MPS Generators

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Heavily inspired by the MPS generators user manual and the "building maintainable generators" guide from Itemis (@coolya)

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- Model-to-model transformations
  - Templates
  - Mapping configurations & generator rules
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  - Generation context
  - The generator algorithm
  - Cross-model generation and generation plans
- Model-to-text transformations
- Common generator patterns (partially inspired by Itemis guide)
- Basic dos and don’ts
- Further reading

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What are (MPS) generators?

- Part of a language specification that defines denotational semantics for the concepts of the language

I would say: it's a specification as you see them typically in term rewrite systems

Denotational semantics as source-to-source translation [edit]

It is often useful to translate one programming language into another. For example, a concurrent programming language might be translated into a process calculus; a high-level programming language might be translated into byte-code. (Indeed, conventional denotational semantics can be seen as the interpretation of programming languages into the internal language of the category of domains.)

In this context, notions from denotational semantics, such as full abstraction, help to satisfy security concerns.[16][17]

Wikipedia (2005)

3.2 Term Rewriting Systems

Definition 3.26 (Term Rewriting System) A *Term Rewriting System* (TRS) is a pair (Σ, R) of an *alphabet* or *signature* Σ and a set of reduction rules (rewrite rules) R. The alphabet Σ consists of

1. a countably infinite set of *variables* $x_1, x_2, \ldots$ also denoted $x, y, z, z', y', \ldots$
2. a non-empty set of *function symbols* or *operator symbols* $F, G, \ldots$ equiped with an *arity* (a natural number) which specifies the number of arguments it is supposed to have. Besides unary, binary, etc., function symbols we also have 0-ary, also called *constants*.

Definition 3.27 (Terms) The set $Terms(\Sigma)$ of terms over Σ is defined inductively:

1. all variables x, y, z of Σ belong to $Terms(\Sigma)$,
2. if F is a function symbol of Σ with arity n and $t_1, \ldots, t_n \in Terms(\Sigma)$ then $F(t_1, \ldots, t_n) \in Terms(\Sigma)$.

Syllabus "Berekeningsmodellen" TU/e (2002)

Definition 7.1 (Denotational Semantics) The denotational semantics of a sequential program is defined by induction on the structure of statements.

a) $\mathcal{D}(x := e)\sigma_0 = \{(\sigma_0 : x \mapsto \mathcal{E}(e)\sigma_0)\}$,

b) $\mathcal{D}(\textbf{skip})\sigma_0 = \{\sigma_0\}$,

c) $\mathcal{D}(S_1\,;\,S_2)\sigma_0 = \{\sigma \mid$ there exists a σ_1 such that $\sigma_1 \in \mathcal{D}(S_1)\sigma_0$ and $\sigma \in \mathcal{D}(S_2)\sigma_1\}$.

To simplify definitions, we define for functions $F_1, F_2 : STATE \to \wp(STATE)$ the function $SEQ(F_1, F_2) : STATE \to \wp(STATE)$ by

$$SEQ(F_1, F_2)\sigma_0 = \{\sigma \mid \text{there exists a } \sigma_1 \text{ such that } \sigma_1 \in F_1(\sigma_0) \text{ and } \sigma \in F_2(\sigma_1)\}.$$

Then we indeed have a compositional formulation:

$$\mathcal{D}(S_1\,;\,S_2) = SEQ(\mathcal{D}(S_1), \mathcal{D}(S_2)).$$

Intermezzo - semantic equivalence

Let $S_1 \sim S_2$ denote that S_1 and S_2 are semantically equivalent, that is, $\mathcal{D}(S_1) = \mathcal{D}(S_2)$.
Note that $\sim$ is an *equivalence relation*, that is, for all S, S_1, S_2, S_3,

(reflexive) $S \sim S$,

(symmetric) if $S_1 \sim S_2$ then $S_2 \sim S_1$

What are MPS generators?

- Dedicated aspect of a language
- Covers all model-to-model transformations
- MPS generator engine responsible for performing transformations specified in generators
- Model-to-text transformations (usally postponed until the last possible moment) officially covered by another aspect: textgen

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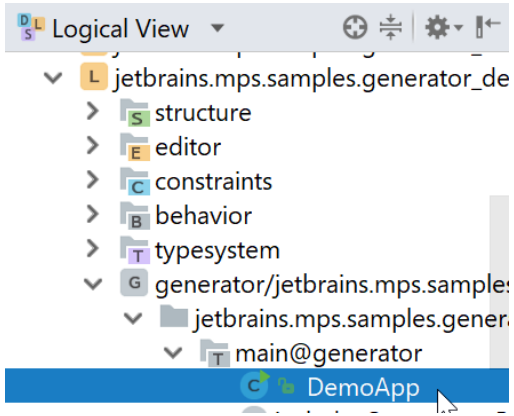
Model-to-model transformations

- Templates
  - Types of templates & template fragments
  - Template elements: macros
- Mapping configurations & generator rules
  - Mapping configurations
  - Types of generator rules
- Mapping labels
- Generation context
- The generator algorithm
- Mapping scripts

Model-to-model transformations

- Templates
  - **Types of templates & template fragments**
  - Template elements: macros
- Mapping configurations & generator rules
  - Mapping configurations
  - Types of generator rules
- Mapping labels
- Generation context
- The generator algorithm
- Mapping scripts

Templates



- Transformations described by means of **templates** (in **template declarations**), which are written in the **output language** (i.e. the language of the output model)
- Applicability of individual templates is defined by **generator rules**, which are grouped into **mapping configurations**
- Root template (lives in a root node) → for producing a root node:

Input model

```
document Button

< button text = " Hello " enabled = " false " >
  ...
</ button >
```

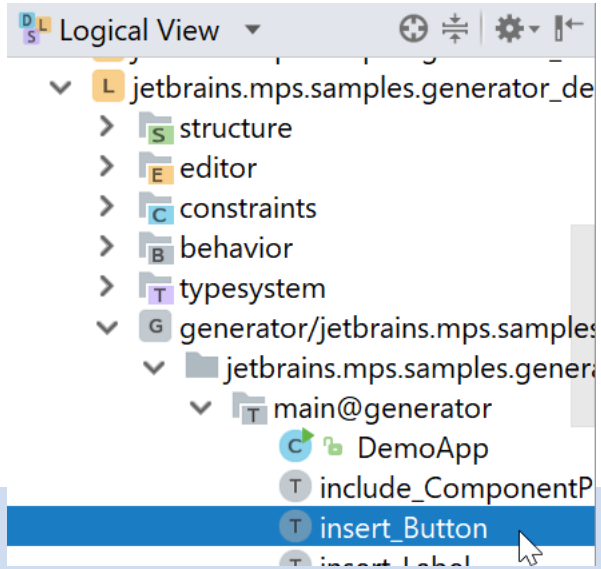
written in: jetbrains.mps.sampleXML

Root template

```
root template
input Document

public class $node.name :string {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    container.add($SWITCH$ { node.rootElement }→ switch_JComponentByElementName);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
```

written in (language of output model): jetbrains.mps.baseLanguage (java)

Templates



- External template (lives in a root node) → for producing a non-root node:

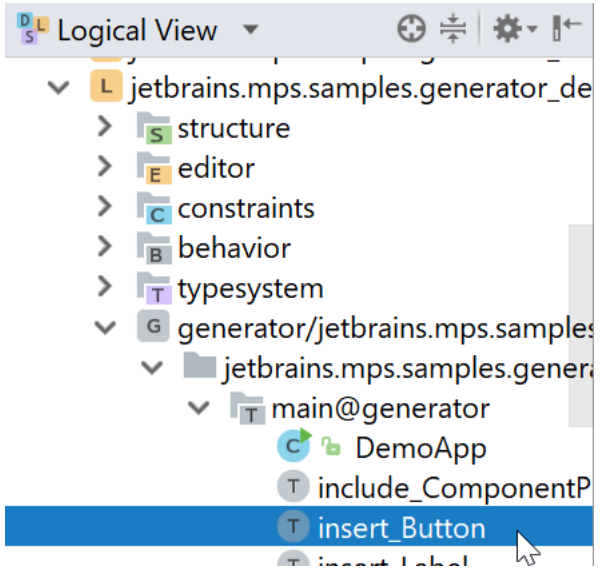
Root template

```
template   insert_Button
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method                                                                    TF>
          public static
              Component $genContext.unique name from (templateValue) in context (<no node>) :string() {
            JButton component = new JButton();
            if( node.attribute.findFirst({~it => it.name.equals("text") }).isNotNull )<T
            component.setText("$node.attribute.findFirst({~it => it.name.equals("text") }).value");
             T>
            $INCLUDE$ { node } → include_ComponentProperties
            return component;
          }
}
```

Input model

```
document Button

< button text = " Hello " enabled = " false " >
  ...
</ button >
```

Templates



- Inline template (directly inside a generator rule) → for producing a non-root node:

Input model

```
document Button

< button text = " Hello " enabled = " false " >
  ...
</ button >
```

Generator rule

```
[concept     Button
 inheritors  false
 condition   <always>]  -->
```

Inline template

```
<T  < button text = " $node.text :string " >  T>
      ...
    </ button >
```

Templates

- The actual template code is 'wrapped' in a **template fragment**. Any code outside template fragment is not used in transformation and serves as a context (for example you can have a Java class, but export only one of its method as a template).

```
template   insert_Button
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
```

Fragment

```
<TF method
public static
    Component $genContext.unique name from (templateValue) in context (<no node>) :string() {
  JButton component = new JButton();
  if( node.attribute.findFirst({~it => it.name.equals("text") }).isNotNull )<T
  component.setText("$node.attribute.findFirst({~it => it.name.equals("text") }).value");
   T>
  $INCLUDE$ { node } → include_ComponentProperties
  return component;
}
TF>
}
```

Model-to-model transformations

- Templates
  - Types of templates & template fragments
  - **Template elements: macros**
- Mapping configurations & generator rules
  - Mapping configurations
  - Types of generator rules
- Mapping labels
- Generation context
- The generator algorithm
- Mapping scripts

Macros - property

Input model

```
document Button

< button text = " Hello " enabled = " false " >
  ...
</ button >
```

- The code in templates can be parameterized through **macros**. The generator language defines three kinds of macros:
  - **property macro** - computes a property value;
  - **reference macro** - computes the target (node) of a reference;
  - **node macro** - used to control template filling at generation time. There are several versions of node macro: IF, LOOP, INCLUDE, CALL, SWITCH, COPY-SRC, COPY-SRCL, MAP-SRC, MAP-SRCL, and WEAVE.
- Property macro:

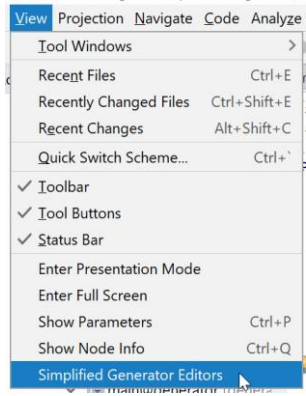
```
concept Document extends     BaseConcept
                 implements INamedConcept

  instance can be root: true
  alias: <no alias>
  short description: <no short descri

  properties:
  << ... >>

  children:
  rootElement : Element[1]

  references:
  << ... >>
```

```
interface concept INamedConcept extends <none>

  properties:
  name : string

  children:
  << ... >>

  references:
  << ... >>
```

```
root template
input Document

public class $node.name :string {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    container.add($SWITCH$ { node.rootElement }→ switch_JComponentByElementName);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
}
```

Macros – two views

- MPS-specific default notation of macros quite different from many other (especially text-based) notations, using the inspector a lot.
  For people that don't like this, there is now a (proof-of-concept) simplified view that makes it more like many others:
- We will be using mostly the normal view.



