

## 22. Generic Programming with Generic Components

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1. Full Genericity in BETA
2. Universal Genericity with Slot Markup Languages
3. Semantic Macros
4. Template Metaprogramming
5. Evaluation

## Obligatory Reading

- ▶ Invasive Software Composition, Chapter 6
- ▶ [BETA-DEF] The BETA language. Free book. <http://www.daimi.au.dk/~beta/Books/>. Please, select appropriate parts.
- ▶ Bent Bruun Kristensen, Ole Lehrmann Madsen, and Birger Møller-Pedersen. 2007. The when, why and why not of the BETA programming language. In *Proceedings of the third ACM SIGPLAN conference on History of programming languages (HOPL III)*. ACM, New York, NY, USA, 10-1-10-57. DOI=10.1145/1238844.1238854 <http://doi.acm.org/10.1145/1238844.1238854>



## Literature

- ▶ BETA home page <http://www.daimi.au.dk/~beta/>
- ▶ [BETA-ENV] J. Lindskov Knudsen, M. Löfgren, O. Lehrmann Madsen, B. Magnusson. Object-Oriented Environments. The Mjølner Approach. Prentice-Hall, 1994. Great book on BETA and its environment. Unfortunately not available on the internet.
- ▶ Ole Lehrmann Madsen. The Mjølner BETA fragment system. In [BETA-ENV]. See also <http://www.daimi.au.dk/~beta/Manuals/latest/yggdrasil>
- ▶ GenVoca: Batory, Don. Subjectivity and GenVoca Generators. In Sitaraman, M. (ed.). proceedings of the Fourth Int. Conference on Software Reuse, April 23-26, 1996, Orlando Florida. IEEE Computer Society Press, pages 166-175
- ▶ [CE00] K. Czarnecki, U. Eisenecker. Generative Programming. Addison-Wesley, 2000.
- ▶ J. Goguen. Principles of Parameterized Programming. In Software Reusability, Vol. I: Concepts and Models, ed. T. Biggerstaff, A. Perlis. pp. 159-225, Addison-Wesley, 1989.
- ▶ [Hartmann] Falk Hartmann. Falk Hartmann. Safe Template Processing of XML Documents. PhD thesis. Juli 2011, Technische Universität Dresden, Fakultät Informatik. <http://nbn-resolving.de/urn:nbn:de:bsz:14-qucosa-75342>
- ▶ [Arnoldus] Jeroen Arnoldus, Jeanot Bijpost, and Mark van den Brand. 2007. Repleo: a syntax-safe template engine. In Proceedings of the 6th international conference on Generative programming and component engineering (GPCE '07). ACM, New York, NY, USA, 25-32. DOI=10.1145/1289971.1289977 <http://doi.acm.org/10.1145/1289971.1289977>
- ▶ The boost C++ library project <http://www.boost.org/>



