Towards Intelligent Coding Assistance for Code Generation in Modeling Frameworks

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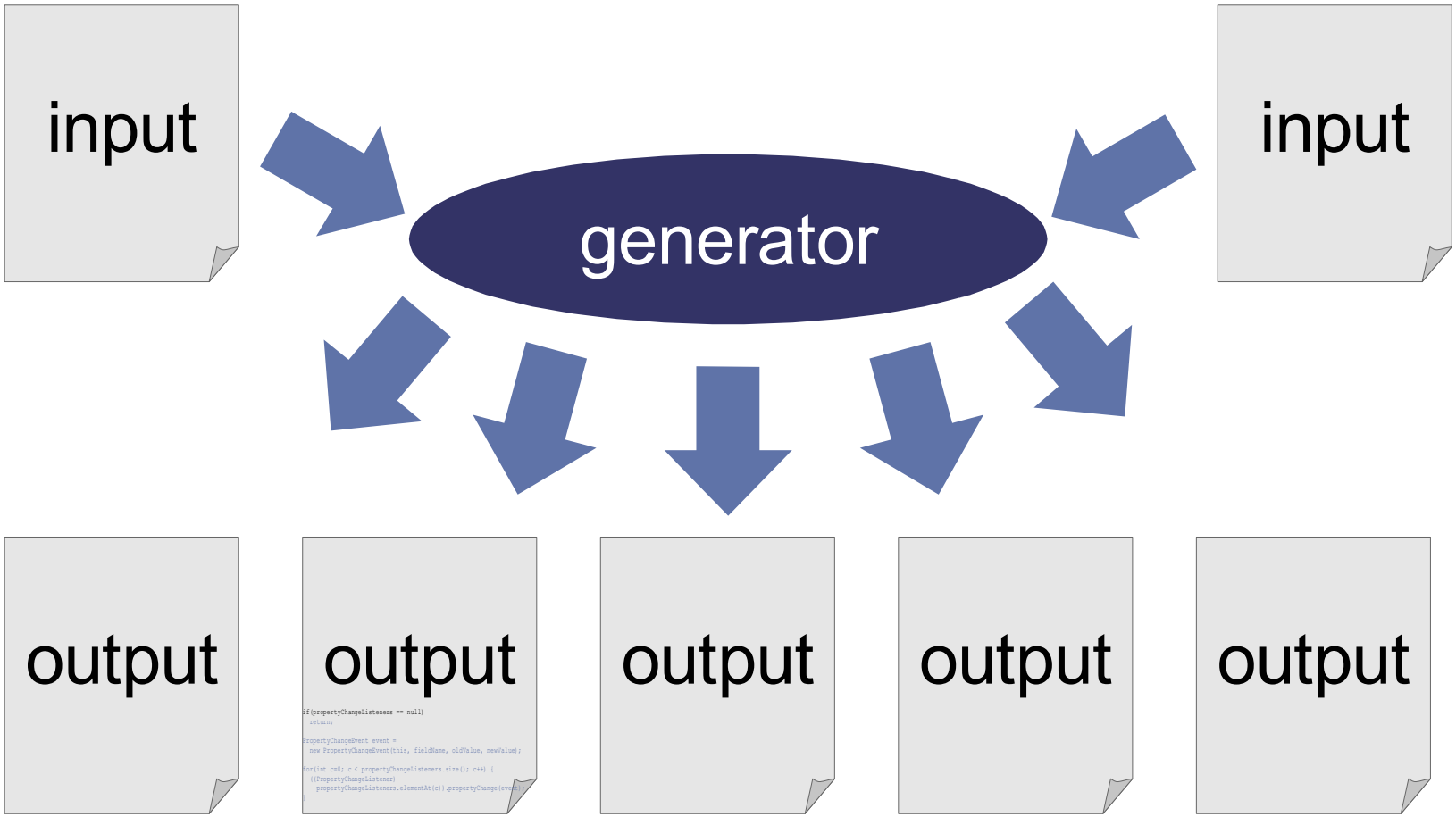
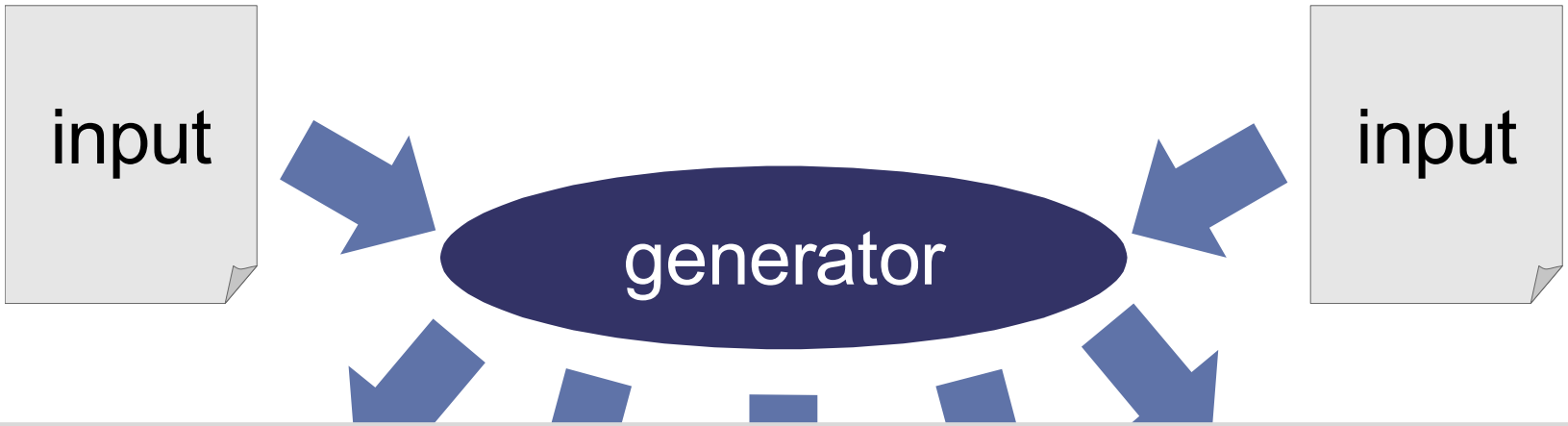
Meta Programming: Implementing Code Generators



Meta Programming: Implementing Code Generators 1

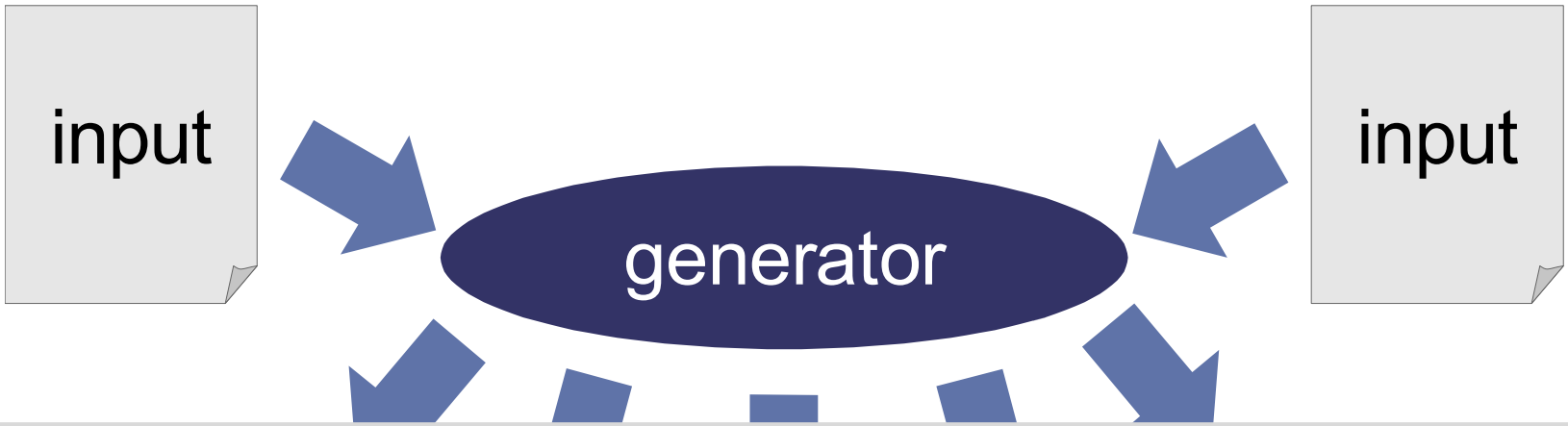



```
if(propertyChangeListeners == null)
  return;

PropertyChangeEvent event =
  new PropertyChangeEvent(this, fieldName, oldValue, newValue);

for(int c=0; c < propertyChangeListeners.size(); c++) {
  ((PropertyChangeListener)
      propertyChangeListeners.elementAt(c)).propertyChange(event);
}
```

Meta Programming: Implementing Code Generators 1




```
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  return;

PropertyChangeEvent event =
  new PropertyChangeEvent(this, fieldName, oldValue, newValue);

for(int c=0; c < propertyChangeListeners.size(); c++) {
  ((PropertyChangeListener)
      propertyChangeListeners.elementAt(c)).propertyChange(event);
}
```

The Topic for Today

Writing code generation templates

```
<<FOREACH ... AS class>>
<<FILE "samples/petclinic/" + class.name + ".java">>
package samples.petclinic;

publc class <<class.name>> {
  private long id;

  public void setId(long id) {
    this.id = id;
  }

  public long getId() {
    return id;
  }
}
<<ENDFILE>>
<<ENDFOREACH>>
```

Part I

Problems with Code Generation Tools

Problem: Syntax Errors in Templates


```
<<FOREACH ... AS class>>
<<FILE "samples/petclinic/" + class.name + ".java">>
package samples.petclinic;

publc class <<class.name>> {
  private long id;

  public void setId(long id) {
    this.id = id;
  }

  public long getId() {
    return id;
  }
}
<<ENDFILE>>
<<ENDFOREACH>>
```

Problem: Syntax Errors in Templates

Why not just test the generator with an example input?

Errors can be input specific:

```
<<IF opposite != null && opposite.isMultivalued()>>
  <many-to-many
     column="<<columnName()>>"
     class="<<type.fqn()>>"
     unique="<<isUnique()>>"
     <<IF unique_Key() != null>>
       unique-key="<<unique_Key()>>"
     <<ENDIF>>/>
<<ELSE>>
  <one-to-many class="<<type.fqn()>>"/>
<<ENDIF>>
```

. . . and of course we don't have code coverage tools.

Problem: Semantic Errors in Templates

Not only syntactic problems: type errors

```
public Collection getChildren(String linkId) {
   Collection returnChildren = new ArrayList();

   <xsl:call-template name="children">
        <xsl:with-param name="lid" select="$lid"/>
        <xsl:with-param name="superTypeLid" select="$superTypeLid"/>
        <xsl:with-param name="classPreFix" select="$classPreFix"/>
        <xsl:with-param name="first" select="true()"/>
        <xsl:with-param name="output">genericGetChildren</xsl:with-param>
   </xsl:call-template>

   return returnChildren;
}
```

```
<xsl:when test="$output = 'genericGetChildren'">
if (linkId.equals(LID_CHILD_LINK_<.../>)) {
  returnChildren = this.getChildren_<.../>();
}
</xsl:when>
```

Problem: Semantic Errors in Templates


```
<xsl:for-each select="//association[
      @target-lid = $lid and @resource-link = 'false'
      and ../@instantiable = 'true']">
if (this.getParent_<xsl:value-of
                 select="translate(../@name, '-', '_')"/>() != null) {
  parent = this.getParent_<xsl:value-of
                              select="translate(../@name, '-', '_')"/>();
}
</xsl:for-each>
```

```
<xsl:for-each select="//association[
      @target-lid = $lid and @resource-link = 'false'
      and ../@instantiable = 'true']">
public <xsl:value-of select="$classPreFix"/><xsl:value-of
                              select="translate(../@name, '-', '_')"/>
  getParent_<xsl:value-of select="translate(../@name, '-', '_')"/>() {
    return this.parent_<xsl:value-of
                              select="translate(../@name, '-', '_')"/>;
}
</xsl:for-each>
```

Problem: No Syntax Highlighting


```
«FOREACH eAllContents.typeSelect(uml::Class).select(e|e.isAbstract==true) AS class»
«FILE "org/springframework/samples/petclinic/" + class.name + ".java"»
package org.springframework.samples.petclinic;

public class «class.name» {

    private long id;

    public void setId(long id) {
        this.id = id;
    }

    public long getId() {
        return id;
    }
}
«ENDFILE»
«ENDFOREACH»
```

Problem: No Intelligent Error Highlighting


```
public rw_PakketResponse getElementrw_Pakket(..., LoggingToken log) {
  logger.debug("WS getAPPParent");

  rw_PakketParentResponse response = new rw_PakketParentResponse();

  if ((security = null) || (log = null)) {
    response.addFout(ServiceFout.SOF_DEFAULT_FOUT);
    return response;
  }

  // Log de aanroep bij de Sofia Management Info Service
  LoggingContext ctx =
    LoggingContext.newInstance(log.getSessieId(), log.getRequestId());

  ContractServiceBSImpl service = new ContractServiceBSImpl();
  response.setArrayrw_PakketOutputDTO(elementrw_PakketOutputDTOs);

  logger.debug("WS end getAPPParent");
  return response;
}
```

Lack of static guarantees

- no guarantee the generated program compiles
- compiler will report problem in terms of generated code

Limited editing support for metaprogrammer

- syntax highlighting
- coding style / formatter
- code completion
- code folding
- error reporting
- debugging

Wait, isn't that obvious?