Normal view

```
root template
input Document

public class $map_Document {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    container.add($SWITCH$ switch_JComponentByElementName[null]);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
}
```

pector

rains.mps.lang.generator.structure.PropertyMacro

```
property value

comment : <none>
value : (templateValue, genContext, node, operationContext)->string {
          node.name;
        }
```

Simplified view

```
root template
input Document

public class $node.name :string {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    container.add($SWITCH$ { node.rootElement }→ switch_JComponentByElementName);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
}
```

Macros - reference

- Reference macro (very similar to property macro) → computes an actual reference in the output model (used together with mapping labels):

Input model

```
document Button

< button text = " Hello " enabled = " false " >
  ...
</ button >
```

```
label method : Element -> StaticMethodDeclaration
```

```
template   insert_Button
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method
    public static Component $[createComponent]() {
      JButton component = new JButton();
      $IF$[component.setText("$[text]");]
      $INCLUDE$ include_ComponentProperties[]
      return component;
    }
  TF>
```

```
template   insert_Label
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method
    public static Component $[createComponent]() {
      JLabel component = new JLabel();
      $IF$[component.setText("$[text]");]
      $INCLUDE$ include_ComponentProperties[]
      return component;
    }
  TF>
}
```

Root template

```
public class DemoApp {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    addContent(container);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
  public static void addContent(Container container) {
    $LOOP$[container.add(->$[component]());]
  }
```

Inspector of reference macro

```
reference target

comment : <none>
referent : (outputNode, genContext, operationContext, node)->join(node<MethodDeclaration> | string | node-ptr<MethodDeclaration>)
             {
               genContext.get output method for (node);
             }
```

Macros - node

- IF macro → The wrapped template code is applied only if the condition is true. Otherwise the template code is ignored and an 'alternative consequence' (if any) is applied:

insert_Label

```
template   insert_Label
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method                                                    TF>
    public static Component $[createComponent]() {
      JLabel component = new JLabel();
      $IF$[component.setText("$[text]");]
      $INCLUDE$ include_ComponentProperties[]
      return component;
```

Inspector

jetbrains.mps.lang.generator.structure.IfMacro

```
conditional branch

comment         : <none>
mapping label   : <no label>
condition       : (genContext, node, operationContext)->boolean {
                    node.attribute.findFirst({~it => it.name.equals("text"); }).isNotNull;
                  }
alternative     : <none>
```

Macros - node

- LOOP macro → Computes new input nodes and applies the wrapped template to each of them:

DemoApp

```
root template
input <unspecified>

public class DemoApp {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    addContent(container);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
  public static void addContent(Container container) {
    $LOOP$[container.add(->$[component]());]
  }
```

Inspector

jetbrains.mps.lang.generator.structure.LoopMacro

```
iterate over sequence of nodes

comment              : <none>
mapping label        : <no label>
iteration sequence   : (genContext, node, operationContext)->sequence<node<>> {
                         genContext.inputModel.nodes(Element);
                       }
counter variable     : <no variable>
```

Macros - node

- INCLUDE macro → The wrapped template code is ignored (it only serves as an anchor for the INCLUDE-macro), a reusable external template will be used instead:
- Null input makes INCLUDE effectively a no-op.

insert_Label

```
parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method
          public static Component $[createComponent]() {
            JLabel component = new JLabel();
            $IF$[component.setText("$[text]");]
            $INCLUDE$ include_ComponentProperties[]
            return component;
          }
TF>
}
```

Inspector

jetbrains.mps.lang.generator.structure.IncludeMacro

```
include outcome of a template

comment          : <none>
mapping label    : <no label>
use input        : <current input node>

include template : include_ComponentProperties
```

insert_Button

```
template   insert_Button
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method
          public static Component $[createComponent]() {
            JButton component = new JButton();
            $IF$[component.setText("$[text]");]
            $INCLUDE$ include_ComponentProperties[]
            return component;
          }
TF>
```

Inspector

jetbrains.mps.lang.generator.structure.IncludeMacro

```
include outcome of a template

comment          : <none>
mapping label    : <no label>
use input        : <current input node>

include template : include_ComponentProperties
```

```
template   include_ComponentProperties
input      Element

parameters
<< ... >>

content node:
JComponent component = null;
<TF {
     $MAP_SRC$[component.setEnabled($[false]);]
     $MAP_SRC${
                component.setOpaque(true);
                component.setBackground(Color.->$[black]);
              }
   }
TF>
```

Macros - node

- CALL macro → Invokes template and replaces wrapped template code with the result of template invocation. Supports templates with parameters.
- Null input node is tolerated, and the template is ignored altogether in this case, i.e. CALL yields empty collection of nodes as a result when input/mapped node is null.

```
insert_Button
template   insert_Button
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF method                                                    TF>
        public static Component $[createComponent]() {
          JButton component = new JButton();
          $IF$[component.setText("$[text]");]
          $CALL$ include_ComponentProperties[]
          return component;
        }
```

```
Inspector
jetbrains.mps.lang.generator.structure.TemplateCallMacro
call template and insert its outcome

comment        : <none>
mapping label  : <no label>
mapped node    : <current input node>

template       : include_ComponentProperties ("myStringValue")
```

```
template        include_ComponentProperties
input           Element

parameters
myParam : string

content node:
JComponent component = null;
<TF [{                                                        TF>
    $MAP_SRC$[component.setEnabled($[false]);]
    $MAP_SRC$[{
        component.setOpaque(true);
        component.setBackground(Color.->$[black]);
    }]
}
```

Macros - node

- SWITCH macro (used with a template switch) → Provides a way to many alternative transformations in the given place in the template code.
- The wrapped template code is applied, if none of switch cases is applicable and no default consequence is specified in template switch.
- For null input node, SWITCH may react with a message (specified along with its rules), anchor template node is ignored, and SWITCH macro yields no results.

map_Document

```
root template
input Document

public class $[map_Document] {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    container.add($SWITCH$ switch_JComponentByElementName[null]);
    frame.pack();
    frame.setLocationRelativeTo(null);
    frame.setVisible(true);
  }
}
```

Inspector

jetbrains.mps.lang.generator.structure.TemplateSwitchMacro

```
switch templates by input node

comment          : <none>
mapping label    : <no label>
use input        : (genContext, node, operationContext)->node<> {
                     node.rootElement;
                   }
```

switch_JComponentByElementName

```
template switch switch_JComponentByElementName extends <none>

parameters
  < ... >>

  null-input message: <none>

  cases:

    [concept    Element                                                  ] --> <T new JButton() T>
    [inheritors false                                                    ]
    [condition  (genContext, node, operationContext)->boolean {          ]
    [             node.name.equals("button");                            ]
    [           }                                                        ]

    [concept    Element                                                  ] --> <T new JLabel() T>
    [inheritors false                                                    ]
    [condition  (genContext, node, operationContext)->boolean {          ]
    [             node.name.equals("label");                             ]
    [           }                                                        ]


  default: DISMISS TOP RULE error : 'button' or 'label' element name is expected
```

Macros - node

- COPY_SRC macro
  → Copies an input node to the output model. The wrapped template code is ignored.

```
template   reduce_Element
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  public static void _method_() {
    <TF [ ->$[_method_]() ] TF>;
  }
}
```

insert_Panel

```
template   insert_Panel
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  public _class_() {
    <no statements>
  }
  <TF factory_method                                                    TF>
                    public static Component $[createComponent]() {
                      JPanel component = new JPanel();
                      $INCLUDE$ include_ComponentProperties[]
                      //  add children
                      $LOOP$[component.add($COPY_SRC$[null]);]
                      return component;
```

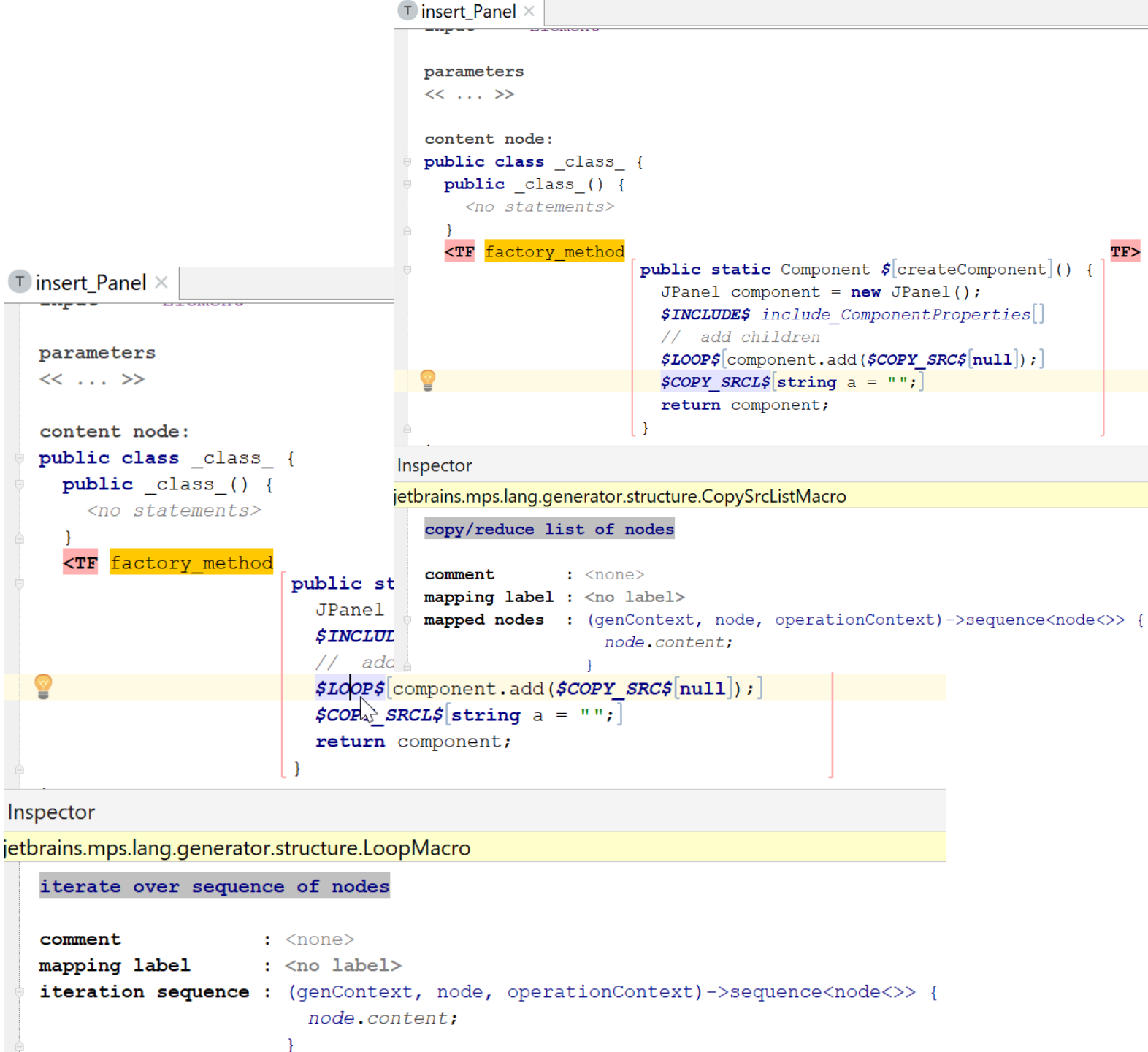
Inspector

jetbrains.mps.lang.generator.structure.CopySrcNodeMacro

```
copy/reduce node

comment        : <none>
mapping label  : <no label>
mapped node    : <current source node>
```