## 22.1 Full Genericity in BETA

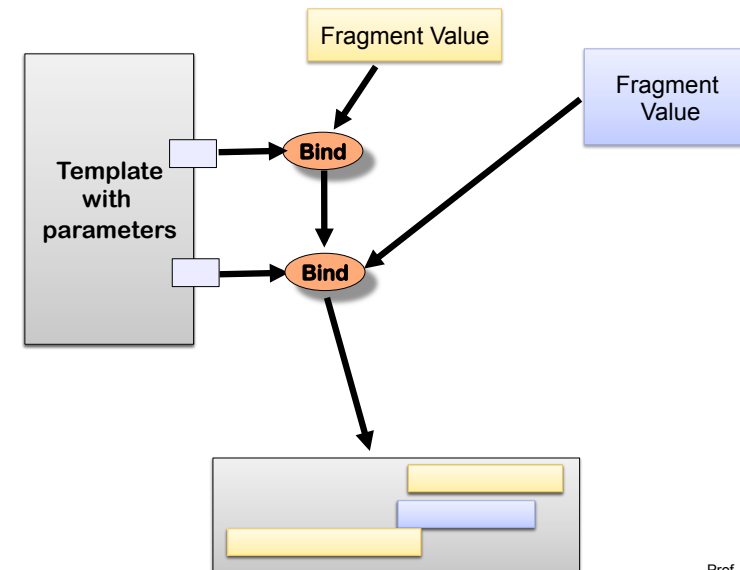


## Generic Components

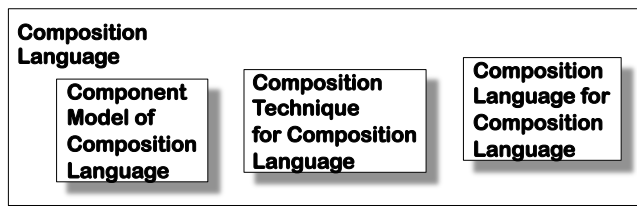
- ▶ A **generic component** is a *template* from which other components can be generated
  - Generic components rely on *bind* operations that bind the template parameter with a value (*parameterization*)
    - The result is called the *extent*
  - A *generic class* is a special case, in which types are parametric
- ▶ A **fully generic language** is a language, in which all language constructs can be generic
  - Then, the language need to have a *metamodel*, by which the parameters are typed

## Binding Templates As Sequence of Compositions

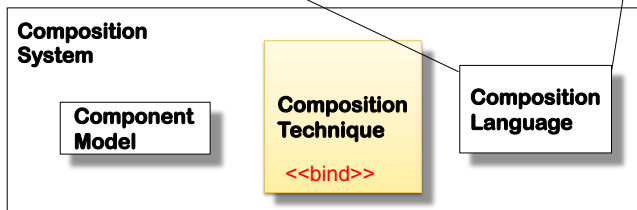
Template parameters (slots) must be bound by fragment values



## Generic Programming is a Composition Technique Relying on the Bind Operator (Parameterization)



Composition Level



## BETA Fragment Metaprogramming System

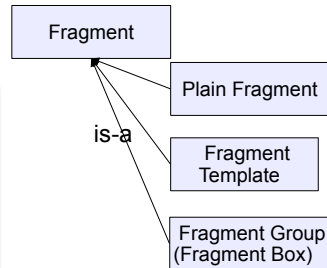
- ▶ BETA is a modern object-oriented language, developed in the North
  - BETA definition [BETA]
  - BETA programming environment Mjölner 1994 [BETA-ENV]
- ▶ Features
  - Single inheritance
  - Classes and methods are unified to *patterns (templates)*
    - Classes are instantiated statically, methods dynamically
  - Environment is controlled by BETA grammar
    - Extension of the grammar changes all tools
  - Fully generic language
  - BETA metaprogramming system *Yggdrasil*
    - Separate compilation for all sentential forms of the grammar (all fragments generatable by the grammar)
    - Essentially, a BETA module is a *generic fragment* of the language
- BETA is a better LISP, supports *typed metaprogramming*



## The Component Model of BETA

- The basic component in the BETA system is a *fragment*
  - Plain Fragment:** Sentential form, a partial sentence derived from a nonterminal
  - Generic Fragment** (fragment form, fragment template): Fragment that still contains nonterminals (*slots*)
  - Fragment Group** (fragment box): Set of fragments

```
define fragment component PersonTemplate = {
  name '/home/assmann/PersonTemplate'
  Person : PatternDecl
  Person : begin
    PersonMembers : begin
      name : @String
      <<EmployerSlot : Attribute>>
    end
  end
end
```



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## Fragments (Snippets)

- A **fragment (snippet)** is a sequence of terminals, derived from a nonterminal in a grammar
- Example:
  - Z ::= Address Salary .
  - Address ::= FirstName SecondName Street StreetNr Town Country.
  - Salary ::= int.
- Then, the following ones are fragments:
  - Uwe Assmann Rudolfstrasse 31 Frankfurt Germany
  - 34
- But a complete sentence is
  - Uwe Assmann Rudolfstrasse 31 Frankfurt Germany 34
- A fragment can be given a *name*
  - MyAddress: Uwe Assmann Rudolfstrasse 31 Frankfurt Germany