Solution: object language aware template compiler

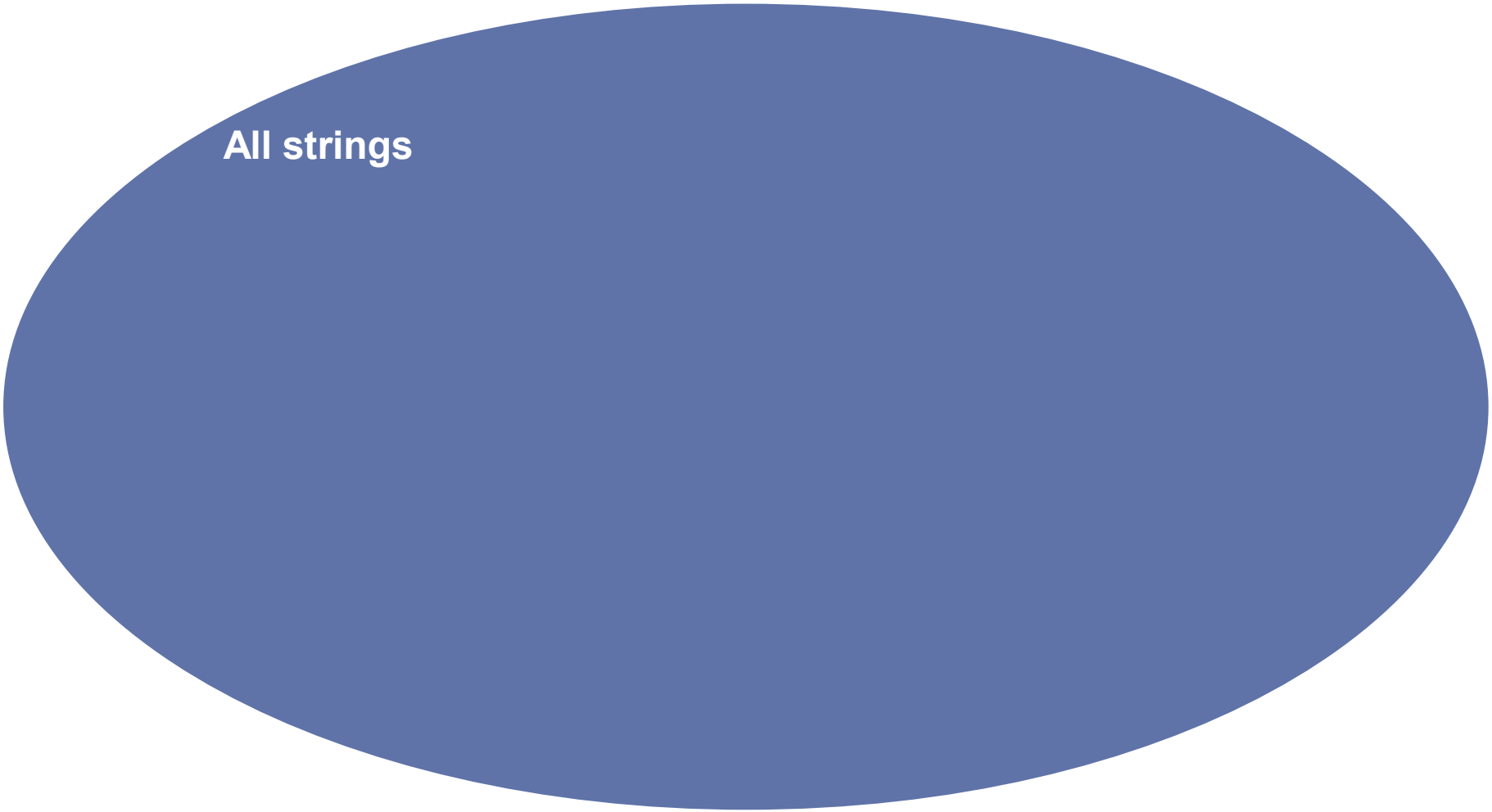
yeah, but . . .

- difficult to realize: current IDEs are mostly realized by brute force manpower
- no spectacular advancement in understanding of how to implement interactive source editors
- move to parsing source code in editor

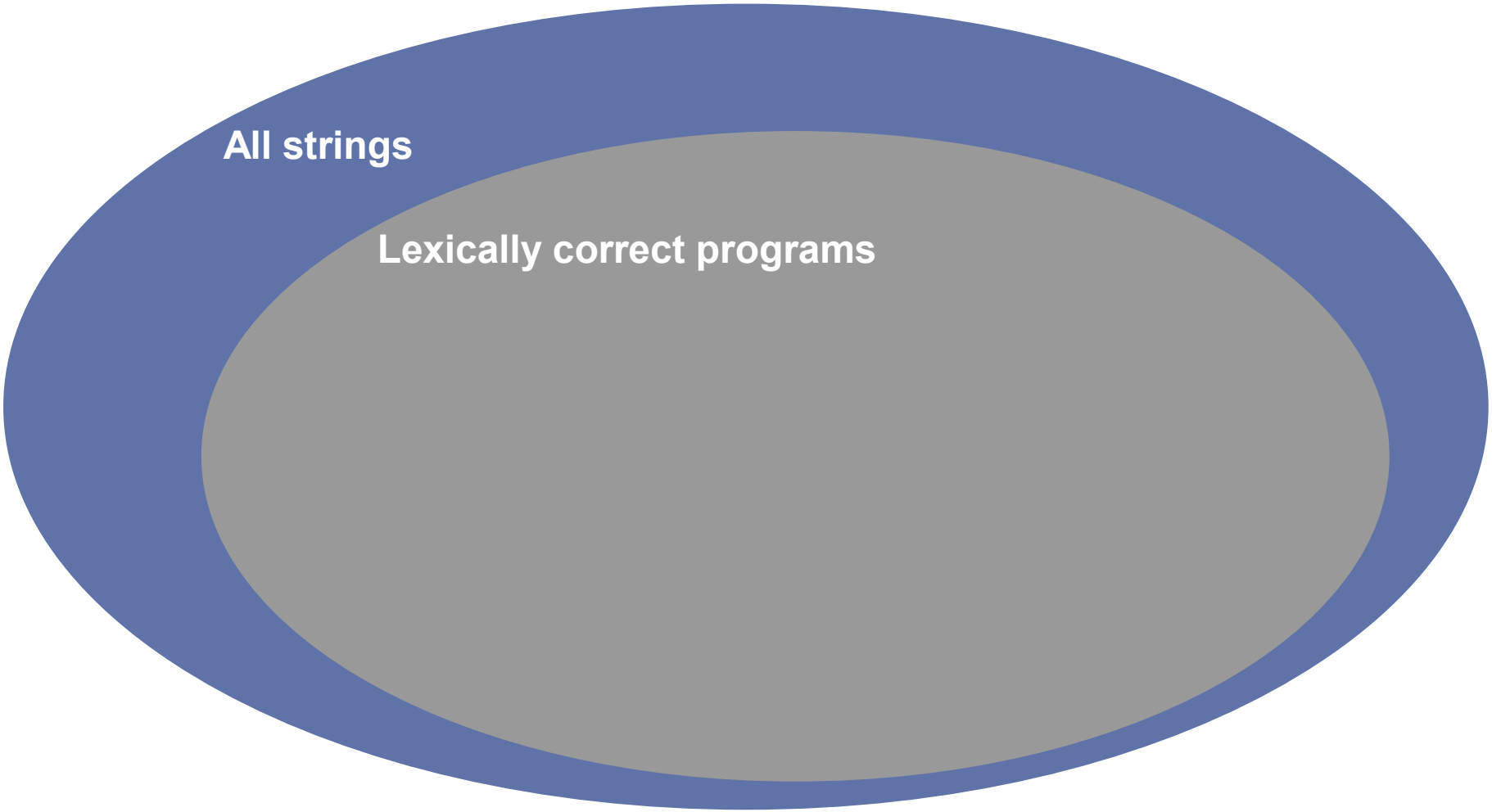
Part II

Overview of Related Work in Research

Problem: Programming Errors in Templates



Problem: Programming Errors in Templates



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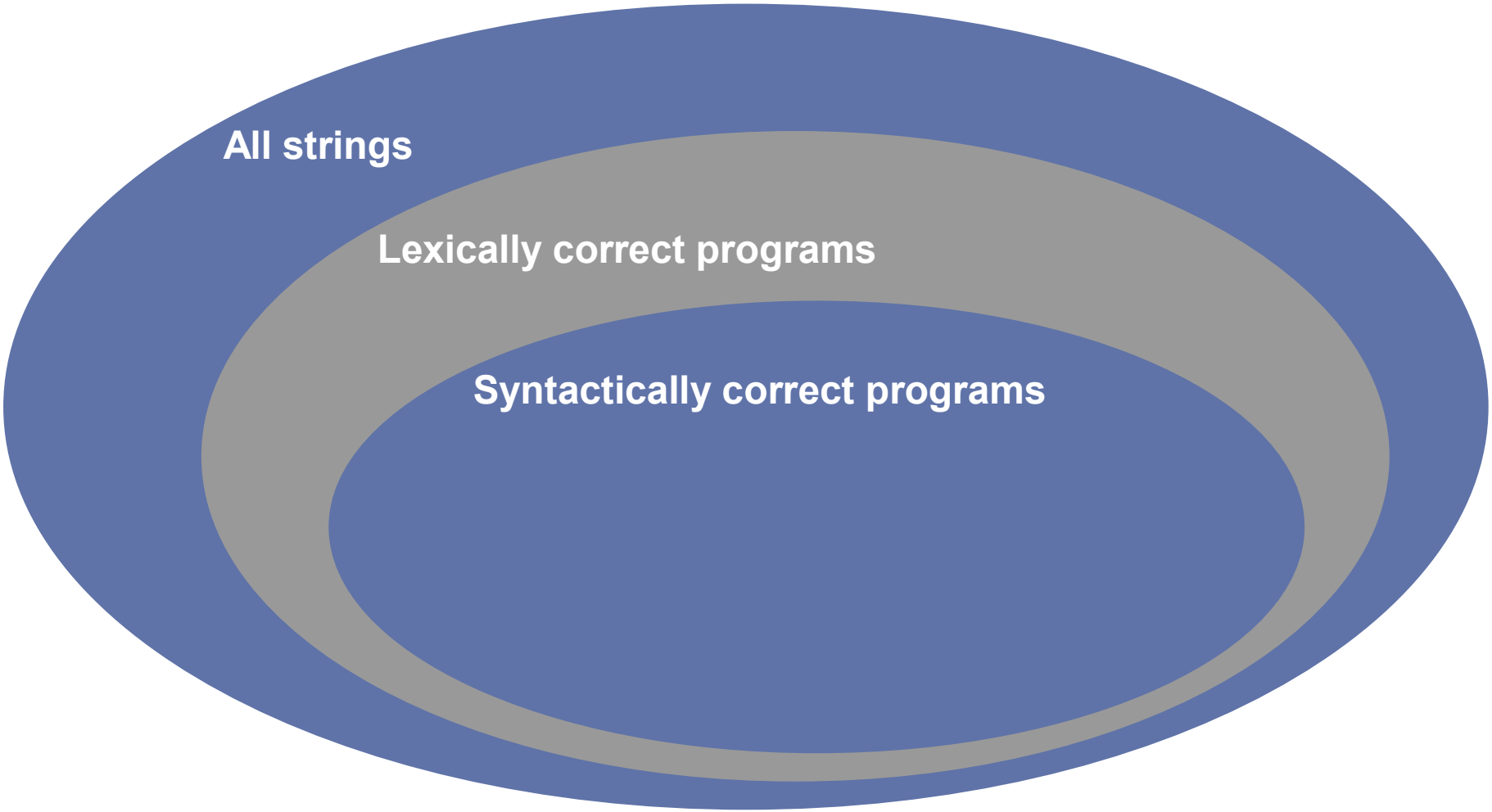