Macros - node

- COPY_SRCL macro → same a COPY_SRC, but can be applied to an list of nodes instead of only one node.
- $COPY_SRCL[…] can be seen as syntactic sugar for $LOOP[$COPY_SRC[…]]



Macros - node

- MAP_SRC macro → Multifunctional macro, can be used for:
  - marking a template code with a mapping label; (note: $LABEL macro can be used for this instead)
  - replacing the current input node with a new one;
  - perform a non-template based transformation;
  - accessing the output node for some reason.
- $MAP_SRCL[…] is syntactic sugar for $LOOP[$MAP_SRC[…]]

include_ComponentProperties

```
template   include_ComponentProperties
input      Element

parameters
<< ... >>

content node:
JComponent component = null;
<TF {
    $MAP_SRC$[component.setEnabled($[false]);]
    $MAP_SRC$ {
                component.setOpaque(true);
                component.setBackground(Color.->$[black]);
              }
}
TF>
```

Inspector

jetbrains.mps.lang.generator.structure.MapSrcNodeMacro

```
map node macro

comment          : <none>
mapping label    : <no label>
mapped node      : (genContext, node, operationContext)->node<> {
                     node.attribute.findFirst({~it => it.name.equals("enabled"); });
```

Macros - node

- WEAVE macro → Allows to insert additional child nodes into the output model. The node wrapped in the WEAVE macro (or provided by the use input function) will have the supplied template applied to it and the generated nodes will be inserted.
- Invokes a specific weaving rule (generator rules treated at a later point in time)

I couldn't find any real usages of this macro, it seems people prefer use of weaving rules instead.

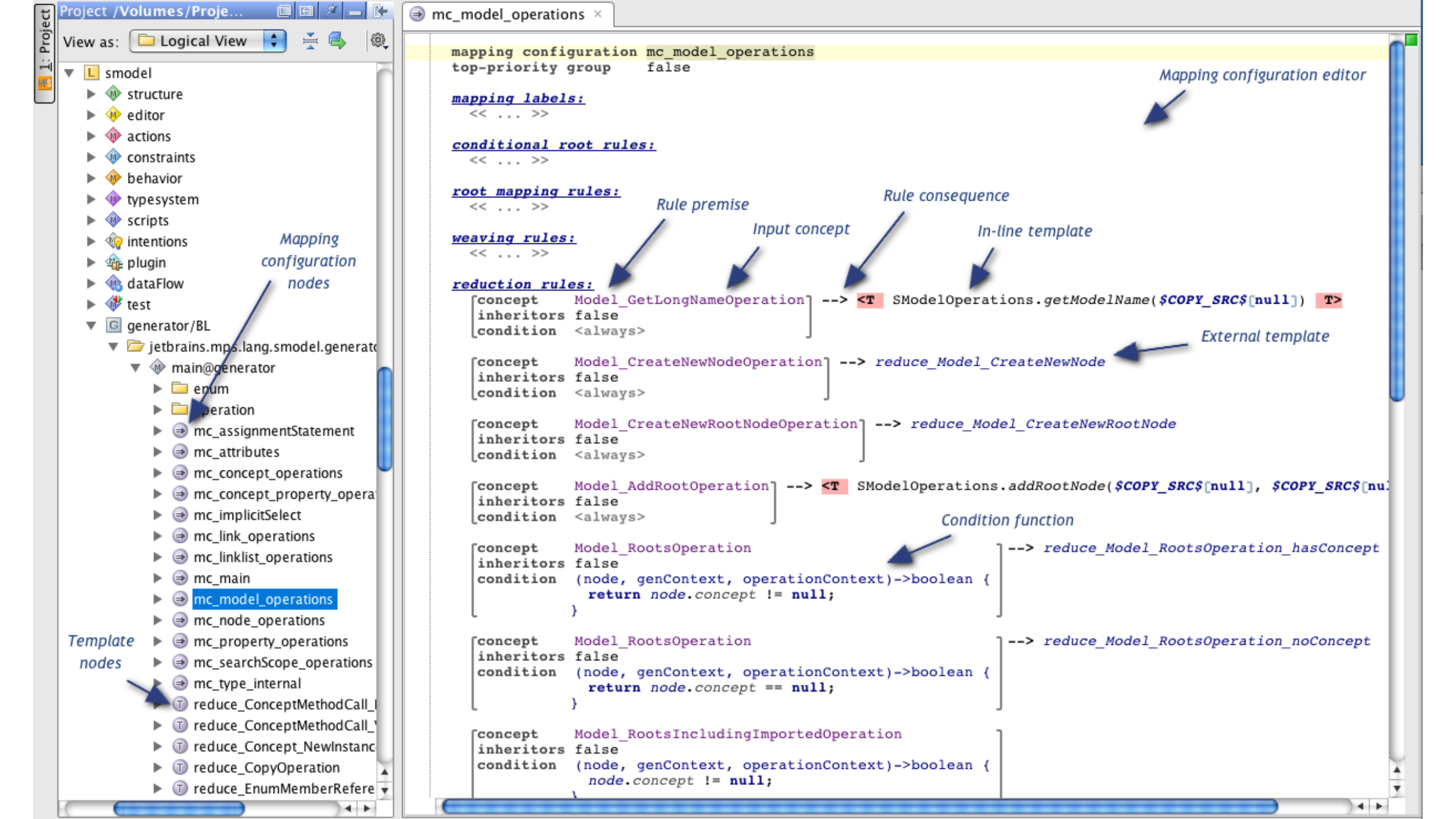
Model-to-model transformations

- Templates
  - Types of templates & template fragments
  - Template elements: macros
- Mapping configurations & generator rules
  - **Mapping configurations**
  - Types of generator rules
- Mapping labels
- Generation context
- The generator algorithm
- Mapping scripts

Mapping configurations

- Applicability of individual templates is defined by **generator rules**, which are grouped into **mapping configurations**
- A **mapping configuration** can form a single generation step, contains **generator rules**, defines **mapping labels** and may include **pre- and postprocessing scripts**
- Almost each generator rule consists of a **premise** and a **consequence**
- Nearly all rules contain a reference to the concept of the **input node** (or just input concept) in its premises. All rule premises also contain an optional **condition function**.
- Rule consequence commonly contains a reference to an **external template** (declared as a root node in the same or different model) or to an **in-line template** (conditional root rule and root mapping rule can only have reference to an external template).
- There are also several other versions of consequences.

```
mapping configuration main
top-priority group    false

mapping labels:
  << ... >>

parameters:
  << ... >>

is applicable:
  <always>

conditional root rules:
  << ... >>

root mapping rules:
  concept          Document  --> map_Document
  inheritors       false
  condition        <always>
  keep input root  default

weaving rules:
  << ... >>

reduction rules:
  << ... >>

pattern rules:
  << ... >>

reduce references:
  << ... >>

abandon roots:
  << ... >>

drop attributes:
  << ... >>

pre-processing scripts:
  << ... >>

post-processing scripts:
  << ... >>
```


Project /Volumes/Proje...
View as: Logical View
smodel
structure
editor
actions
constraints
behavior
typesystem
scripts
intentions
plugin
dataFlow
test
generator/BL
jetbrains.mps.lang.smodel.generat
main@generator
enum
mc_assignmentStatement
mc_attributes
mc_concept_operations
mc_concept_property_opera
mc_implicitSelect
mc_link_operations
mc_linklist_operations
mc_main
mc_model_operations
mc_node_operations
mc_property_operations
mc_searchScope_operations
mc_type_internal
reduce_ConceptMethodCall_
reduce_ConceptMethodCall_
reduce_Concept_NewInstanc
reduce_CopyOperation
reduce_EnumMemberRefere
Mapping configuration nodes
Template nodes
mc_model_operations
mapping configuration mc_model_operations
top-priority group false
mapping labels:
<< ... >>
conditional root rules:
<< ... >>
root mapping rules:
<< ... >>
weaving rules:
<< ... >>
reduction rules:
concept Model_GetLongNameOperation
inheritors false
condition <always>
--> <T SModelOperations.getModelName($COPY_SRC$[null]) T>
concept Model_CreateNewNodeOperation
inheritors false
condition <always>
--> reduce_Model_CreateNewNode
concept Model_CreateNewRootNodeOperation
inheritors false
condition <always>
--> reduce_Model_CreateNewRootNode
concept Model_AddRootOperation
inheritors false
condition <always>
--> <T SModelOperations.addRootNode($COPY_SRC$[null], $COPY_SRC$[nu
concept Model_RootsOperation
inheritors false
condition (node, genContext, operationContext)->boolean {
return node.concept != null;
}
--> reduce_Model_RootsOperation_hasConcept
concept Model_RootsOperation
inheritors false
condition (node, genContext, operationContext)->boolean {
return node.concept == null;
}
--> reduce_Model_RootsOperation_noConcept
concept Model_RootsIncludingImportedOperation
inheritors false
condition (node, genContext, operationContext)->boolean {
node.concept != null;
}
Mapping configuration editor
Rule premise
Input concept
Rule consequence
In-line template
External template
Condition function