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## Generic Fragments

- A **generic fragment** (*fragment form, sentential form*) is a sequence of terminals and nonterminals, derived from a nonterminal in a grammar
- Example:
  - Uwe Assmann <<Strasse>> Frankfurt Germany
  - MyAddress: Uwe Assmann <<Strasse>> Frankfurt Germany
- In BETA, the “left-in” nonterminals are called *slots*

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## Binding a Slot of a Generic Fragment in BETA

Done implicitly by name binding

```
define fragment component PersonTemplate = {
  name '/home/assmann/PersonTemplate'
  Person : PatternDecl
  Person : begin
    PersonMembers : begin
      name : @String
      <<EmployerSlot : Attribute>>
    end
  end
end
```

```
define fragment component PersonFiller = {
  name '/home/assmann/PersonFiller'
  origin '/home/assmann/PersonTemplate'
  EmployerSlot: Attribute
  EmployerSlot: begin
    employer: @Employer;
    salary: Integer
  end
}
```



```
Person : PatternDecl
Person : begin
  PersonMembers : begin
    name : @String
    employer: @Employer;
    salary: Integer
  end
end
```

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## Binding a Slot Seen as a Composition in BETA

- Binding a slot can be seen as a call to the **bind** composition operator

```
define fragment component PersonTemplate = {
  name '/home/assmann/PersonTemplate'
  Person : PatternDecl
  Person : begin
    PersonMembers : begin
      name : @String
      <<EmployerSlot : Attribute>>
    end
  end
}
```

```
define fragment component PersonFiller = {
  name '/home/assmann/PersonFiller'
  origin '/home/assmann/PersonTemplate'
  EmployerSlot: Attribute
  EmployerSlot: begin
    employer: @Employer;
    salary: Integer
  end
}
```

```
fragment Person = PersonTemplate.
  EmployerSlot.bind(PersonFiller);
```

```
Person : PatternDecl
Person : begin
  PersonMembers : begin
    name : @String
    employer: @Employer;
    salary: Integer
  end
end
```

## Generic Statements in BETA Slot Syntax

```
Component methodComponent = cs.createTemplate("P");
Slot statement = methodComponent.findSlot("MY");
```

```
if (StdoutVersion) {
  statement.bind("System.out.println("Hello World");");
} else {
  statement.bind("FileWriter.println("no way");");
}
```

```
P = public print() {
  <<MY:Statement>>;
}
```

```
public print () {
  System.out.println("Hello World");
}
```

```
public print () {
  FileWriter.println("no way");
}
```

## BETA Fragment Groups

- A **fragment group** is a group of sentential forms, derived from the same nonterminal:

```
standardLoopIterators = {
  Upwards: for (int i = 0; i < array.<<len:Function>>; i++)
  Downwards: for (int i = array.<<len:Function>>-1; i >= 0; i--)
}
```

len:Function

```
standardLoopIterators = {
  Upwards: for (int i = 0; i < array.<<len:Function>>; i++)
  Downwards: for (int i = array.<<len:Function>>-1; i >= 0; i--)
}
```

## Implicit Binding also works in BETA Fragment Groups

- Fragments can be combined with others by reference (*implicit* bind operation)
- Given the following fragments:

```
len = { size() }
standardLoopIterators = {
  Upwards: for (int i = 0; i < array.<<len:Function>>; i++)
  Downwards: for (int i = array.<<len:Function>>-1; i >= 0; i--)
}
LoopIterators = standardLoopIterators, len
```

- The reference binds all used slots to defined fragments. Result:

```
LoopIterators = {
  Upwards: for (int i = 0; i < array.size(); i++)
  Downwards: for (int i = array.size()-1; i >= 0; i--)
}
```

## Advantages

- Fine-grained *fragment component model*
  - The slots of a beta fragment form its *composition interface*
  - The BETA compiler can compile all fragments separately
  - Snippets with all kinds of language constructs can be reused
  - Type-safe composition with composition operation *bind-a-fragment*
  - Mjølner metaprogramming environment is one of the most powerful software IDE in the world (even after 15 years)