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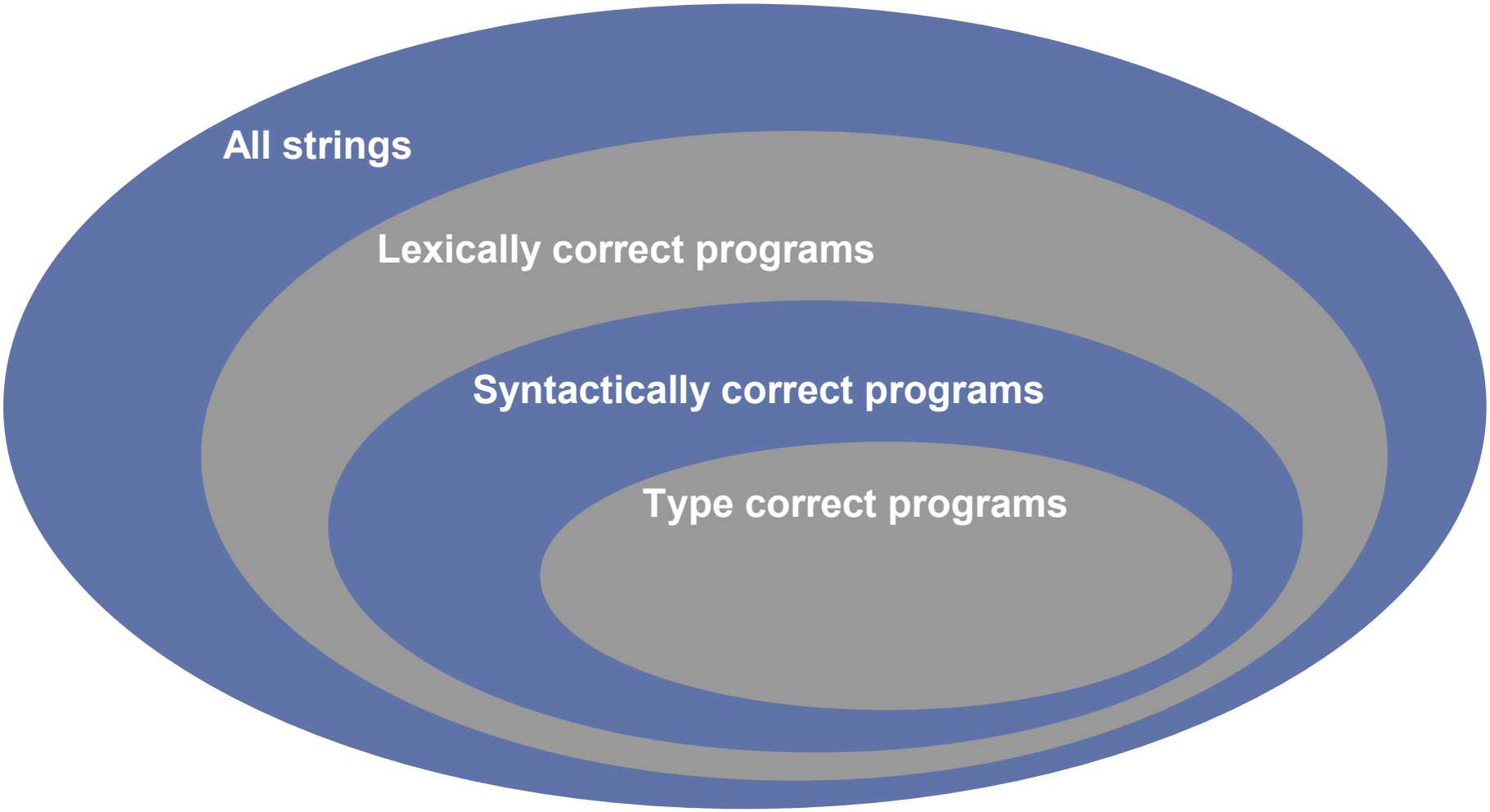
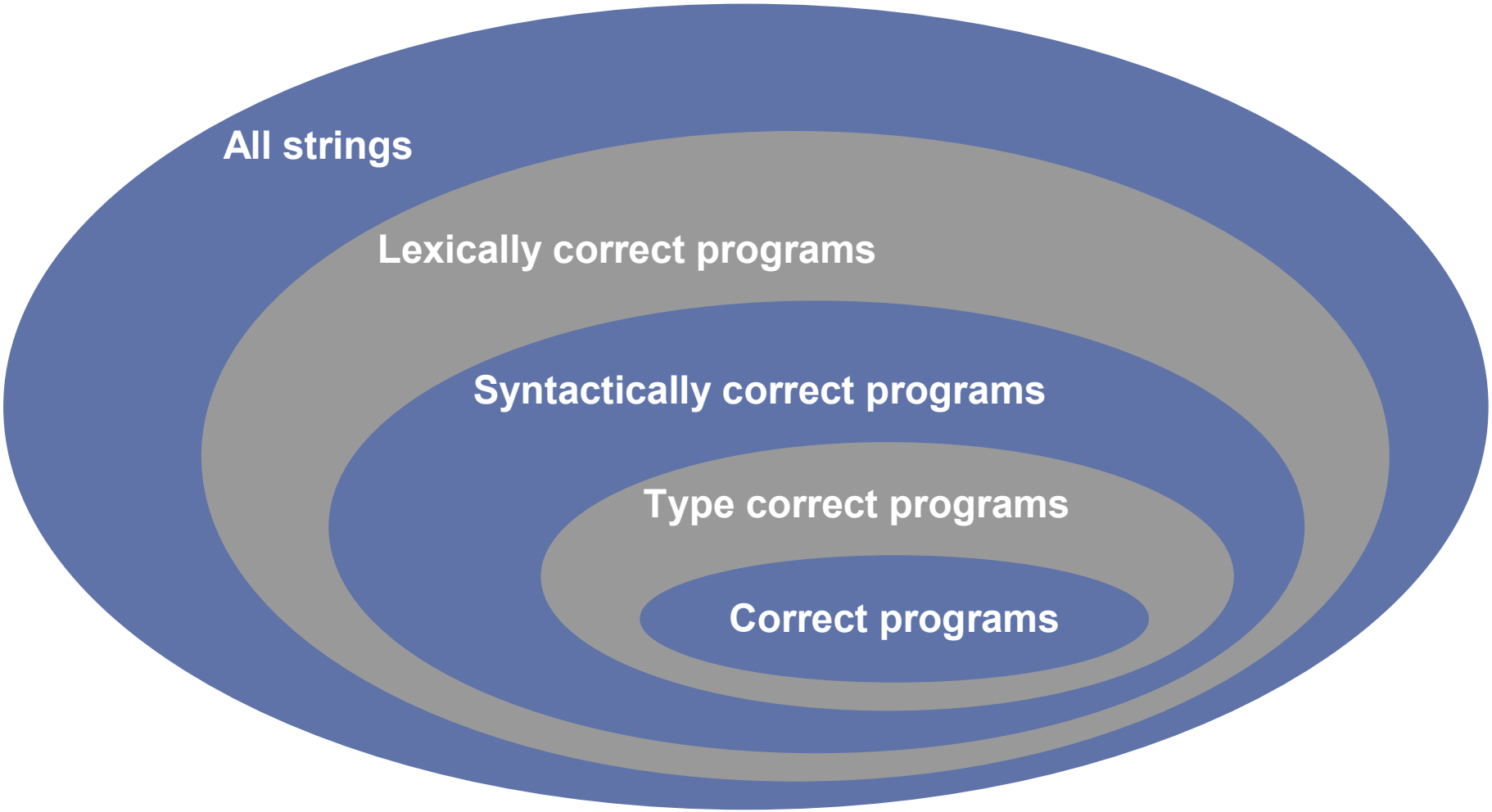


Problem: Programming Errors in Templates



Parsing of code templates

- for static guarantees
- to avoid tricky code generation errors
- issues: parsing combinations of languages

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- issues: parsing combinations of languages

Interactively parsing code templates

- for interactive coding assistance
- isssues: performance, error reporting and recovery

Parsing of code templates

- for static guarantees
- to avoid tricky code generation errors
- issues: parsing combinations of languages

Interactively parsing code templates

- for interactive coding assistance
- isssues: performance, error reporting and recovery

Semantic analysis of code templates

- for coding assistance
- for static guarantees
- issues: insufficient context information, false positives

Syntax-Safe Program Generation

- Concrete syntax
  - ASF+SDF MetaEnvironment, Stratego/XT, Repleo
  - DMS, JTS, Meta-AspectJ
- Abstract syntax

Statically Safe Program Generation

- SafeGen, MJ
- Generalized Algebraic Data Types (GADT)

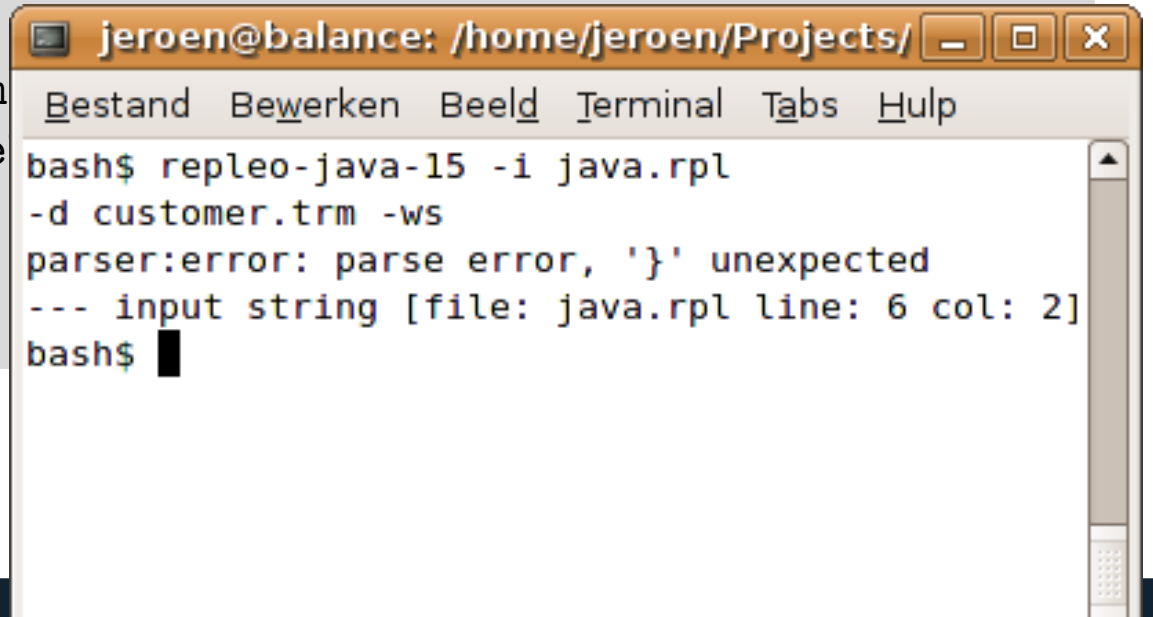
IDE Plugin Development Tools

- Eclipse IDE Meta-tooling Platform (aka Safari)
- Project Schliemann (NetBeans)