Model-to-model transformations

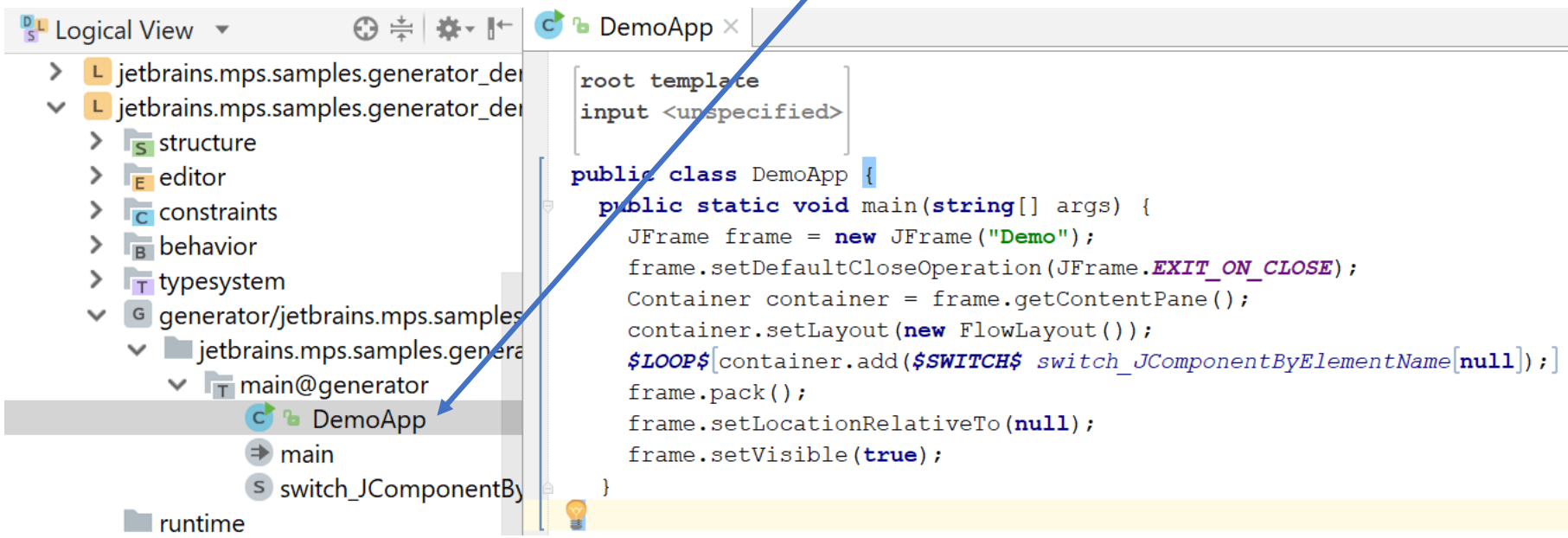
- Templates
  - Types of templates & template fragments
  - Template elements: macros
- Mapping configurations & generator rules
  - Mapping configurations
  - **Types of generator rules**
- Mapping labels
- Generation context
- The generator algorithm
- Mapping scripts

Rules – conditional root

- Generates a root node in the output model:
- Applied only one time (max) during a single generation step.

```
conditional root rules:
  condition (genContext, operationContext)->boolean {
    true;
  }
  --> : DemoApp
```

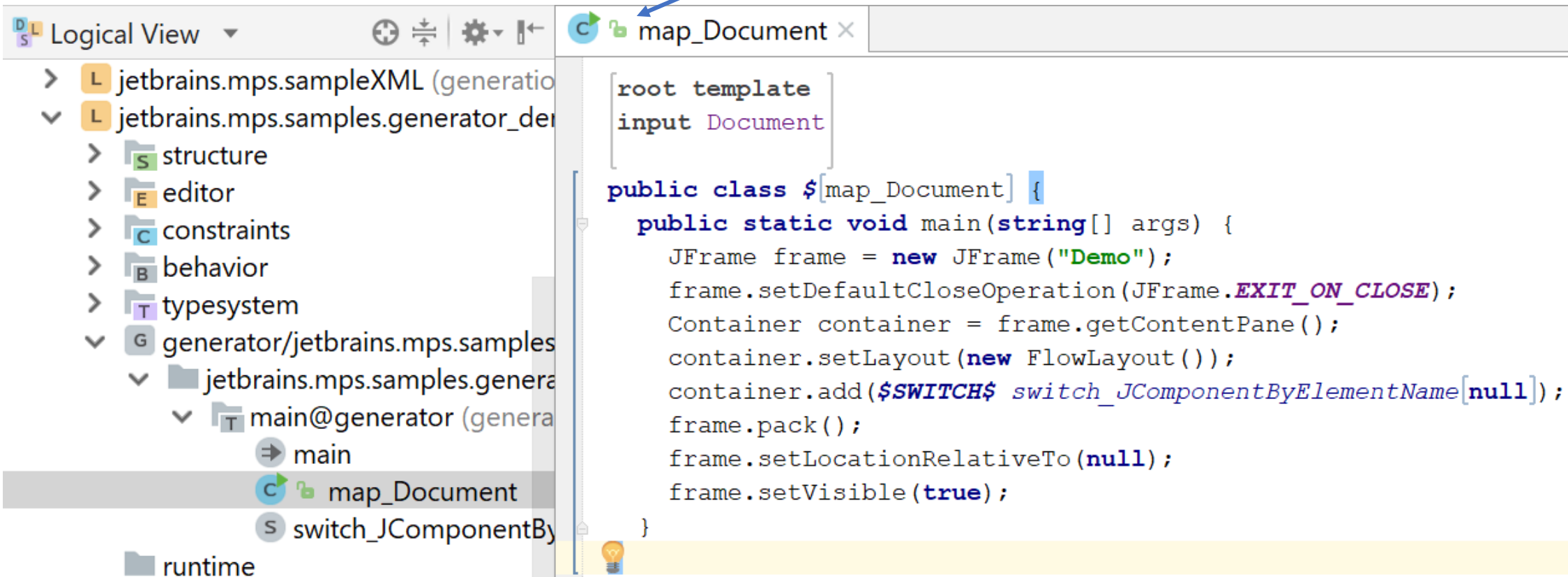
```
conditional root rules:
  condition <always> --> : DemoApp
```



Rules – root mapping

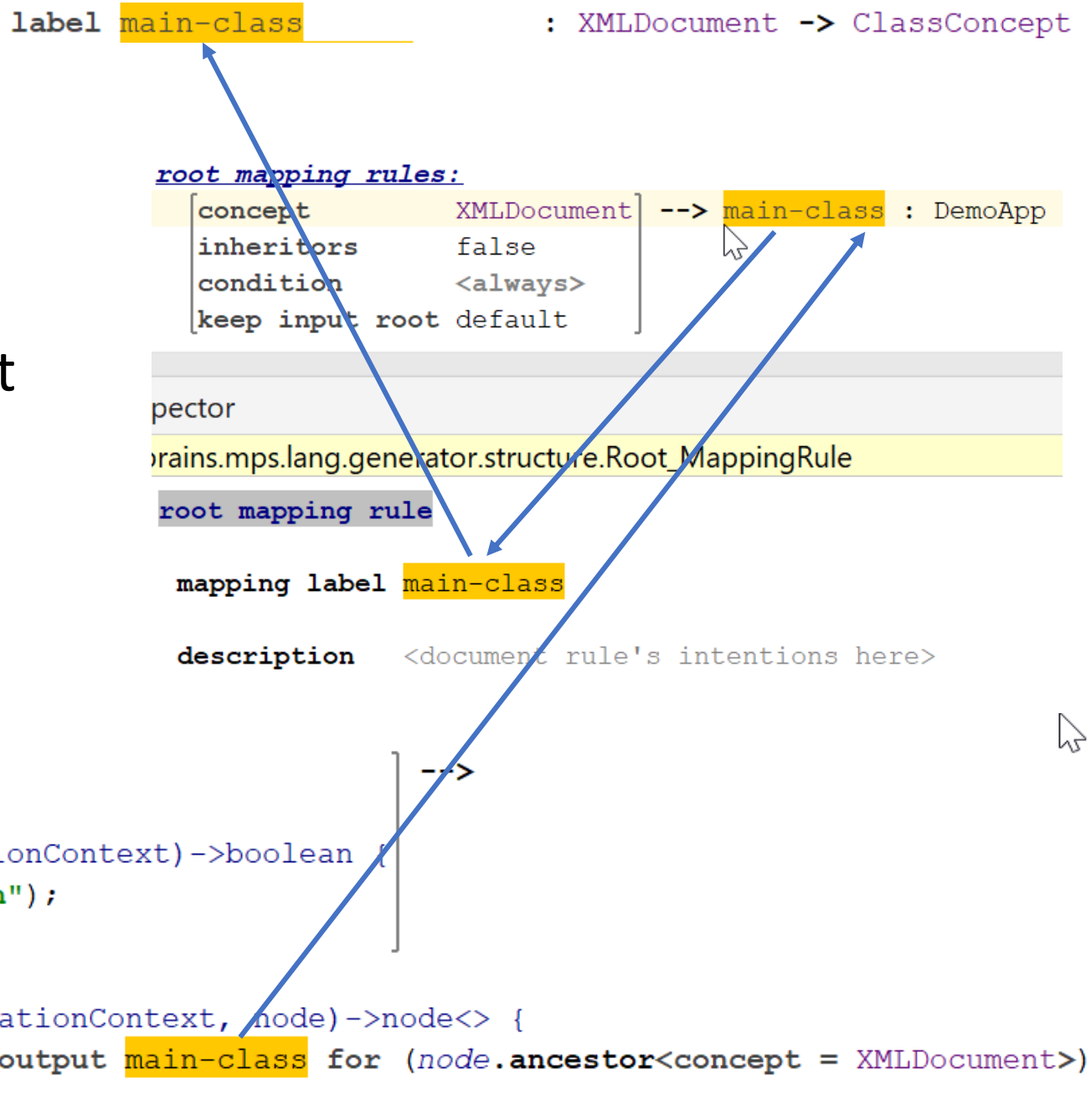
- Generates a root node in the output model:

```
root mapping rules:
  concept          Document  --> map_Document
  inheritors       false
  condition        <always>
  keep input root  default
```



Rules – weaving

- Allows to insert additional child nodes into the output model:
- The rule is applied on each input node of the specified concept.
- The parent node for insertion should be provided by the **context** function.