**Full genericity:** A language is called *fully generic*, if it provides genericity for every language construct.



## Evaluating BETA as a Composition System

- ▶ BETA's fragment combination facilities use as composition operations:
  - An *implicit bind* operation (fragment referencing by slots)
  - An inclusion operation (concatenation of fragments)
- ▶ Hence, BETA's composition language is rather simple, albeit powerful



## Inclusion of Fragments into Fragment Groups

- ▶ Fragments can be inserted into others by the *include* operator
- ▶ Given the above fragments and a new one

```
whileloopbody = WHILE <<statements:statementList>> END;
```

- ▶ A while loop can be defined using the include operator:

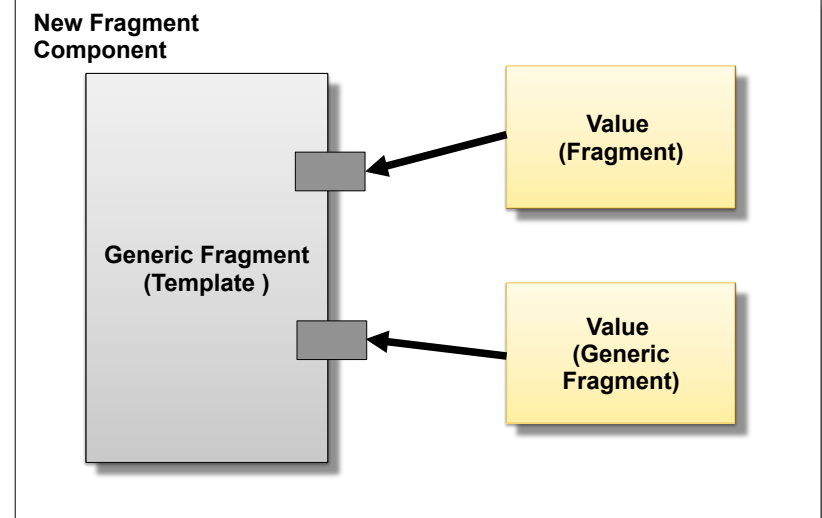
```
whileloop = {  
  include LoopIterators.Upwards  
  whileloopbody  
}
```

- ▶ BETA is a fully generic language:

- Modular reuse of all language constructs
- Separate compilation: The BETA compiler can compile every fragment separately
- Much more flexible than ADA or C++ generics!



## Generic Components (Templates) Bind at Compile Time



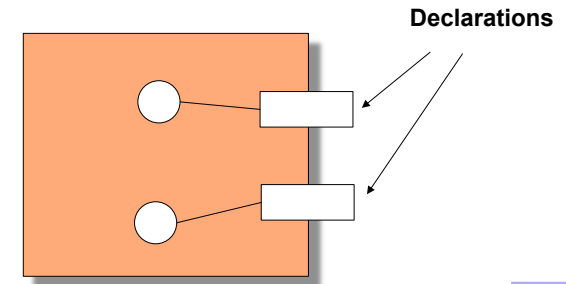
## 22.2 Universal Genericity with Slot Markup Languages



## Slots (Declared Hooks)

Slots are declared variation points of fragments.

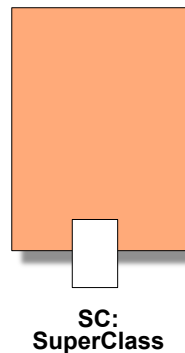
Slots (declared hooks) are declared by the component writer as code parameters



## Different Ways to Declare Slots

Slots are denoted by metadata. There are different alternatives:

- Language extensions with **new keywords**
  - SlotDeclaration ::= 'slot' <Construct> <slotName> ';
  - In BETA, angle brackets are used:
  - SlotDeclaration ::= '<<' SlotName ':' Construct '>>'
- Meta-Data Attributes** are language-specific
  - Java: @superclass(SC)
  - C#: [superclass(SC)]
- Comment Tags** can be used in any language
  - class Set /\* @superClass \*/
- Markup Tags** in XML can be used for marking up code
  - <superclasshook> SC </superclasshook>^
- Standardized Names (Hungarian Notation)**
  - class Set extends genericSCSuperClass { }