Repleo template engine

```
public class <%class/name%> {
  <%foreach class/attribute do%>
  private <%type%>  <%name%>;
  public <%type%> <%get||name%>(){
    return <%name%>
  }

  public void <%set||nam
    this.<%name%>=<%name
  }
  <%od%>
}
```



SafeGen

```
#defgen makeDelegator ( input(Class c) => !Abstract(c) )
{
  #foreach( Class c : input(c) )
  {
    public class Delegator extends #[c]
    {
      #foreach(Method m : MethodOf(m, c) & !Private(m))
      {
        #[m.Modifiers] #[m.Type] #[m] ( #[m.Formals] )
        {
          return super.#[m](#[m.ArgNames]);
        }
      }
    }
  }
}
```

Part III

Metaprogramming with Concrete Object Syntax

Metaprogramming with Concrete Object Syntax 16

- *Meta*programming:
  - Generating, transforming, or analyzing *object* programs
- Metaprograms should use concrete syntax of object language
  - Implications for metalanguage implementation
- General architecture for extending metalanguages
  - Modular syntax definition
  - Meta explosion and assimilation
  - By default available in Stratego/XT
- Running example
  - Metalanguage: Stratego
  - Object language: Tiger
  - Meta program: instrumentation of Tiger program

```
String vName = "propertyChangeListeners";
jsc.add("if (");
jsc.append(vName);
jsc.append(" == null) return;");
jsc.add("PropertyChangeEvent event = new ");
jsc.append("PropertyChangeEvent");
jsc.append("(this, fieldName, oldValue, newValue);");
jsc.add("for (int i = 0; i < ");
jsc.append(vName);
jsc.append(".size(); i++) {");
jsc.indent();
jsc.add("((PropertyChangeListener) ");
jsc.append(vName);
jsc.append(".elementAt(i)).");
jsc.append("propertyChange(event);");
jsc.unindent();
jsc.add("}");
```

```
String vName = "propertyChangeListeners"
jsc.add("if (");
jsc.append(vName);
jsc.append(" == null) return;");
jsc.add("PropertyChangeEvent event = new
jsc.append("PropertyChangeEvent");
jsc.append("(this, fieldName, oldValue,
jsc.add("for (int i = 0; i < ");
jsc.append(vName);
jsc.append(".size(); i++) {");
jsc.indent();
jsc.add("((PropertyChangeListener) ");
jsc.append(vName);
jsc.append(".elementAt(i)).");
jsc.append("propertyChange(event);");
jsc.unindent();
jsc.add("}");
```

Uses the Java syntax: the syntax of the domain.

No syntactic checks of the generated code.

Escaping to the meta language is difficult.

Code generator tries to do some pretty printing.

```
<<FILE "...." .... ".java">>
  if(<<listeners>> == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < <<listeners>>.size(); c++) {
    ((PropertyChangeListener)
        <<listeners>>.elementAt(c)).propertyChange(event);
  }
<<ENDFILE>>
```

```
<<FILE "...." .... ".java">>
  if(<<listeners>> == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < <<listeners>>.size();
    ((PropertyChangeListener)
        <<listeners>>.elementAt(c)).propertyChange(event);
  }
<<ENDFILE>>
```

Uses the Java syntax: the syntax of the domain.

No syntactic checks of the generated code.

Easy to escape to the meta language

```
VariableDeclarationFragment fragment =
    _ast.newVariableDeclarationFragment();
fragment.setName(_ast.newSimpleName("event"));
ClassInstanceCreation newi = _ast.newClassInstanceCreation();
newi.setType(_ast.newSimpleType(
    _ast.newSimpleName("PropertyChangeEvent")));
List<Expression> args = newi.arguments();
args.add(_ast.newThisExpression());
args.add(_ast.newSimpleName("fieldName"));
args.add(_ast.newSimpleName("oldValue"));
args.add(_ast.newSimpleName("newValue"));
fragment.setInitializer(newi);
VariableDeclarationStatement vardec =
    _ast.newVariableDeclarationStatement(fragment);
vardec.setType(_ast.newSimpleType(
    _ast.newSimpleName("PropertyChangeEvent")));
```

```
VariableD                                    =
    _ast.newVariableDeclarationFragment(
fragment.setName(_ast.newSimpleName("eve
ClassInstanceCreation newi = _ast.newCla
newi.setType(_ast.newSimpleType(
    _ast.newSimpleName("PropertyChangeEvent")));
List<Expression> args = newi.arguments();
args.add(_ast.newThisExpression());
args.add(_ast.newSimpleName("fieldName"));
args.add(_ast.newSimpleName("oldValue"));
args.add(_ast.newSimpleName("newValue"));
fragment.setInitializer(newi);
VariableDeclarationStatement vardec =
    _ast.newVariableDeclarationStatement(fragment);
vardec.setType(_ast.newSimpleType(
    _ast.newSimpleName("PropertyChangeEvent")));
```

Extremely verbose and unclear: 90 lines of code!

Does not correspond to the structure of the code to be generated.

Syntactically checked by meta compiler and further processing is possible.

Don't worry about the layout.

```
String x = "propertyChangeListeners";

List<Statement> stms = stmt* |[
  if(#(id)[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #(id)[x].size(); c++) {
    ((PropertyChangeListener)
      #(id)[x].elementAt(c)).propertyChange(event);
  }
]|;
```

Quotation:

|[Java (Object)]|

```
String x = "propertyChangeListeners";

List<Statement> stms = stmt* |[
  if(#(id)[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #(id)[x].size(); c++) {
    ((PropertyChangeListener)
      #(id)[x].elementAt(c)).propertyChange(event);
  }
]|;
```

Anti-Quotation:

#[Java (Meta)]

```
String x = "propertyChangeListeners";

List<Statement> stms = stmt* |[
  if(#(id)[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #(id)[x].size(); c++) {
    ((PropertyChangeListener)
      #(id)[x].elementAt(c)).propertyChange(event);
  }
]|;
```

```
String x = "propertyChangeListeners";

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    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #(id)[x].size(); c++) {
    ((PropertyChangeListener)
      #(id)[x].elementAt(c)).propertyChange(event);
  }
]|;
```

Uses the syntax of the domain: Java.

Syntax of the generated code is checked and further processing is possible.

Separate pretty-printer: don't worry about the layout.

Support for interaction between the generated code and the meta language.

Syntax of Stratego (meta language)
is **extended** with
syntax of Tiger (object language)

Recipe

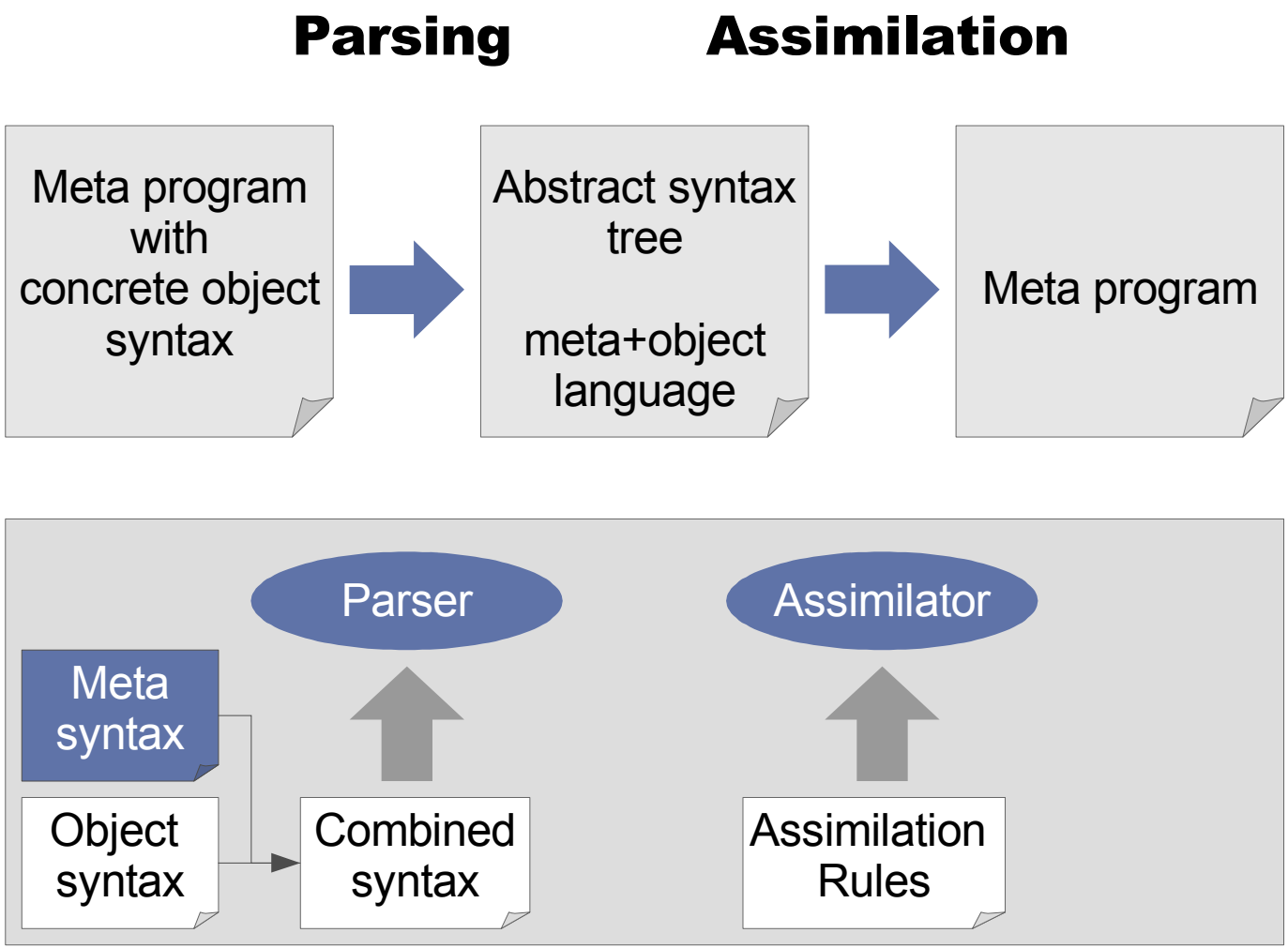
Combine syntax of meta- and object-languages

Parse meta-program with combined syntax

Feed parse tree to meta-language compiler

Ingredients

- *M*-compile: meta-language compiler
- SDF: Modular syntax definition formalism
- SGLR: Scannerless Generalized LR parser


Parsing
Assimilation
Meta program with concrete object syntax
Abstract syntax tree
meta+object language
Meta program
Parser
Assimilator
Meta syntax
Object syntax
Combined syntax
Assimilation Rules

Small example program

```
let x = 3 in x * x end
```

```
Let(
  [ VarDec("x", Int("3")) ]
. [ Mul(Var("x"), Var("x")) ]
)
```

SDF syntax definition

```
module Tiger
exports
  context-free syntax
    "let" Dec* "in" {Exp ";"}* "end" -> Exp {cons("Let")}
    Id "=" Exp  -> Dec {cons("VarDec")}
    Id          -> Exp {cons("Var")}
    Int         -> Exp {cons("Int")}
    Exp "*" Exp -> Exp {cons("Mul"), left}
    Id ":=" Exp -> Exp {cons("Assign")}
    "(" {Exp ";"}* ")" -> Exp {cons("Seq")}
  lexical syntax
    [A-Za-z]+ -> Id
    [0-9]+    -> Int
```

```
regular tree grammar
productions
    Exp -> Int(<string>)
         | Var(<string>)
         | Mul(Exp, Exp)
         | Assign(<string>, Exp)
         | Seq(Exp*)
         | Let(Dec*, Exp*)
    Dec -> VarDec(Id, Exp)
```

