generation - Summary

- Started from source code generation
  - UML -> Java, C++, ….
- Used in many other text based artifacts
  - document generation (web)
  - report generation (XML, XLS, CSV, print)
  - Configuration (wsdl)
- Strong tool support
  - Xpand
  - Xtend
  - (CodeDOM)
- There are some use cases outside of the MDE field