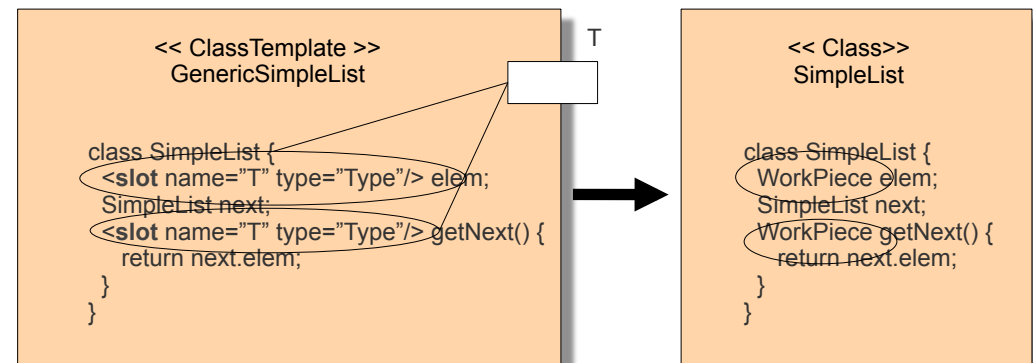


## Defining Generic Types with XML Markup

[Hartmann] showed that any XML language can be enriched by a **slot markup language** to define slots

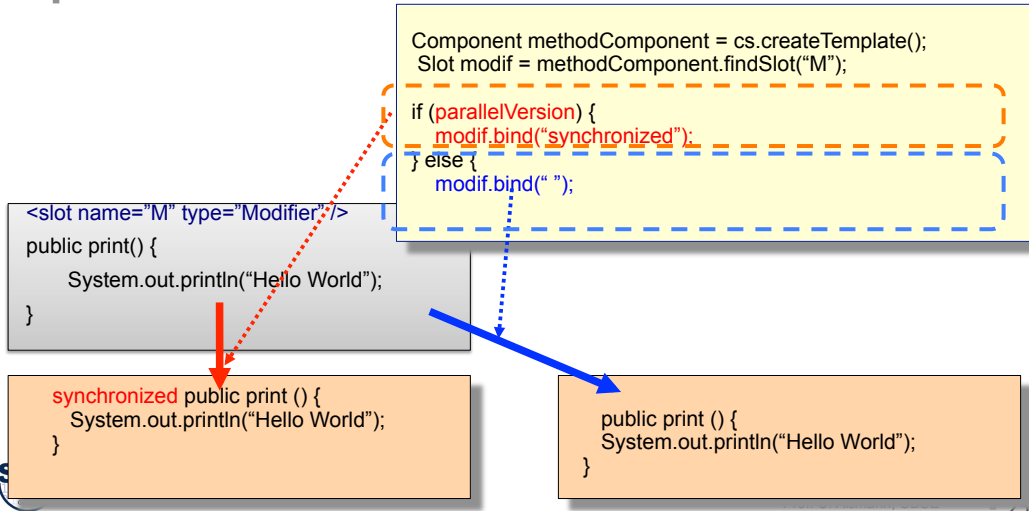
Slot markup languages use **hedge symbols** to demarcate template and slot (BETA: << >>, XML: < >)

[Arnoldus] did the same for textual languages



## Generic Modifiers in XML Markup Syntax

- Slot markup languages may contain elements of a composition language, i.o.g., control flow structures
- A **slot program** expands the slot to a fragment [Hartmann]



## Universal Genericity with Slot Markup Languages

- Do not use string template engines, they render development error-prone
- Use slot markup languages to exploit their typing
- With appropriate hedge symbols, a slot markup language can be combined with a base language [Hartmann]

**Principle of universal genericity:**  
With slot markup separated by appropriate hedge symbols, any language may have typed generic components, as well as full genericity.