Stategо rewrite rule for Tiger

```
a := let b = 3 in b * b end   ->   let b = 3 in a := b * b end
```

```
Assign(x, Let(d*,e*)) -> Let(d*, [Assign(x,Seq(e*))])
```

```
|[ x := let d* in e* end ]| -> |[ let d* in x := (e*) end ]|
```

Implementation: Syntax of Meta Language (Stratego) 25

Statego rewrite rule for Tiger

```
Assign(x, Let(d*,e*)) -> Let(d*, [Assign(x,Seq(e*))])
```

SDF syntax definition for Stratego

```
module Stratego
exports
  context-free syntax
    Id                          -> Term {cons("Var")}
    "[" {Term ","}* "]"         -> Term {cons("List")}
    Id "(" {Term ","}* ")" -> Term {cons("Op")}
    Term "->" Term              -> Rule {cons("Rule")}

  lexical syntax
    [A-Za-z]+ "*"? -> Id
```

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Stategо rewrite rule for Tiger

```
Assign(x, Let(d*,e*)) -> Let(d*, [Assign(x,Seq(e*))])
```

Stategо rewrite rule for Tiger, after parsing

```
Rule(
  Op("Assign",[
    Var("x"),
    Op("Let",[Var("d*"),Var("e*")])]
  )
, Op("Let",[
    Var("d*")
  , List([
      Op("Assign",[Var("x"), Op("Seq",[Var("e*")])])
    ])
  ])
)
```

```
module Stratego+Tiger
imports TigerMix[Tiger]
imports StrategoMix[Stratego]
exports
  context-free syntax
    "|[" Dec[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}
    "|[" Exp[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}

    "${" Term[[Stratego]] "}" -> Exp[[Tiger]]         {cons("FromTerm")}
    "${" Term[[Stratego]] "}" -> {Exp[[Tiger]] ";"}+ {cons("FromTerm")}

  variables
    [xyzfgh][0-9]* -> Id[[Tiger]]
    [e][0-9]*      -> Exp[[Tiger]]
    "e"[0-9]* "*"  -> {Exp[[Tiger]] ";"}+
```

Qualify nonterminals to unintended avoid clashes

```
module Stratego+Tiger
imports TigerMix[Tiger]
imports StrategoMix[Stratego]
exports
  context-free syntax
    "|[" Dec[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}
    "|[" Exp[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}

    "${" Term[[Stratego]] "}" -> Exp[[Tiger]]         {cons("FromTerm")}
    "${" Term[[Stratego]] "}" -> {Exp[[Tiger]] ";"}+ {cons("FromTerm")}

  variables
    [xyzfgh][0-9]* -> Id[[Tiger]]
    [e][0-9]*      -> Exp[[Tiger]]
    "e"[0-9]* "*"  -> {Exp[[Tiger]] ";"}+
```

```
module Stratego+Tiger
imports TigerMix[Tiger]
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exports
  context-free syntax
    "|[" Dec[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}
    "|[" Exp[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}

    "${" Term[[Stratego]] "}" -> Exp[[Tiger]]         {cons("FromTerm")}
    "${" Term[[Stratego]] "}" -> {Exp[[Tiger]] ";"}+ {cons("FromTerm")}

  variables
    [xyzfgh][0-9]* -> Id[[Tiger]]
    [e][0-9]*      -> Exp[[Tiger]]
    "e"[0-9]* "*"  -> {Exp[[Tiger]] ";"}+
```

Quotation: inject object expressions in meta expressions

Anti-quotation: inject meta expressions into object expressions

```
module Stratego+Tiger
imports TigerMix[Tiger]
imports StrategoMix[Stratego]
exports
  context-free syntax
    "|[" Dec[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}
    "|[" Exp[[Tiger]]    "]|" -> Term[[Stratego]] {cons("ToTerm")}

    "${" Term[[Stratego]] "}" -> Exp[[Tiger]]         {cons("FromTerm")}
    "${" Term[[Stratego]] "}" -> {Exp[[Tiger]] ";"}+ {cons("FromTerm")}

  variables
    [xyzfgh][0-9]* -> Id[[Tiger]]
    [e][0-9]*      -> Exp[[Tiger]]
    "e"[0-9]* "*"  -> {Exp[[Tiger]] ";"}+
```

Declare meta-variables for object sorts

Meta Variables

```
TraceProcedure :
  |[ function f(x*) = e ]|
    ->
  |[ function f(x*) = (enterfun(s); e; exitfun(s)) ]|
  where
    s := f
```

meta-variables

object identifiers

Distinguish meta-variables by anti-quotation

```
TraceProcedure :
  |[ function ${f}(${xs}) = ${e} ]| ->
  |[ function ${f}(${xs}) = (enter(${s}); ${e}; exit(${s})) ]|
  where
    s := f
```

Splice code generated by meta-computation into object code

```
TraceProcedure :
  |[ function ${f}(${xs}) = ${e} ]| ->
  |[ function ${f}(${xs}) =
       (print(${f + " entry"});
        ${e};
        print(${f + " exit"});
       ) ]|
```

```
|[ x := let d* in ${e*} end ]| -> |[ let d* in x := (${e*}) end ]|
```

```
Rule(ToTerm(Assign(meta-var("x"),
                   Let(meta-var("d*"),FromTerm(Var("e*"))))),
     ToTerm(Let(meta-var("d*"),
                [Assign(meta-var("x"),
                        Seq(FromTerm(Var("e*"))))])))
```

```
Rule(Op("Assign",[Var("x"),
                  Op("Let",[Var("d*"),Var("e*")])]),
     Op("Let",[Var("d*"),
               List([Op("Assign",[Var("x"),
                                  Op("Seq",[Var("e*")])])])]
     ]))
```

```
Assign(x, Let(d*,e*)) -> Let(d*, [Assign(x,Seq(e*))])
```

Extend meta language with object language syntax

- combine arbitrary meta and object language
- meta-language does not need to be designed for this purpose
- limitation: language should have context-free syntax

Modular syntax definition is essential

- reuse existing syntax definitions – no changed needed

Scannerless Generalized LR parsing

- Only context-free grammars closed under composition
- No compositionality: regular grammars, LR, LL

Part IV

Ambiguities

```
String x = "propertyChangeListeners";

List<Statement> stms = |[
  if(#[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #[x].size(); c++) {
    ((PropertyChangeListener)
      #[x].elementAt(c)).propertyChange(event);
  }
]|;
```

```
String x = "propertyChangeListeners";

List<Statement> stms = stmt* |[
  if(#(id)[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #(id)[x].size(); c++) {
    ((PropertyChangeListener)
      #(id)[x].elementAt(c)).propertyChange(event);
  }
]|;
```

Ambiguities in Concrete Object Syntax


```
String x = "propertyChangeListeners";

List<Statement> stms = stmt* |[
  if(#(id)[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #(id)[x].size(); c++) {
    ((PropertyChangeListener)
      #(id)[x].elementAt(c)).propertyChange(event);
  }
]|;
```

Syntactic clutter of explicit typing.

Intimate knowledge of syntactic structure required.

Limited number of quotations and anti-quotations are supported.

```
String x = "propertyChangeListeners";

List<Statement> stms = |[
  if(#[x] == null)
    return;

  PropertyChangeEvent event =
    new PropertyChangeEvent(this, fieldName, oldValue, newValue);

  for(int c=0; c < #[x].size(); c++) {
    ((PropertyChangeListener)
      #[x].elementAt(c)).propertyChange(event);
  }
]|;
```

Ambiguities: Quotations

- Single quotation symbol
- Multiple object non-terminals

Example:

- ⟦ `class Foo {}` ⟧

TypeDeclaration

```
package bar;

class Foo {}
```

CompilationUnit

```
class Foo {}
```

Statement

```
class Bar {
  void fred() {
    class Foo {}
  }
}
```

- Single anti-quotation symbol
- Multiple object non-terminals
- Syntactical category of meta code unknown

Examples:

- `|[ return #[x]; ]|`
  - x can be `Expression`
  - x can be `SimpleName`
  - x can be `String` (identifier)
- `|[ foo(#[xs]) ]|`
  - xs can be `Expression`
  - xs can be `List<Expression>`
  - ...

```
⟦
  class Foo() {
    #[type] getBar() {
      ...
    }
  }
⟧
```

- *type* can be `Type, Id`
- *type* can be `BodyDeclaration`
- *type* can be `List<BodyDeclaration>`
- *type* can be `Modifier`
- *type* can be `List<Modifier>`

Ambiguities: Current Solutions

Use Different (Anti-)Quotation Symbols

- JTS, DMS, Stratego, Template Haskell, Jumbo
- Redundant
- Support for (anti-)quotations irregular

Type-based Disambiguation by Context-Sensitive Parsing

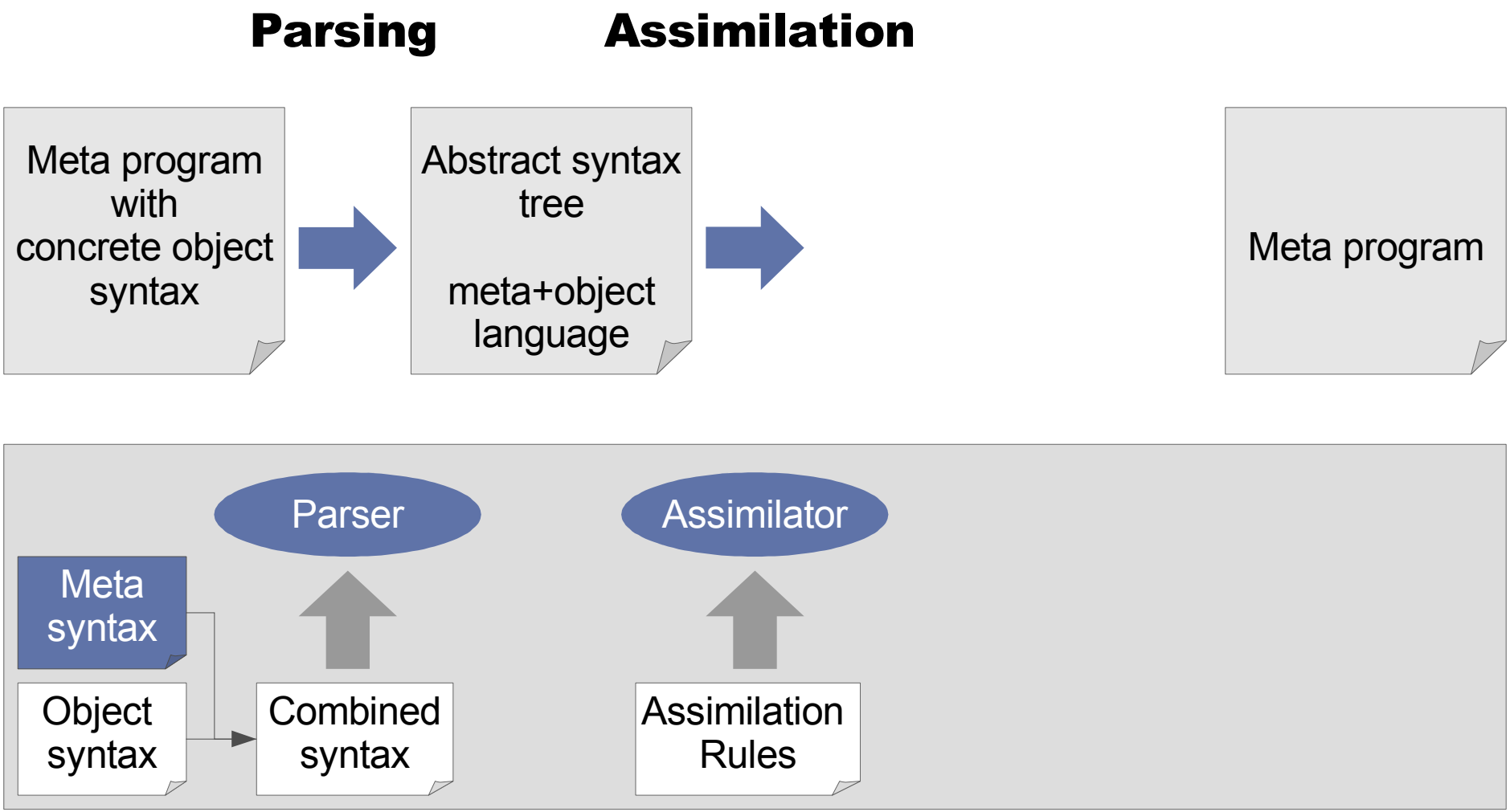
- Meta-AspectJ, Aasa (ML)
- Excellent usability
- Parsing and type-checking tangled
- Object language specific, no multiple object languages