Rules – weaving

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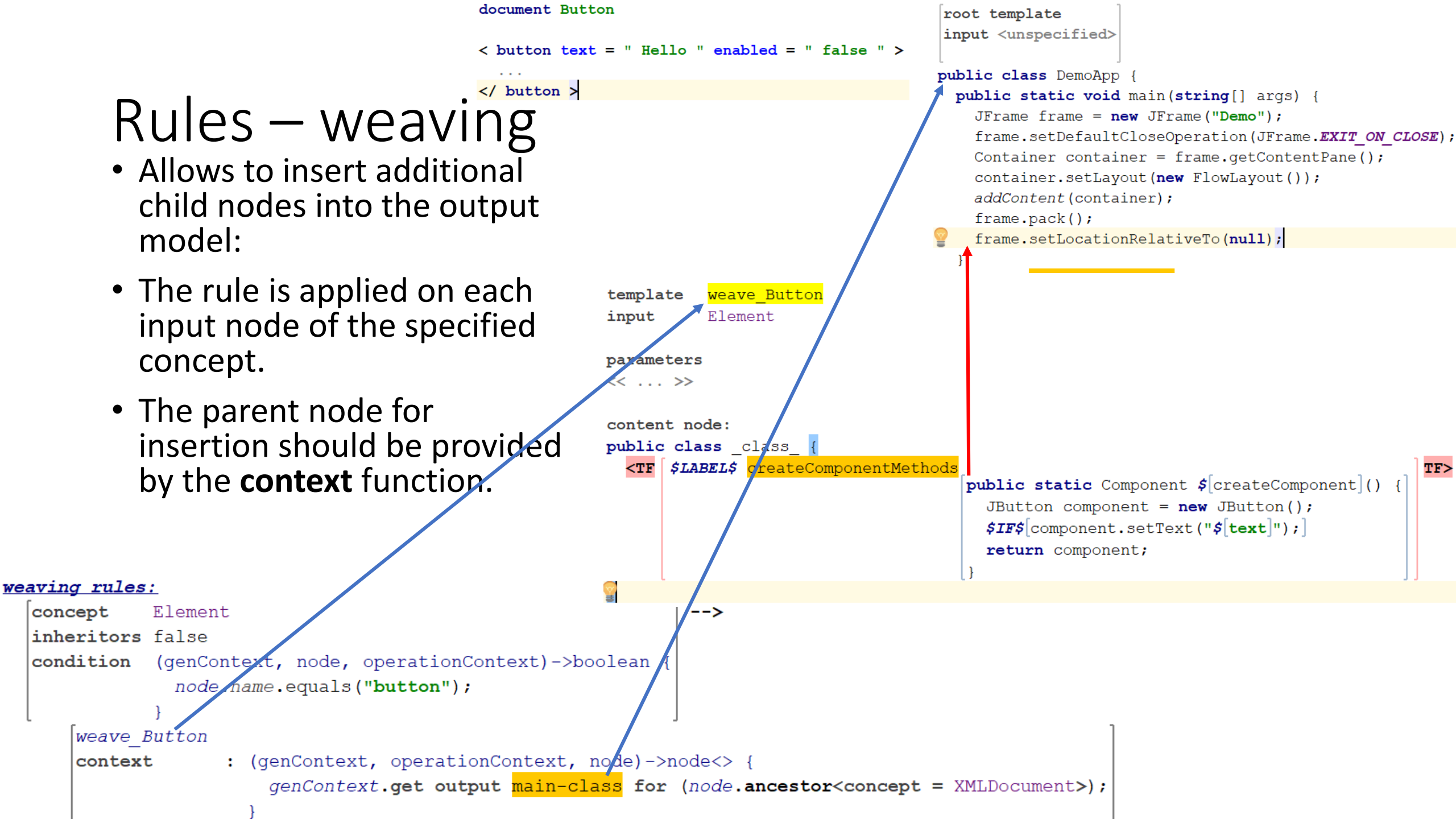
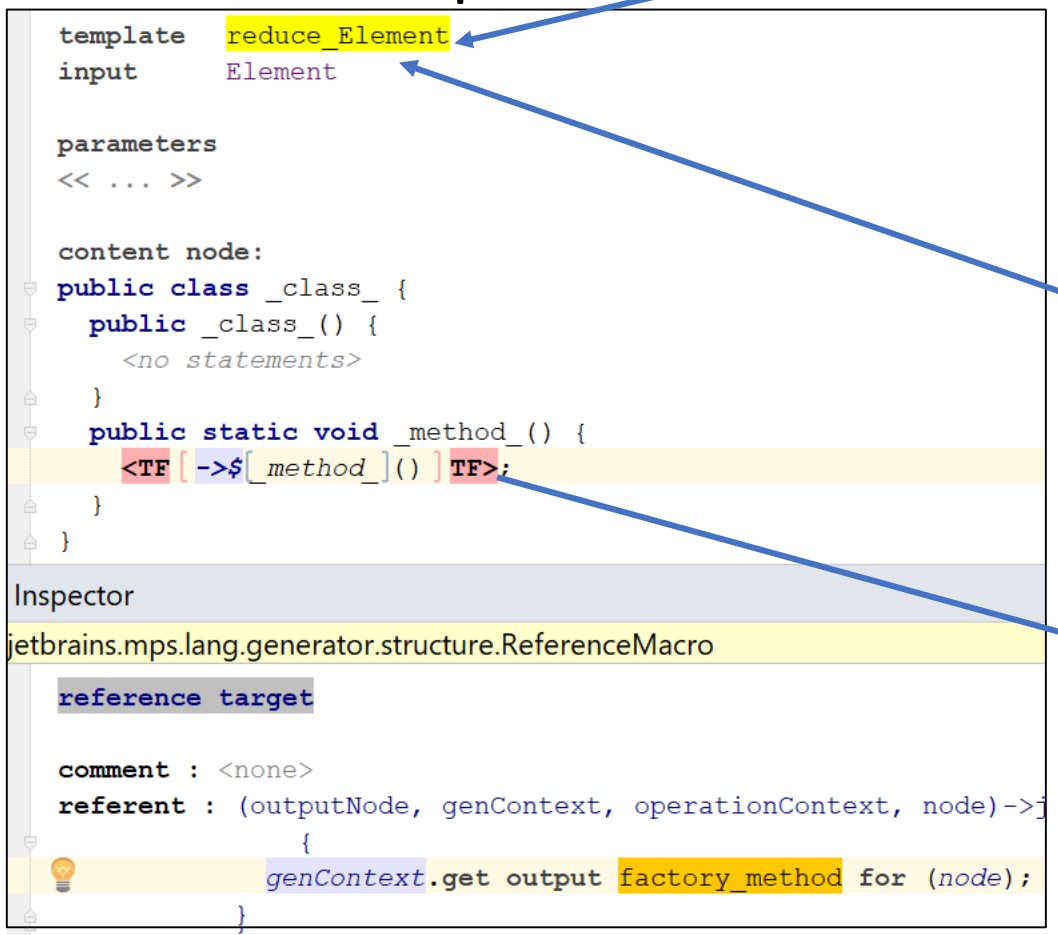
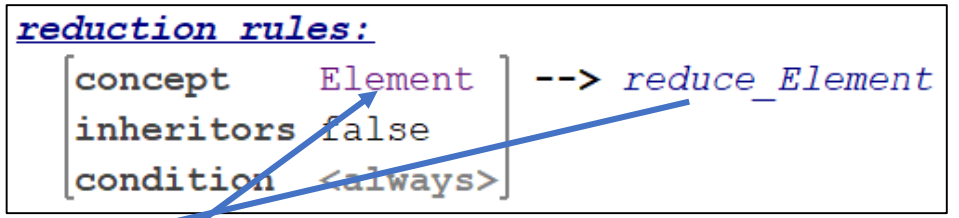
- The rule is applied on each input node of the specified concept.
- The parent node for insertion should be provided by the **context** function.

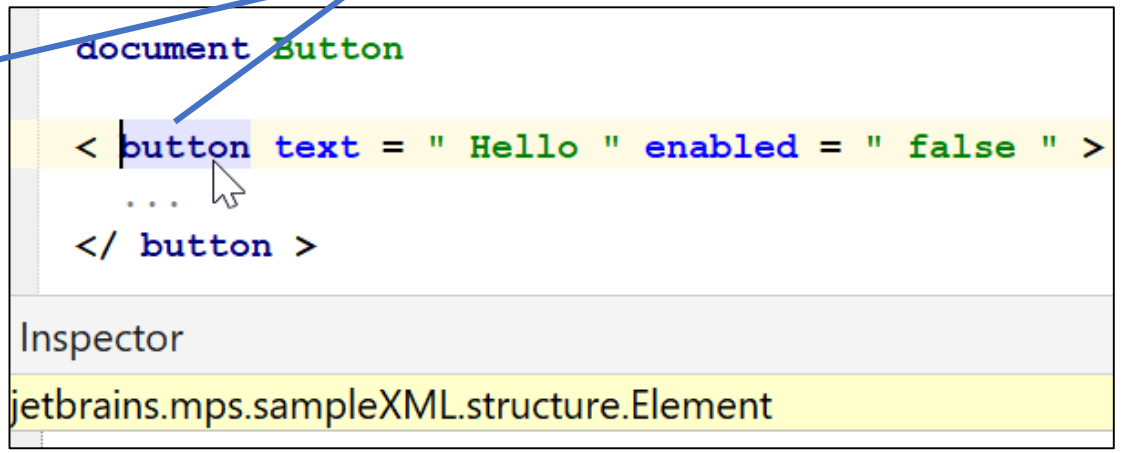


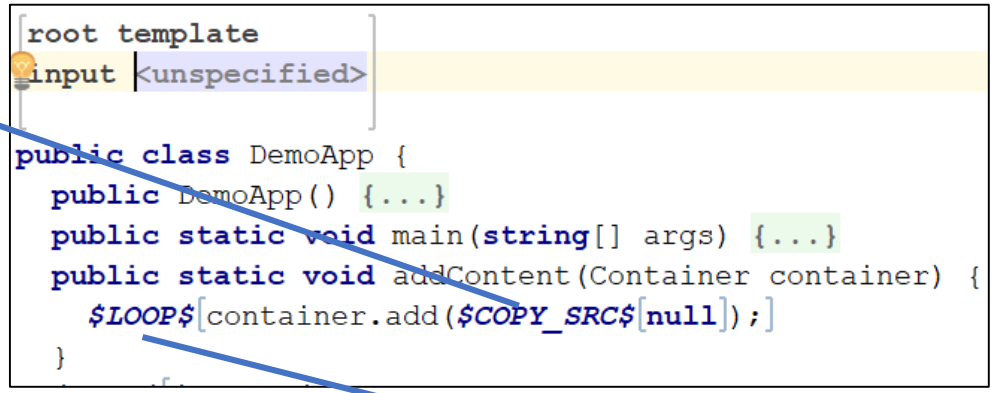
Rules – reduction

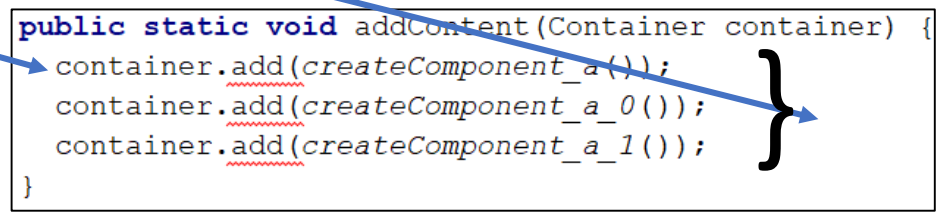
- Transforms the input node while this node is being copied to the output model:





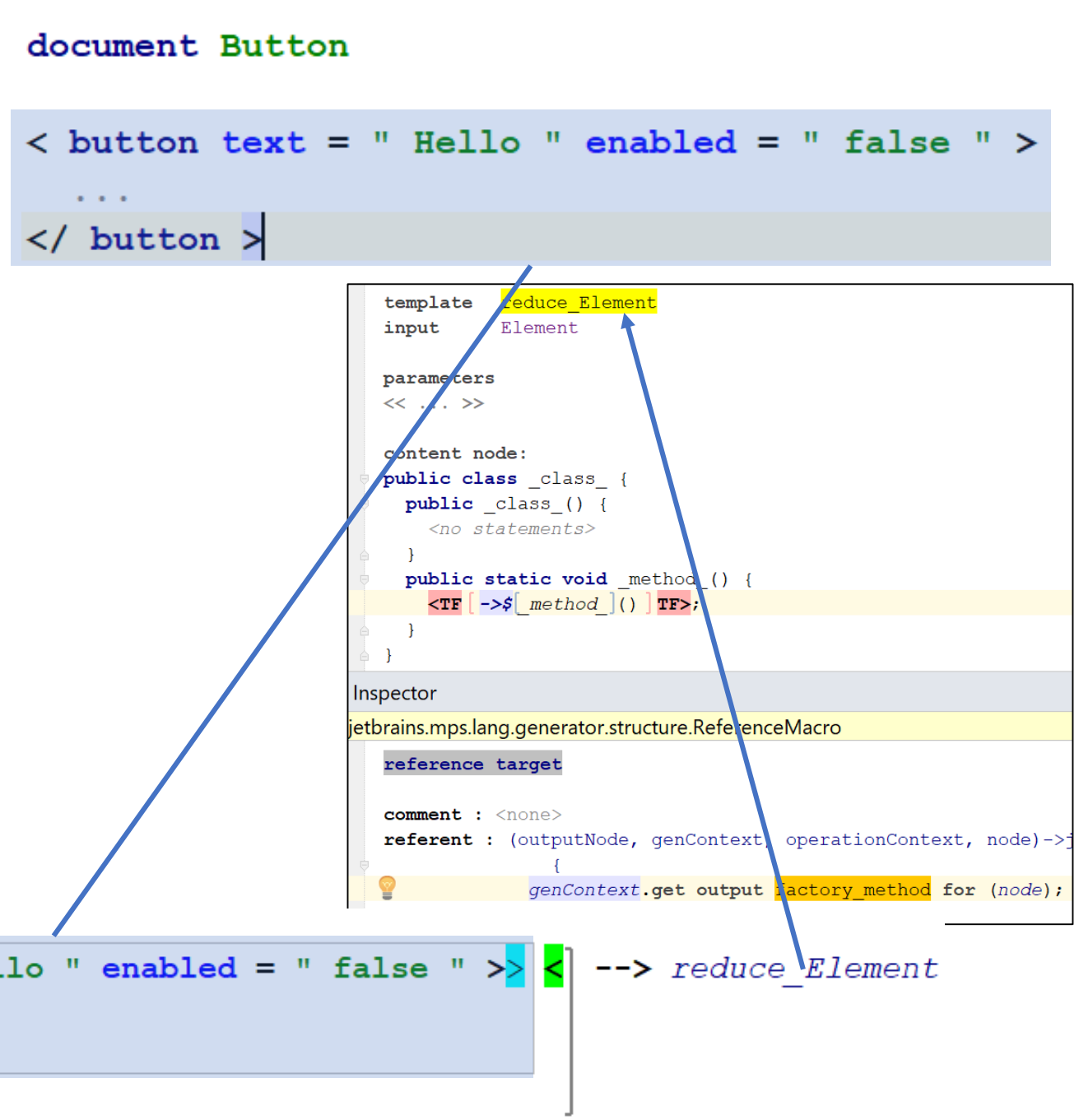






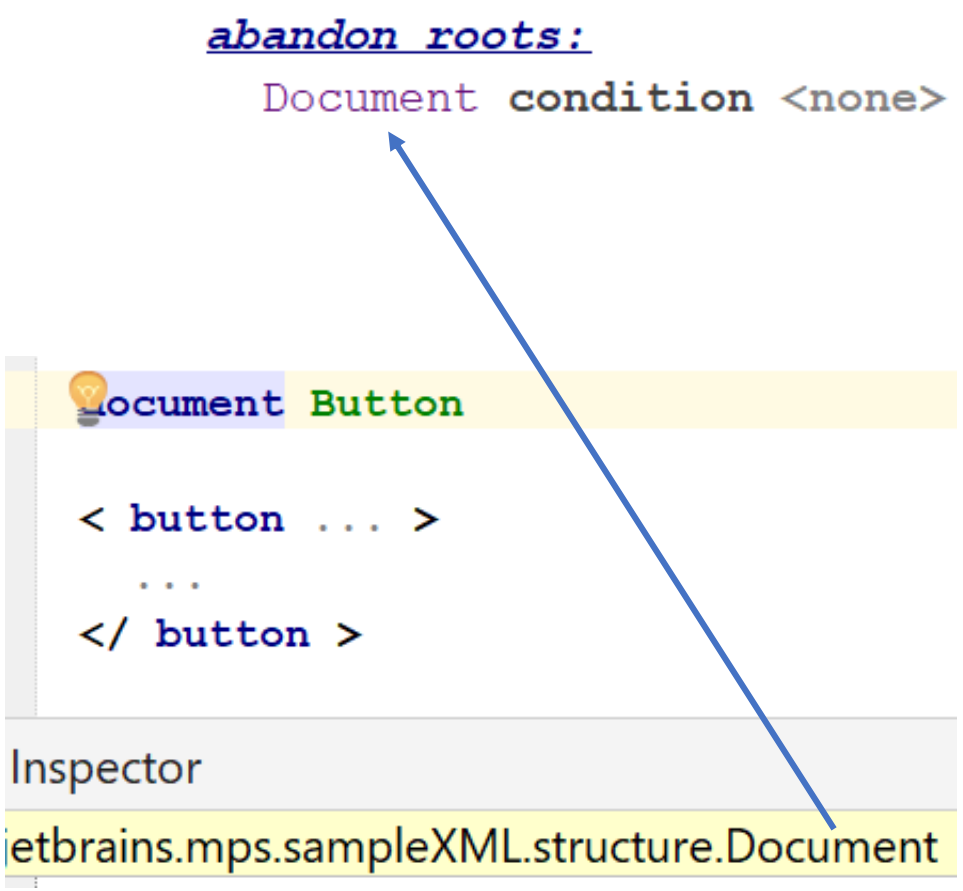
Rules – pattern

- Transforms the input node, which matches the pattern:
- Similar to reduction rules, but premise is pattern instead of concept.
- Patterns are specified in terms of the input language.



Rules – abandon root

- Allows to drop an input root node which otherwise would be copied into the output model:



Rules – drop attribute

- For a transformed node, controls which attributes get copied from the input node:

```
concept Element extends     ElementPart
                implements <none>

  instance can be root: false
  alias: <
  short description: element

  properties:
  << ... >>

  children:
  attribute : Attribute[0..n]
  content   : ElementPart[0..n]

  references:
  << ... >>
```

```
@attribute info
  multiple: <inherited>
  role: <inherited>
  attributed concepts: Element
concept ElementAnnotation extends     NodeAttribute
                          implements <none>

  instance can be root: false
  alias: <no alias>
  short description: <no short description>

  properties:
  << ... >>

  children:
  << ... >>

  references:
  << ... >>
```

drop attributes:

ElementAnnotation **condition** <none>

Model-to-model transformations

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- Mapping configurations & generator rules
  - Mapping configurations
  - Types of generator rules
- **Mapping labels**
- Generation context
- The generator algorithm
- Mapping scripts

Mapping labels

- Mapping Labels are declared in a mapping configuration and references stored to this declaration are used to label generator rules, macros and template fragments. Such marks allow finding of an output node by a known input node.

```
mapping labels:
  label main-class              : XMLDocument -> ClassConcept
  label addContentMethod        : XMLDocument -> StaticMethodDeclaration
  label createComponentMethods  : Element     -> StaticMethodDeclaration
```

```
root mapping rules:
  concept          XMLDocument --> main-class : DemoApp
  inheritors       false
  condition        <always>
  keep input root  default
```

```
root template
input <unspecified>

public class DemoApp {
  public static void main(string[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    addContent(container);
    frame.pack();
    frame.setLocationRelativeTo(null);
  }
  $LABEL$ addContentMethod
          public static void addContent(Container container) {
            <no statements>
          }
}
```

```
template   weave_Button
input      Element

parameters
<< ... >>

content node:
public class _class_ {
  <TF $LABEL$ createComponentMethods
          public static Component $createComponent() {
            JButton component = new JButton();
            $IF$component.setText("$text");
            return component;
          }
  TF>
```

Model-to-model transformations

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Generation context

- Generation context (the *genContext* parameter in macro- and rule-functions) allows finding of nodes in the output model, generating unique names and provides other useful functionality.
- Generation context can be used not only in the generator models, but also in utility models (i.e. root nodes declared in models outside of the generator model, but used in it) - as a variable of type **gencontext**.
- Operations of genContext are invoked using the familiar dot-notation: *genContext.operation.* Categories of operations are:
  - Finding output node: usually on mapping labels and nodes
  - Generating unique name
  - Getting contextual info
  - Transferring user data: transient, step, or session object (see later, **generator algorithm**).

```
reference target

comment : <none>
referent : (outputNode, genContext, operationContext, node)->join(node<VariableDeclaration> | string | node-ptr<VariableDeclaration>)
                {
                    genContext.get output addContentMethod for (node.ancestor<concept = XMLDocument>).parameter.first;
                }
```