## 22.3 Semantic Macros

Macros based on metamodels or grammars



## Semantic Macros (Hygenic Macros)

- Usually, macros are string-replacement functions (lambdas)
- Macro arguments can be typed by nonterminals (as in BETA; builds on the typed lambda calculus)

```

function makeExpression(Left:Expression, Op:Operator,
    Right:Expression):Expression {
    return Left ++ Op ++ Right; // ++ is AST concatenation
}

function incr(a:Expression):Expression {
    return makeExpression(1,+,a); }

function sqr(a:Expression):Expression {
    return makeExpression(a,*,a); }

Code result = incr(2);
i:int = eval(result);
// result: i == 3;
k:int = eval(sqr(10));
// result k == 100;
    
```





## Comparing Semantic Macros and Slot Markup Languages

- Semantic Macros use the functional application symbols () as hedge symbols, i.e., are better integrated with the host language
  - Like slot programs they expand in-place
- Semantic Macros are better reusable, because they have a name
  - Slot programs are anonymous lambdas



## Template Metaprogramming

- ▶ Template Metaprogramming [CE00] is an attempt to realize the generic programming facilities of BETA in C++
  - C++ has templates, i.e., parameterized expressions over types, but is not a fully generic language
  - C++ template expressions are Turing-complete and are evaluated at compile time
  - C++ uses class parameterization for composition
- ▶ Disadvantage: leads to unreadable programs, since the template concept is being over-used
- ▶ Advantage: uses standard tools
- ▶ Widely used in the
  - C++ Standard Template Library STL
  - boost library [www.boost.org](http://www.boost.org)
- Should be replaced by full genericity (generic fragments) or semantic macros



## 22.4 Template Metaprogramming and Layered Template Metaprogramming



The poor man's generic programming



## Template Metaprogramming in C++

```

template <int N>
struct fact {
    enum { value = N * fact<N-1>::value };
};

template <>
struct fact<1> {
    enum { value = 1 };
};

std::cout << "5! = " << fact<5>::value << std::endl;

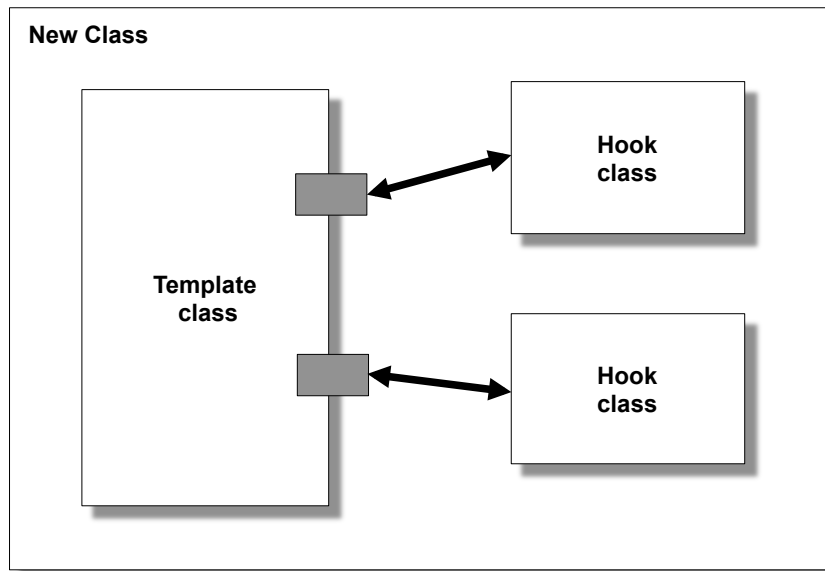
```

More advanced examples in [CE00]