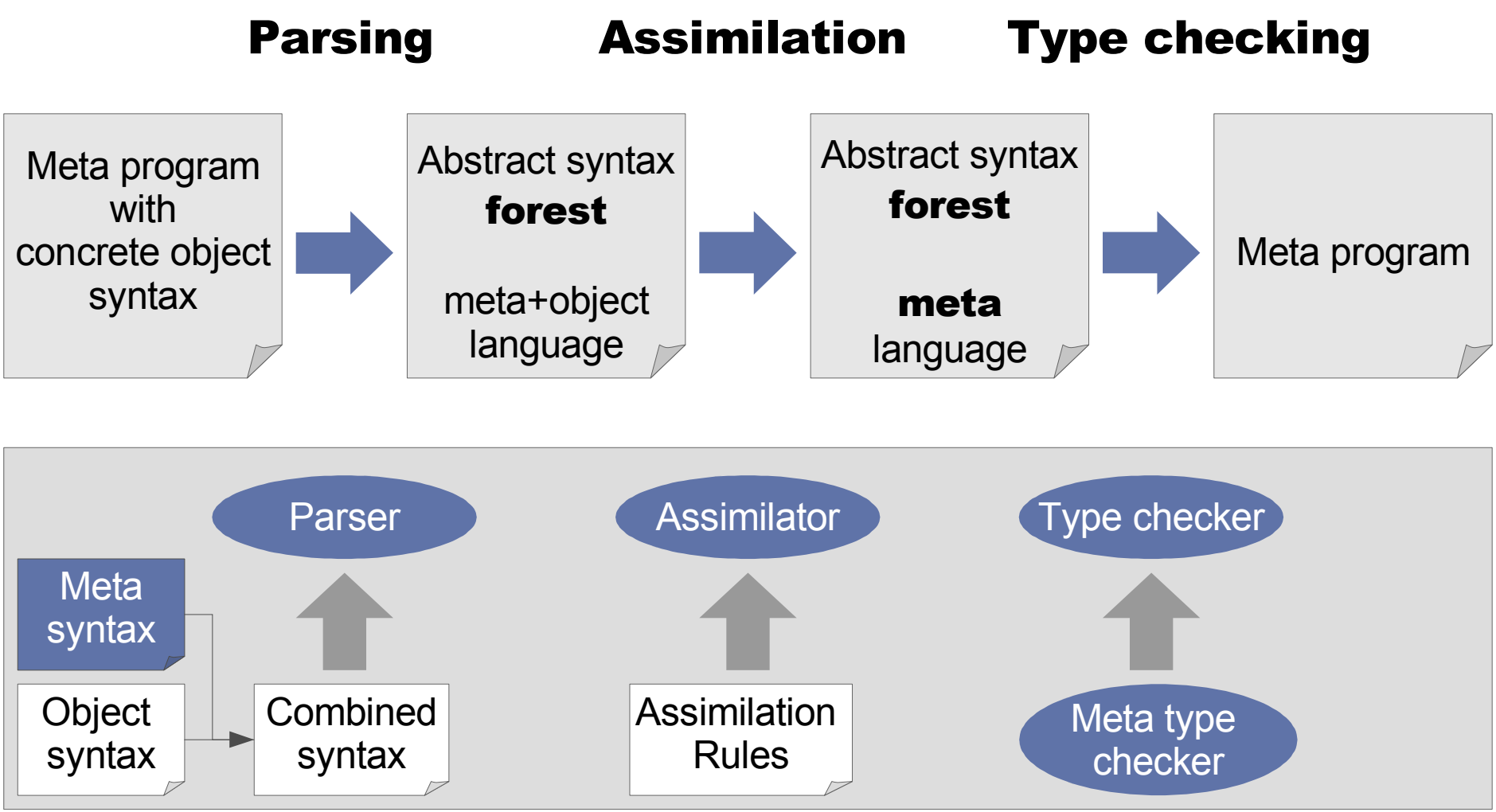
We need a *general* architecture for type-based disambiguation.

- **Introduce type-based disambiguation**
  - Single quotation and anti-quotation symbol
- **Preserve modular syntax definition**
  - Fully automatic parser generation
- **Preserve modular assimilation**
  - Embedding multiple object languages

Define only syntactical embedding and assimilation rules

Type-based Disambiguation




Parsing
Assimilation
Type checking
Meta program with concrete object syntax
Abstract syntax forest
meta+object language
Abstract syntax forest
meta language
Meta program
Parser
Assimilator
Type checker
Meta syntax
Object syntax
Combined syntax
Assimilation Rules
Meta type checker

Example: Syntax Definition and Parsing


```
context-free syntax
  "|[" CompilationUnit "]|" -> MetaExpr {cons("ToMetaExpr")}
  "|[" TypeDec         "]|" -> MetaExpr {cons("ToMetaExpr")}
  "|[" ClassBodyDec*   "]|" -> MetaExpr {cons("ToMetaExpr")}

context-free syntax
  "#[" MetaExpr "]"-> ID   {cons("FromMetaExpr")}
  "#[" MetaExpr "]"-> Expr {cons("FromMetaExpr")}
```

```
|[ package bar; class Foo {} ]|
```

```
ToMetaExpr(
  CompilationUnit(
    Some(PackageDec([], PackageName([Id("bar")]))), []
  , [ ClassDec(
        ClassDecHead([], Id("Foo"), None, None, None)
      , ClassBody([])
      )
    ]))
```

Example: Syntax Definition and Parsing


```
dec = ⟦ class Foo {} ⟧
```

```
Assign(ExprName(Id("dec")),
  amb([
    ToMetaExpr(  CompilationUnit(... ClassDec(... Id("Foo")...) ...) )



  , ToMetaExpr(  ClassDec(... Id("Foo") ...)   )


  , ToMetaExpr([ ClassDec(... Id("Foo") ...) ] )


  , ToMetaExpr(  ClassDecStm(ClassDec(... Id("Foo") ...)   ))

  , ToMetaExpr([ ClassDecStm(ClassDec(... Id("Foo") ...)   )])

  ]))
```

Example: Syntax Definition and Parsing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dec = ⟦ class Foo {} ⟧
```

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Assign(ExprName(Id("dec")),
  amb([
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  , ToMetaExpr(  ClassDec(... Id("Foo") ...)   )
  , ToMetaExpr([ ClassDec(... Id("Foo") ...) ] )
  , ToMetaExpr(  ClassDecStm(ClassDec(... Id("Foo") ...)   ))
  , ToMetaExpr([ ClassDecStm(ClassDec(... Id("Foo") ...)   )])
  ]))
```

Ambiguities are preserved by the GLR parser

All possible parses, represented by ambiguity nodes

Example: Assimilation


```
dec = ⟦ class Foo {} ⟧
```

```
Assign(ExprName(Id("dec")),
  amb([
    {| CompilationUnit cu_0 = _ast.newCompilationUnit(); ...
       TypeDeclaration class_0 = _ast.newTypeDeclaration();
       class_0.setName(_ast.newSimpleName("Foo"));  ... | cu_0 |}

  , ToMetaExpr(  ClassDec(... Id("Foo") ...)   )


  , ToMetaExpr([ ClassDec(... Id("Foo") ...) ] )


  , ToMetaExpr(  ClassDecStm(ClassDec(... Id("Foo") ...)   ))

  , ToMetaExpr([ ClassDecStm(ClassDec(... Id("Foo") ...)   )])

  ]))
```

Example: Assimilation


```
dec = ‖[ class Foo {} ]‖
```

```
Assign(ExprName(Id("dec")),
  amb([
    {| CompilationUnit cu_0 = _ast.newCompilationUnit(); ...
       TypeDeclaration class_0 = _ast.newTypeDeclaration();
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  , {| TypeDeclaration class_1 = _ast.newTypeDeclaration();
       class_1.setName(_ast.newSimpleName("Foo"));  ... | class_1 |}

  , ToMetaExpr([ ClassDec(... Id("Foo") ...) ] )


  , ToMetaExpr(  ClassDecStm(ClassDec(... Id("Foo") ...)   ))

  , ToMetaExpr([ ClassDecStm(ClassDec(... Id("Foo") ...)   )])

  ]))
```

Example: Assimilation


```
dec = ⟦ class Foo {} ⟧
```

```
Assign(ExprName(Id("dec")),
  amb([
    {| CompilationUnit cu_0 = _ast.newCompilationUnit(); ...
       TypeDeclaration class_0 = _ast.newTypeDeclaration();
       class_0.setName(_ast.newSimpleName("Foo"));  ... | cu_0 |}

  , {| TypeDeclaration class_1 = _ast.newTypeDeclaration();
       class_1.setName(_ast.newSimpleName("Foo"));  ... | class_1 |}

  , {| List<BodyDeclaration> decs_0 = new ArrayList<BodyDeclaration>();
       decs_0.add( ... );  ... | decs_0 |}

  , ToMetaExpr(  ClassDecStm(ClassDec(... Id("Foo") ...)   ))

  , ToMetaExpr([ ClassDecStm(ClassDec(... Id("Foo") ...)   )])

  ]))
```

Example: Assimilation


```
dec = ⟦ class Foo {} ⟧
```

```
Assign(ExprName(Id("dec")),
  amb([
    {| CompilationUnit cu_0 = _ast.newCompilationUnit(); ...
       TypeDeclaration class_0 = _ast.newTypeDeclaration();
       class_0.setName(_ast.newSimpleName("Foo"));  ... | cu_0 |}

  , {| TypeDeclaration class_1 = _ast.newTypeDeclaration();
       class_1.setName(_ast.newSimpleName("Foo"));  ... | class_1 |}

  , {| List<BodyDeclaration> decs_0 = new ArrayList<BodyDeclaration>();
       decs_0.add( ... );  ... | decs_0 |}

  , _ast.newTypeDeclaratonStatement(...);

  , ToMetaExpr([ ClassDecStm(ClassDec(... Id("Foo") ...)   )])

  ]))
```