Model-to-model transformations

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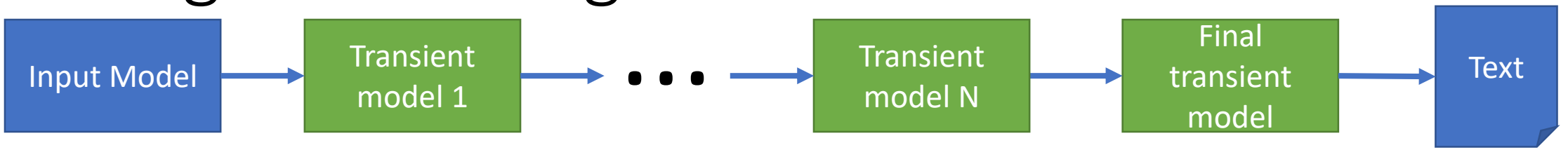
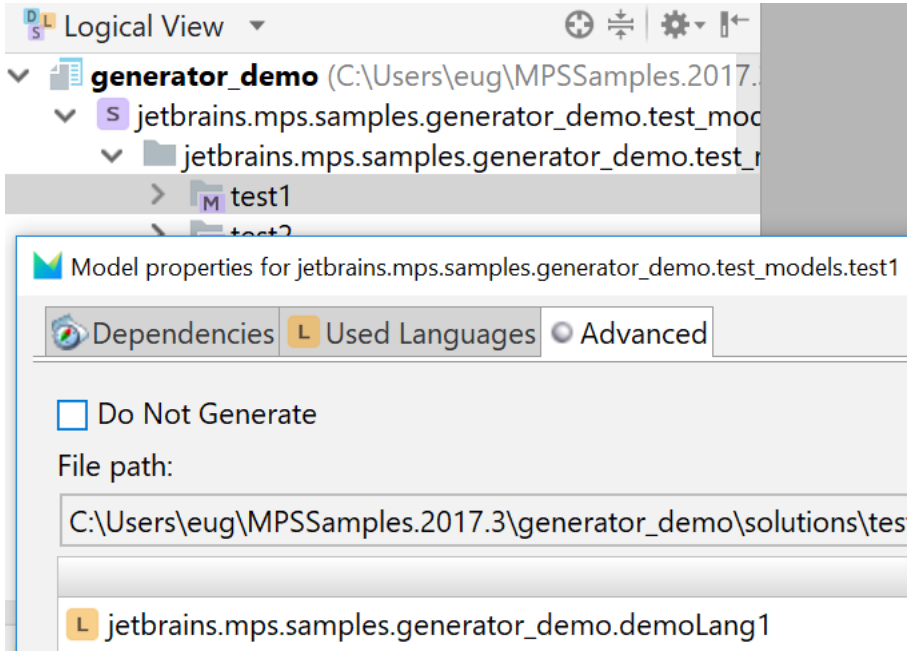
The generator algorithm



- Reduction is done in a bunch of transient models, until a fix-point has been reached
- The process of generation of target assets from an input model (generation session) includes 5 stages:
  - Defining all generators that must be involved
  - Defining the order of priorities of transformations
  - Step-by-step model transformation
  - Generating text and saving it to a file (for each root in output model)
  - Post-processing assets: compiling, etc.
- The first 3 stages live in model-to-model “land”, so we will explain them.

Defining generators involved

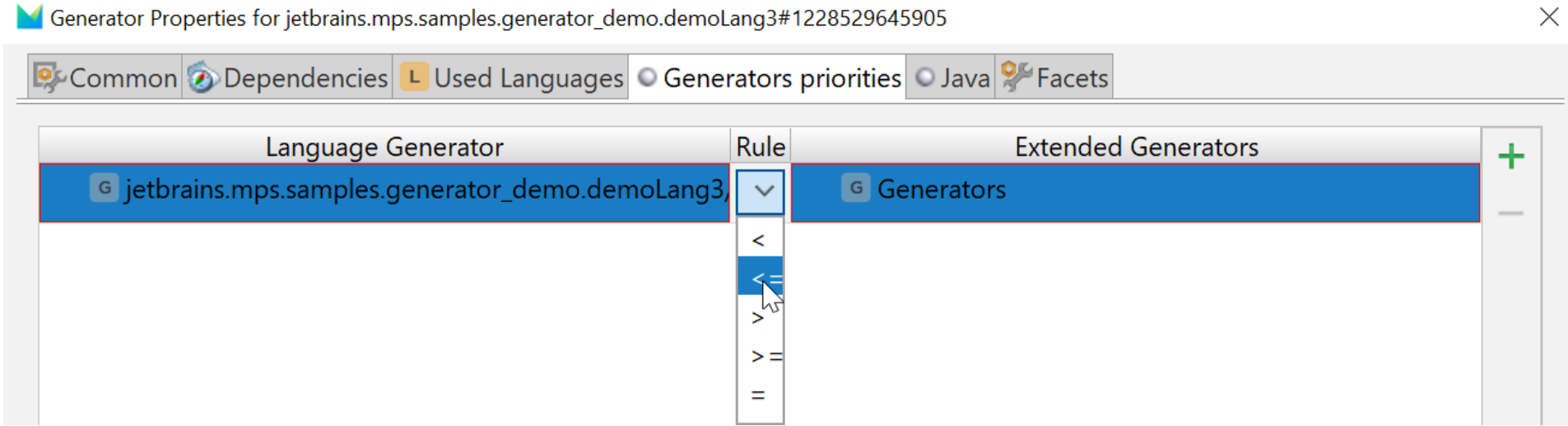
- MPS examines input model & determines which languages are used in it. MPS examines each node in the model and gathers languages that are actually used (so there is no reliance on user-specified language dependencies).
- From each 'used language' MPS obtains its generator module. Only 1 generator per module is supported. If any generator in this list depends on other generators (as specified in the 'depends on generators' property), those generators are added to the list as well.
- After MPS obtains the initial list of generators, it determines based on generator's templates what languages will be used in intermediate (transient) models. The languages detected this way are handled in the same manner as the languages used in the original input model. This procedure is repeated until no more 'used languages' can be detected.
- Explicit Engagement: In some rare cases, MPS is unable to detect a language whose generator must be involved in the model transformation. This may happen if that language is not used in the input model or in the template code of other (detected) languages. In this case, you can explicitly specify the generator engagement via the *Languages Engaged on Generation* section in the input model's properties dialog (*Advanced* tab).



Generator priorities

- It is often required that some mappings must be applied before (or not later than, or together with) some other mappings. Priority rules work on the **model** granularity level.
- The language developer specifies such a relationship between mappings by means of mapping constraints in the generator properties dialog.
- After MPS builds the list of involved generators, it divides all mappings into groups, according to the mapping priorities specified.
- All mappings for which no priority has been specified fall into the last (least-priority) group.

- MPS automatically inserts "not later than" rules for all **generator models** in the source and target languages (languages produced by templates).



Step-by-step model transformation

- Each group of mappings is applied in a separate **generation step**. The entire generation session consists of as many generation steps as there were mapping groups formed during the mapping partitioning. A generation step includes three phases:
  - Executing pre-mapping scripts
  - Template-based model transformation
  - Executing post-mapping scripts

Step-by-step model transformation

- The template-based model transformation phase consists of one or more micro-steps. A micro-step is a single-pass model transformation of an input model into a transient (output) model.
- Micro-steps are executed according to the following procedure:
  1. Apply conditional root rules (only once - on the 1-st micro-step)
  2. Apply root mapping rules
  3. Copy input roots for which no explicit root mapping is specified (this can be overridden by means of the 'keep input root' option in root mapping rules and by the 'abandon root' rules)
  4. Apply weaving rules
  5. Apply delayed mappings (from MAP_SRC macro)
  6. Revalidate references in the output model (all reference-macro are executed here)

Step-by-step model transformation

- There is no separate stage for the application of reduction and pattern rules. Instead, every time MPS copies an input node into the output model, it attempts to find an applicable reduction (or pattern) rule and performs the node copying when it is either copying a root node or executing a COPY_SRC-macro. Therefore, the reduction can occur at either stage of the model transformation.
- MPS uses the same rule set (mapping group) for all micro-steps within the generation step.
- After a micro-step is completed and some transformations have taken place during its execution, MPS starts the next micro-step and passes the output model of the previous micro-step as input to the next micro-step.
- The whole generation step is considered completed if no transformations have occurred during the execution of the last micro-step (fixpoint), that is, when there are no more rules in the current rule set that are applicable to nodes in the current input model.
- The next generation step (if any) will receive the output model of previous generation step as its input.

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- **Mapping scripts**

Mapping scripts

- A Mapping script is user code, which is executed either before a model transformation (pre-processing script) or after it (post-processing script).
- It should be referenced from the mapping configuration to be invoked as a part of it's generation step. Mapping scripts provide the ability to perform non-template based model transformations.
- Pre-processing scripts are commonly used for collecting certain information from input model that can be later used in the course of template-based transformation. The information collected by script is saved as a transient-, step- or session-object.

```
mapping script refine_text

script kind : post-process output model

(genContext, model, operationContext)->void {
  TextUtil.fixText(model);
}
```

pre-processing scripts:
fix_text

post-processing scripts:
refine_text

```
mapping script fix_text

script kind    : pre-process input model
modifies model : true

(genContext, model, operationContext)->void {
  // find all text nodes
  nlist<Text> texts = model.nodes(Text);
  foreach text in texts {
    // replace with a 'label' element
    node<Element> label = text.replace with new(Element);
    label.name = "label";
    // Add a text attribute to the 'label' element
    node<Attribute> attribute = label.attribute.add new(<default>);
    attribute.name = "text";
    attribute.value = text.text;
  }
}
```

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  - Cross-model generation and generation plans
- **Model-to-text transformations**
- Common generator patterns
- Basic dos and don’ts
- Further reading

Model-to-text transformations

- Textgen usually only used for very simple model-to-text scenarios where the cognitive gap between the model and the generated text is minimal (preferably cognitive gap is 0, i.e. model and text are 1:1), e.g.: translate a baseLanguage if-statement to a java if-statement or translate an attribute from an XML model to XML text

```
text gen component for concept IfStatement {
  (node)->void {
    append \n;
    indent buffer;
    append {if (} ${node.condition} {) {};
    with indent {
      append ${node.ifTrue};
    }
    append \n {}} $list{node.elsifClauses};
    if (node.ifFalseStatement.isNotNull) {
      append { else} ${node.ifFalseStatement};
    }
  }
}
```

```
if (true) {
  System.out.println("test");
}
```

```
concept IfStatement extends     Statement
                    implements  IContainsStatementList
                                ~~IDontSubstituteByDefault~~
                                IConditional

  instance can be root: false
  alias: if
  short description: <no short description>

  properties:
  forceOneLine    : boolean
  forceMultiLine  : boolean

  children:
  condition         : Expression[1]
  ifFalseStatement  : Statement[0..1]
  ifTrue            : StatementList[1]
  elsifClauses      : ElsifClause[0..n]

  references:
  << ... >>
```

Model-to-text transformations & plaintextgen

- Textgen usually only used for very simple model-to-text scenarios.
- For all other model-to-text scenarios, plaintextgen is recommended. Examples of such scenarios:
  - For quickly getting text out of any model on any abstraction level
  - For generating to GPLs or horizontal DSLs (e.g. markup languages) that are not yet fully modeled in MPS
- Plaintextgen plugin encapsulates the textgen aspect and emulates textual-editor appearance and models the elements of plaintext in a certain flexible way that allows more maintanable and understandable text generators
- General advice: always use only plaintextgen and just skip textgen altogether