## Generic Classes (Class Templates) Bind At Compile Time

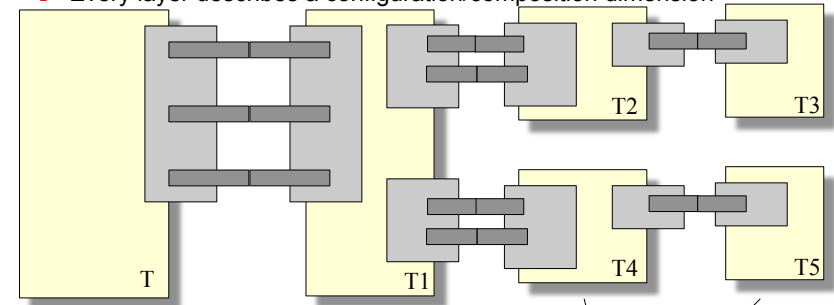


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## Layered Template Metaprogramming with GenVoca

- ▶ GenVoca: Composition by Nesting of Generic Classes [Batory]
- ▶ Use nesting of templates parameters to parameterise multiply
  - Every nesting level is called a *layer*
  - Every layer describes a configuration/composition dimension



Template  $T < T1 < T2 < T3 > , T4 < T5 > > >$

all  $T_i$  can be exchanged independent of each other, i.e., configured! (static composition)

Dimension/layer

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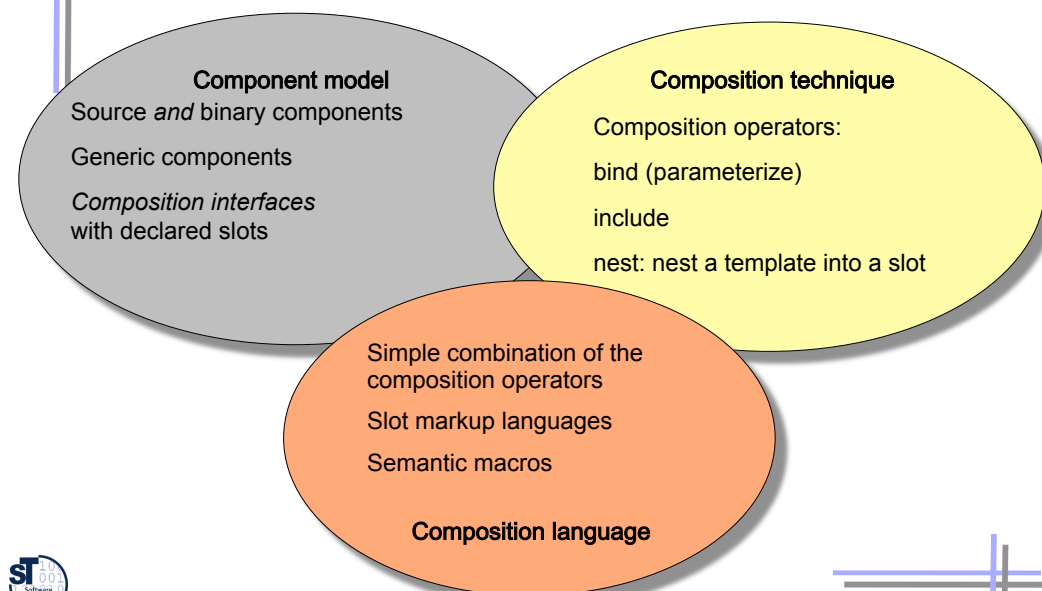
## GenVoca

- ▶ Applications
  - Parameterizing implementations of data structures
  - Synchronization code layers
- ▶ Interesting parameterization concept
  - Not that restricted as C++ templates: nested templates are a simpler form of GenVoca
  - Maps to context-free grammars. A single configuration is a word in a context-free language
  - Many tools around the technique
- ▶ However: parameterization is the only composition operator, there is no full composition language
- ▶ more in "Design Patterns and Frameworks"

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## 22.5 Evaluating BETA Fragments, TMP, GenVoca as Composition Systems



**Component model**  
Source and binary components  
Generic components  
*Composition interfaces* with declared slots

**Composition technique**  
Composition operators:  
bind (parameterize)  
include  
nest: nest a template into a slot

Simple combination of the composition operators  
Slot markup languages  
Semantic macros

**Composition language**

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# The End

- Do not use string template engines, they render development error-prone
- Use slot markup languages and semantic macros to exploit their typing
- Look out for languages with full genericity