Example: Assimilation


```
dec = ⟦ class Foo {} ⟧
```

```
Assign(ExprName(Id("dec")),
  amb([
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       class_0.setName(_ast.newSimpleName("Foo"));  ... | cu_0 |}

  , {| TypeDeclaration class_1 = _ast.newTypeDeclaration();
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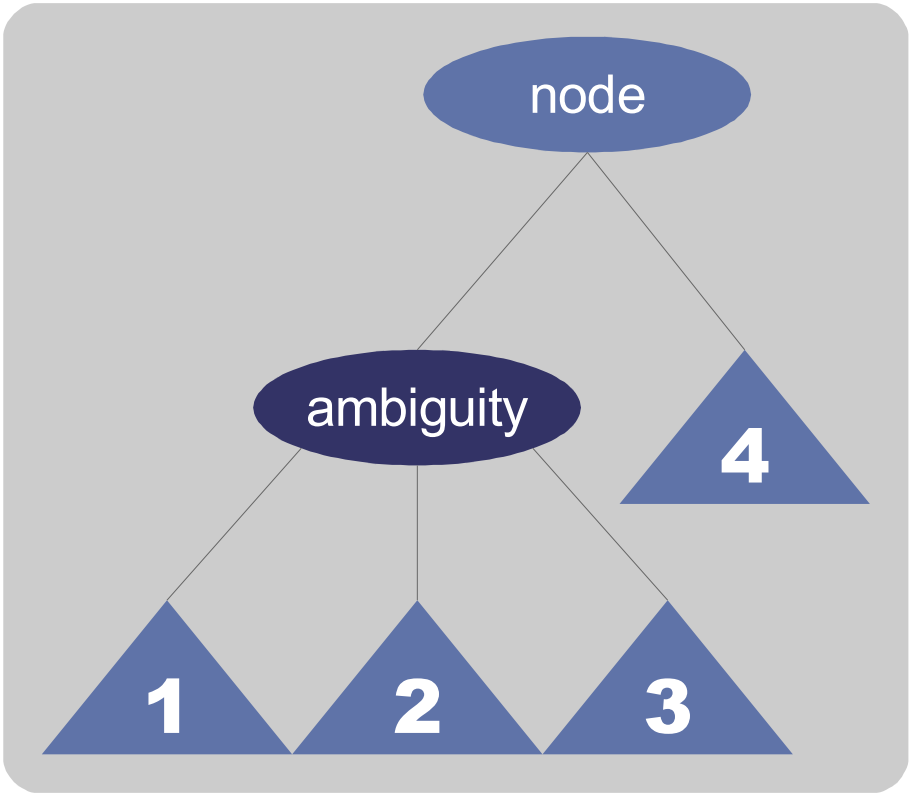
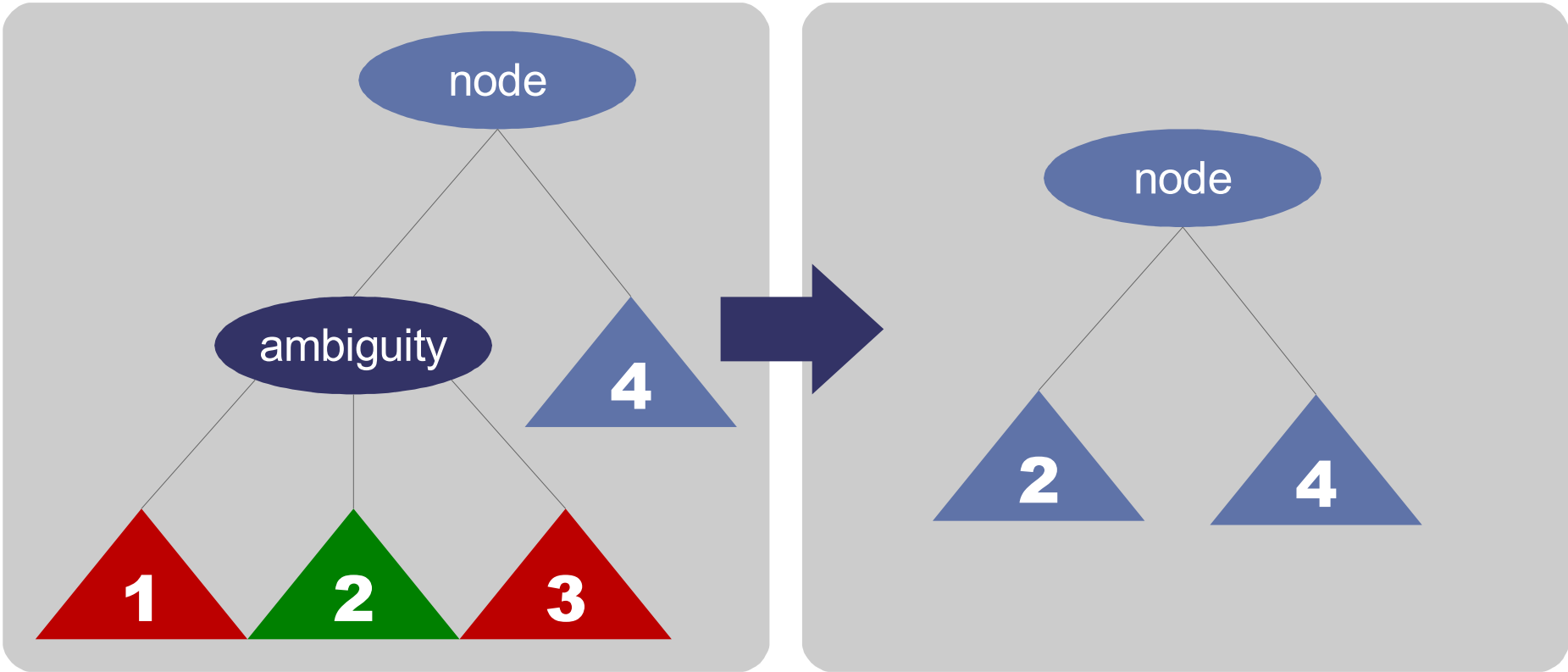
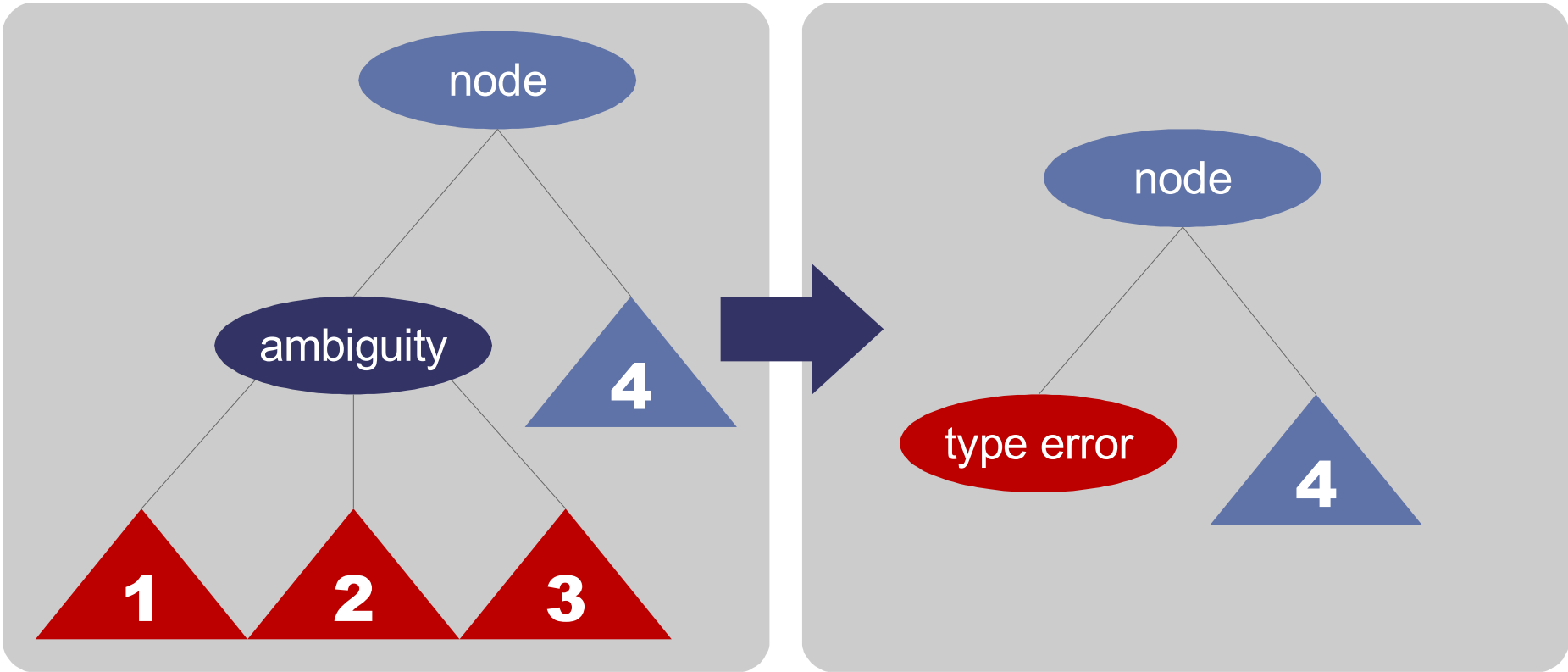
  , {| List<BodyDeclaration> decs_0 = new ArrayList<BodyDeclaration>();
       decs_0.add( ... );  ... | decs_0 |}

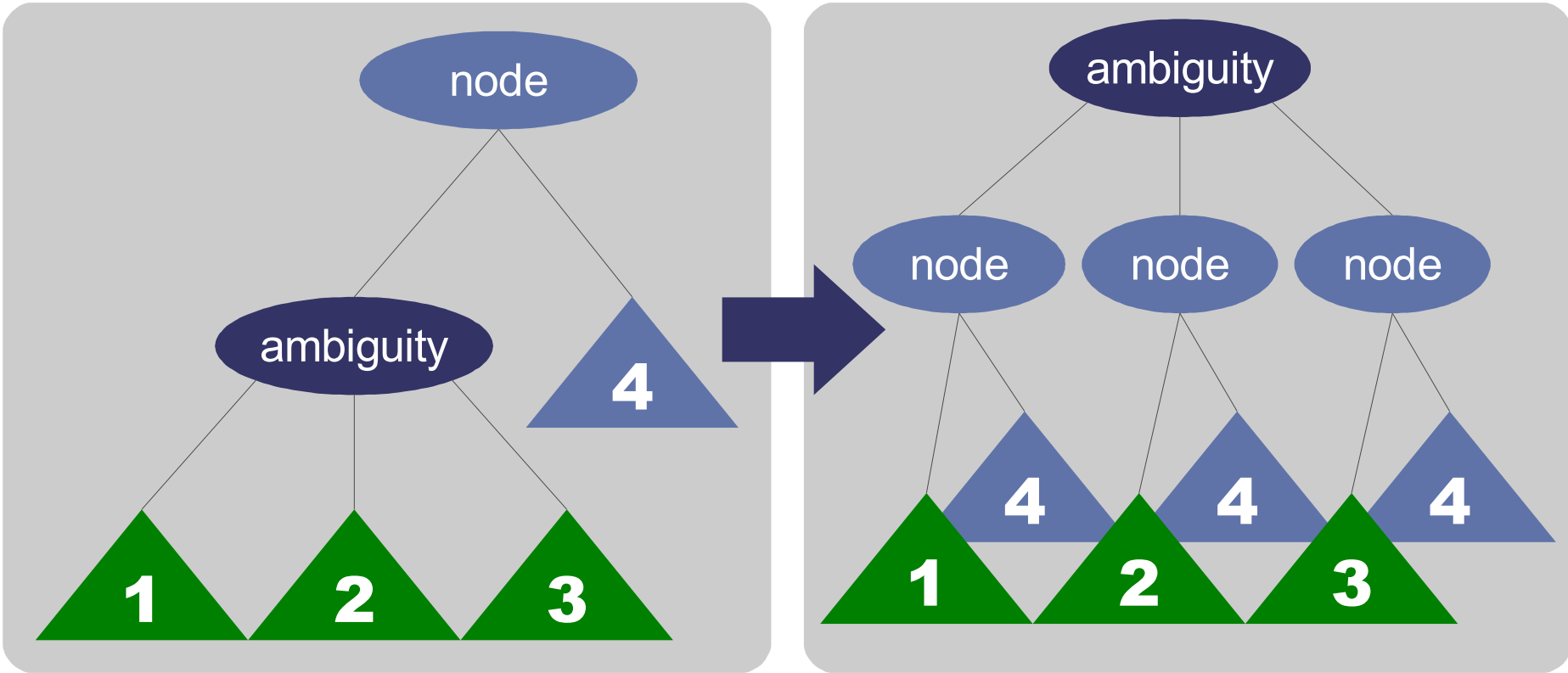
  , _ast.newTypeDeclaratonStatement(...);

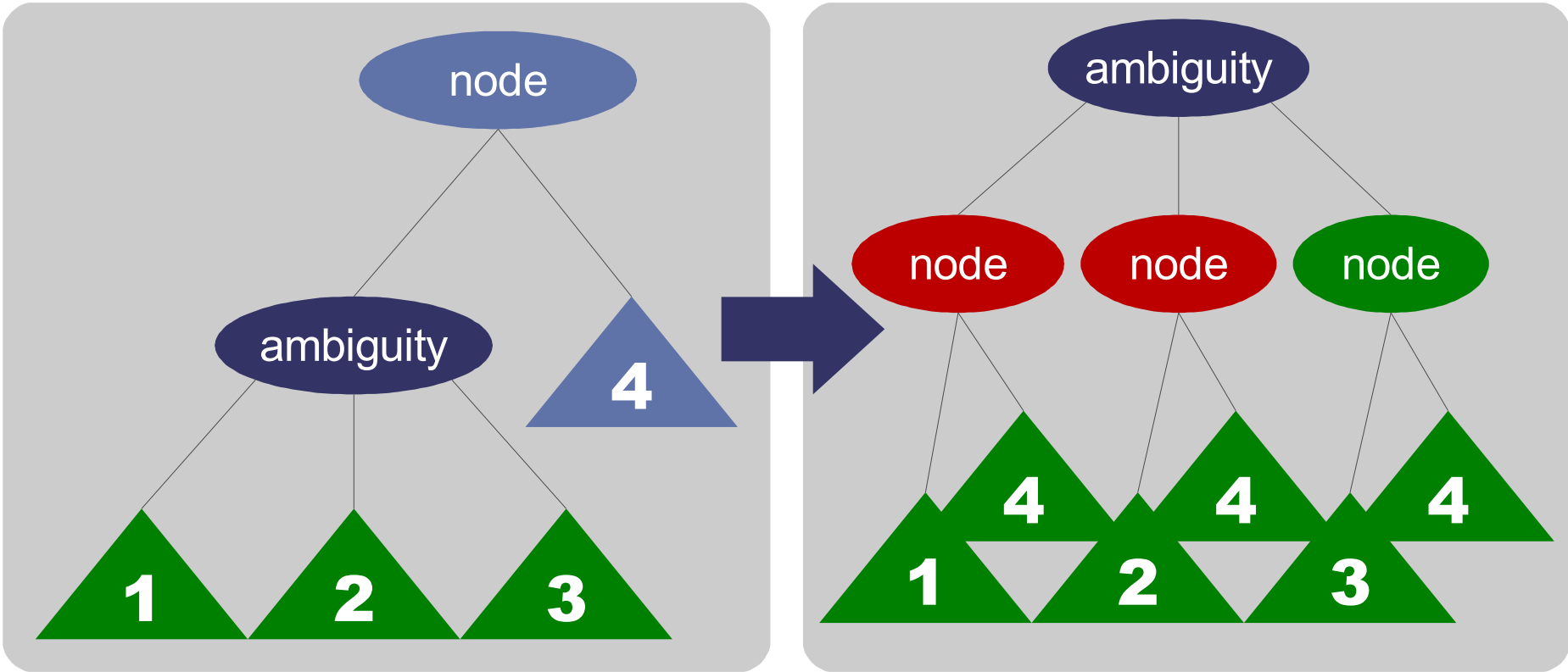
  , {| List<Statement> stms_0 = new ArrayList<Statement>();
       stms_0.add(_ast.newTypeDeclaratonStatement(...)); ... | stms_0 |}
  ]))
```