Typical plaintextgen scenario

- Create textual template
- Paste into analyzer
- Templatize

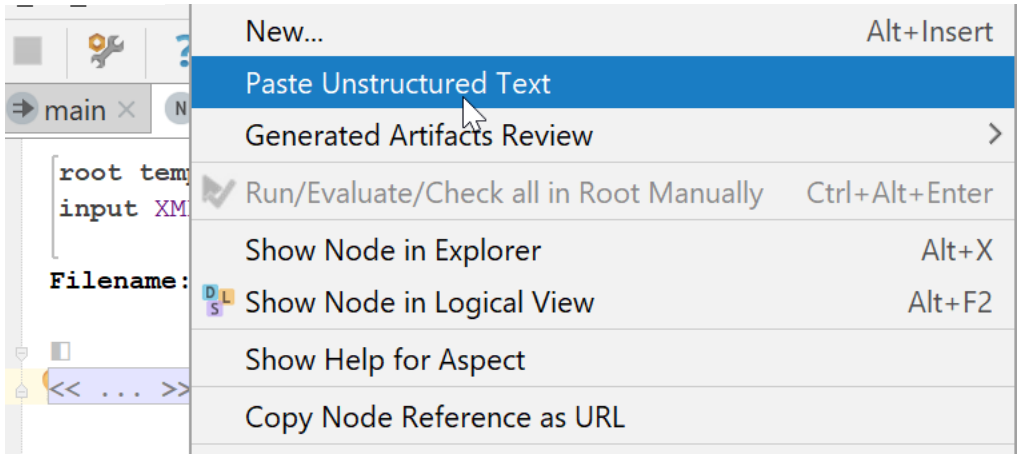
```
concept          XMLDocument --> map_XMLDocument
inheritors       false
condition        <always>
keep input root  default
```

```
public class DemoApp {
  public static void main(String[] args) {
    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    addContent(container);
    frame.pack();
    frame.setLocationRelativeTo(null);
  }
}
```

```
root template
input XMLDocument
```

Filename: map_XMLDocument.xml

<< ... >>




```
root template
input XMLDocument
```

Filename: map_XMLDocument.xml

```
public class DemoApp {

  public static void main(String[] args) {

    JFrame frame = new JFrame("Demo");
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    Container container = frame.getContentPane();
    container.setLayout(new FlowLayout());
    addContent(container);
    frame.pack();
    frame.setLocationRelativeTo(null);
  }
}
```

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Common generator patterns

- **Detecting tests**: complex generators depending on some context may need to act differently in tests. Com.mbeddr.mpsutil.blutil.genUtil contains a **is-in-tests** construct detecting a test.
- **Preprocessing instead of reductions**: when the structures of source and target nodes are too different from each other, it may help to use pre/post processing scripts instead. In some cases, these are also easier to debug than unnecessarily convoluted
- **Introducing intermediate languages**: when the gap between source and target language is too big, it is helpful to introduce an intermediate language to reduce it. This also introduces an extra layer of decoupling, improving maintainability.

Common generator patterns

- **Error handling**: don’t use exceptions (java) for error handling in generators. Instead, use genContext.show error “myErrorMessage”... This makes sure that generation doesn’t stop immediately, improving debugging capabilities tremendously.
- **Reductions and extensibility**: if you need to provide many extension points for your generator, don’t use a LOOP macro or do the transformation in place. Instead, use COPY_SRC/COPY_SRCL or LOOP in combination with a SWITCH macro that delegates to templates. Each of the places where you delegate to a template is a place where extensions can contribute/override with their own reduction rules.

Common generator patterns

- **SWITCH over IF**: When the condition of an IF macro is other than a boolean property, it is usually a smell that this IF should be replaced with a template switch. Using a SWITCH, makes the choice open for extension by the **extends** relation in each template switch.
- **(Currently) priority rules over predefined generation plans**: If extensibility is important for your generator, then use the priority rule mechanism to specify instead of the generation plan mechanism. When extension is not so important, generator plans can make things easier/faster to build.

Common generator patterns – multiple outputs from a single model

- These patterns apply for producing various outputs (e.g. XML, C++ code, java code, etc.) from a single model
- **Generator configuration**: the source model contains the actual contents to be generated, while there is/are (a) model(s) that are dedicated to the configuration of the generation. Example: mbeddr BuildConfiguration.
  Such dedicated configuration models contain a reference to (part of) the contents-model. The generator of such a configuration model is responsible to copy all contents from the contents-model to the configuration model.
  This also allows MPS to generate multiple outputs concurrently (as we have a single model per output we want to produce).

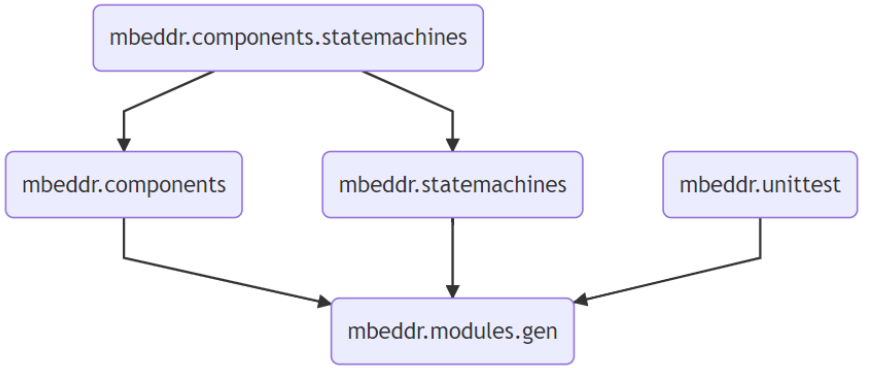
Common generator patterns – multiple outputs from a single model

- **Implementation of multi-output generators**: the generator of a dedicated configuration model needs to copy all relevant contents from the content-model. Instead of manually writing a lot of code that copies nodes, use *copies = genContext.copy with trace*.
  This makes MPS automatically take care of changing the references in the nodes thare are copied. A big effort-saver.

Common generator patterns – complex multistage generators

- When writing large sets of generators and languages that build on top of each other it can be a challenge to understand what is going on during generation. Especially defining generator priorities to order them correctly can get messy quickly.
- If not taken care of it can happen that a lot of cross generator dependencies are introduced just for the sake of making sure generators are executed in the correct order.
- A pattern to counter this is to define logical barriers in your generator priorities. Priorities are the assigned relative to these barriers. The barriers represent levels of abstraction.
- If a generator requires a certain level of abstraction as input, its priorities are defined according to that. It is important a single generator is picked for each of these barriers to have single point where these dependencies are relative to. This makes debugging much easier.
- Mbeddr Example: While mbeddr itself uses over 30 generators in total, their priorities are in most cases easy to understand. Most of the generators are isolated and most of them only define that they need to be run before the the modules.gen generator.

Common generator patterns – complex multistage generators



- In this example we will look at 3 logical stages of mbeddr all of them on different layers of abstraction. They are explained from the bottom to the top.
- **mbeddr.modules.gen layer (lowest layer of abstraction)**: This layer assumes that the input is mbeddr C99 representation, basically a simplified version of C99 without headers and some minor adaptions w.r.t. C99.
  This generator transforms its input into real C99 code with .c and .h files. If a language extension (e.g. the mbeddr.unittest language) provides a higher abstraction than this, then it defines its generator priorities relative to this generator.
- **The middle layer**: This layer contains various abstractions on a higher level than C. They are all independent from each other, but at some point they need to generate down to mbeddr C.
  This needs to happen before the modules.gen generator is executed, because it assumes that the input is C. All of the languages define their priority relative the modules.gen generator. Due to this, debugging if the order is correct is easy. If transformations are not applied correctly, it is easy to check the generation plan for a model to see if all the generators reducing the abstraction to C have been executed before the modules.gen generator.
- **Higher Level Abstractions**: The top layer in our example is a language that integrates state-machines and components. Its priorities are only set relative to the two generators it extends: mbeddr.statemachines and mbeddr.components. Since these generators itself have priorities that require them to be executed before the modules.gen generator is run, no additional priorities are required.

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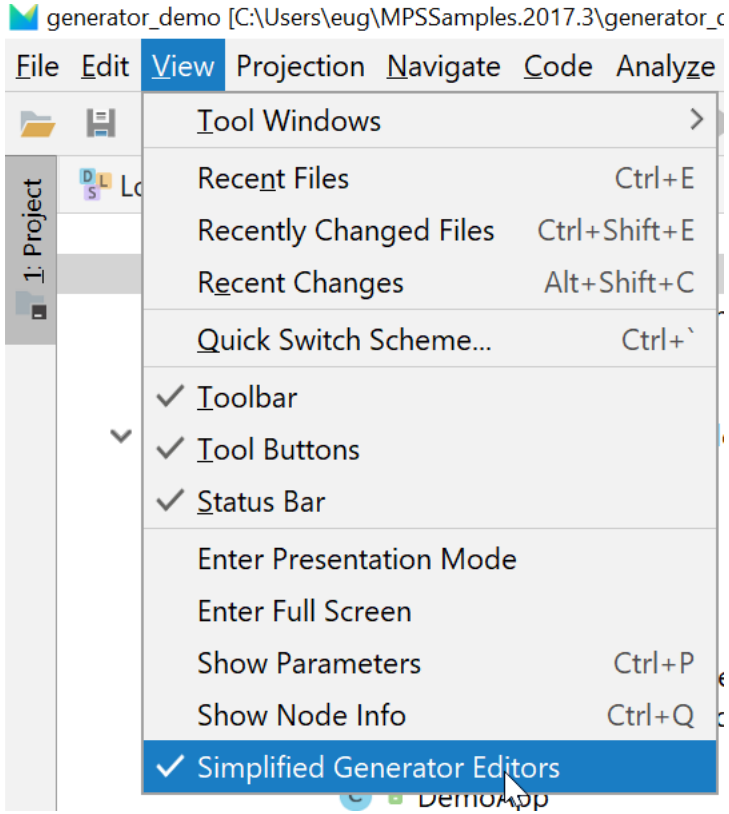
Dos and don’ts – good practices

- Tool
  - If you don’t like the default MPS way of displaying, use the simplified MPS generator editors plugin (https://github.com/coolya/mps-generator-editors) → currently only usable as a view, not editor
  - To avoid any confusion, always follow this rule: after any changes made to the generator model, the model must be re-generated (*Shift+F9*). Even better is to use *Ctrl+F9*, which will re-generate all modified models in the generator module.
  - Use “save transient models” for generator debugging
  - Use generator trace tooling for debugging
  - You can check the mapping partitioning for any (input) model by selecting *Show Generation Plan* action in the model's popup menu.
- Method
  - A very good way to find/extract good examples is from the mbeddr codebase (use Ctrl+N+N to searh for root nodes, explore the **mbeddr tutorial**, and look in the **modules pool** for example languages)



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Further reading

- https://confluence.jetbrains.com/display/MPSD20182/Generator
- The MPS Language Workbench book (Fabien Campagne)
- Itemis guide on maintainable MPS generators: https://coolya.github.io/maintainable-generators/
- https://confluence.jetbrains.com/display/MPSD20182/Generator+cookbook
- https://confluence.jetbrains.com/display/MPSD20182/Generator+User+Guide+Demo6#GeneratorUserGuideDemo6-savingtransientmodels
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