node
ambiguity
4
1
2
3


node
ambiguity
4
1
2
3
node
2
4


node
ambiguity
4
1
2
3
node
type error
4


node
ambiguity
4
1
2
3
ambiguity
node
node
node
4
4
4
1
2
3


node
ambiguity
4
1
2
3
ambiguity
node
node
node
4
4
4
1
2
3

Example: Type-based Disambiguation


```
dec = ⟦ class Foo {} ⟧
```

```
Assign(ExprName(Id("dec")), amb([
    CompilationUnit
  , TypeDeclaration
  , List<BodyDeclaration>
  , TypeDeclaratonStatement
  , List<Statement>
]))
```

```
amb([
  Assign(ExprName(Id("dec")), CompilationUnit)
, Assign(ExprName(Id("dec")), TypeDeclaration)
, Assign(ExprName(Id("dec")), List<BodyDeclaration>)
, Assign(ExprName(Id("dec")), TypeDeclaratonStatement)
, Assign(ExprName(Id("dec")), List<Statement>)
])
```

Example: Type-based Disambiguation


```
dec = ‖[ class Foo {} ]‖
```

```
Assign(ExprName(Id("dec")), amb([
    CompilationUnit
  , TypeDeclaration
  , List<BodyDeclaration>
  , TypeDeclaratonStatement
  , List<Statement>
]))
```

```
amb([
  Assign(ExprName(Id("dec")), CompilationUnit)
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, Assign(ExprName(Id("dec")), List<BodyDeclaration>)
, Assign(ExprName(Id("dec")), TypeDeclaratonStatement)
, Assign(ExprName(Id("dec")), List<Statement>)
])
```

Example: Anti-Quotation


```
Expression expr = ...
Statement stmt = |[ return #[expr]; ]|
```

```
Return(
  Some(
    amb([
      FromMetaExpr(ExprName(Id("expr")))
    , ExprName([ FromMetaExpr(ExprName(Id("expr"))) ])
    , ExprName([ Id(FromMetaExpr(ExprName(Id("expr")))) ])
    ])))
```

```
Expression expr = ...
Statement stmt = {|
  ReturnStatement return_1 = _ast.newReturnStatement();
  return_1.setExpression(amb([expr, _ast.newSimpleName(expr)]));
  | return_1 |};
```

Example: Anti-Quotation


```
Expression expr = ...
Statement stmt = |[ return #[expr]; ]|
```

```
Return(
  Some(
    amb([
      FromMetaExpr(ExprName(Id("expr")))
    , ExprName([ FromMetaExpr(ExprName(Id("expr"))) ])
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    ])))
```

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Expression expr = ...
Statement stmt = {|
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  | return_1 |};
```

Example: Anti-Quotation


```
Expression expr = ...
Statement stmt = |[ return #[expr]; ]|
```

```
Return(
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    ])))
```

```
Expression expr = ...
Statement stmt = {|
  ReturnStatement return_1 = _ast.newReturnStatement();
  return_1.setExpression(expr);
  | return_1 |};
```

- Code generators do not need to know the exact type of every AST node.
- no need to determine the exact category statically, or even dynamically: it's ok for a value to belong to multiple syntactical categories.
- Therefore, we associate a set of syntactic categories to every node and preserve ambiguities.
- Fragments that do not are programming errors.

Parse first, solve ambiguities later.

Enablers

- Generalized-LR parsing produces all alternatives
- Separate type checking on ambiguous program

Results

- Modular syntactical embedding and assimilation
- Object language independent disambiguation
- Extensible type checker
- General architecture extended with type-based disambiguation

Part V

The Parsing Techniques

Conventional parsing techniques do not support this.

- LR/LL parsers do not compose
- Scanners (regular grammars) do not compose

Restricted classes of context-free grammars not closed under composition.

What is the problem?

```
public aspect Caching {
  private Map<Integer, Integer> cache =
      new HashMap<Integer, Integer>();

  pointcut cached(int value):
      execution(* Fib.calc(int)) && args(value);

  int around(int value): cached(value) {
    if(cache.containsKey(value)) {
      return cache.get(value);
    }
    else {
      int result = proceed(value);
      cache.put(value, result);
      return result;
    }
  }
}
```

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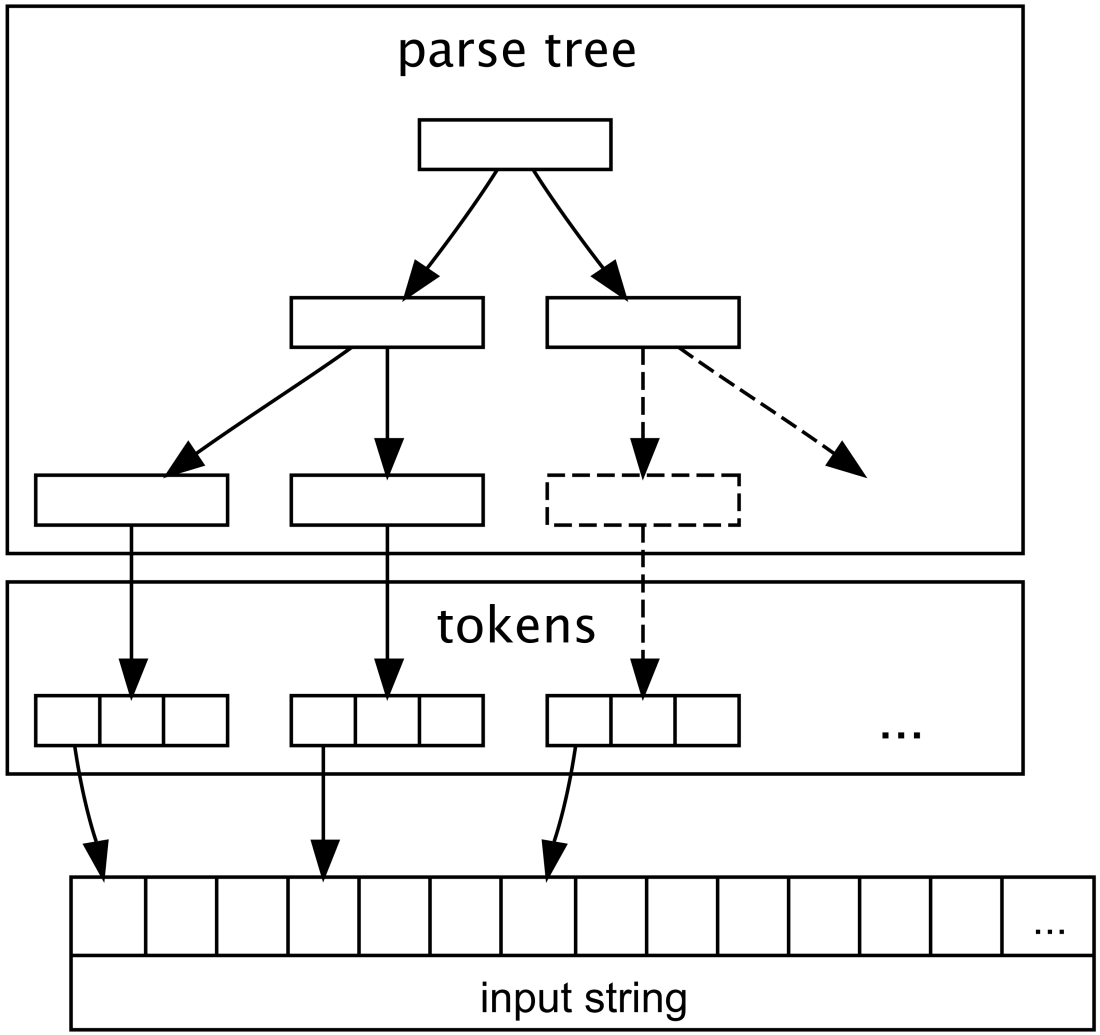
    if(cache.containsKey(value)) {
      return cache.get(value);
    }
    else {
      int result = proceed(value);
      cache.put(value, result);
      return result;
    }
  }
}
```


parse tree
tokens
...
...
input string

Lexical syntax is context-sensitive

- Java context:

```
int x = get* y + z;
```

- Pointcut context:

```
pointcut g(): call(* get*(..));
pointcut c(): call(Foo+.new());
```

Keywords cannot be reserved globally

- `get(* Foo.*)`, `target(e)`, `args(event)` ...

Lexical syntax is context-sensitive

- Java context:

```
int x = get* y + z;
```

- Pointcut context:

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```
pointcut g(): call(* get*(..));
```

```
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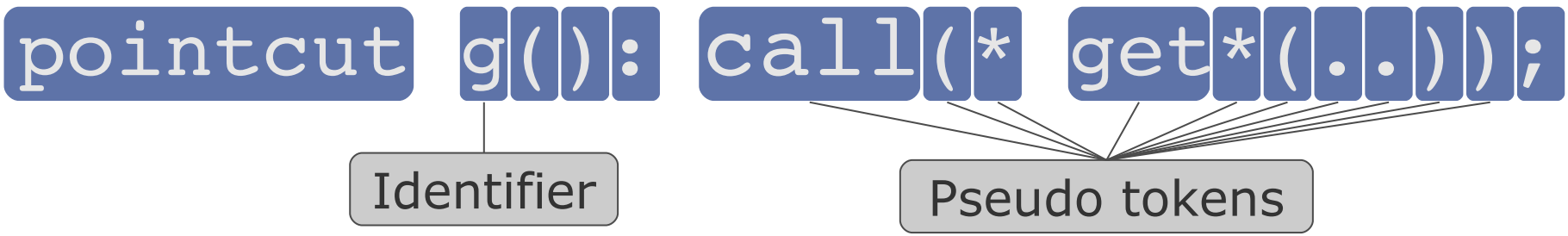
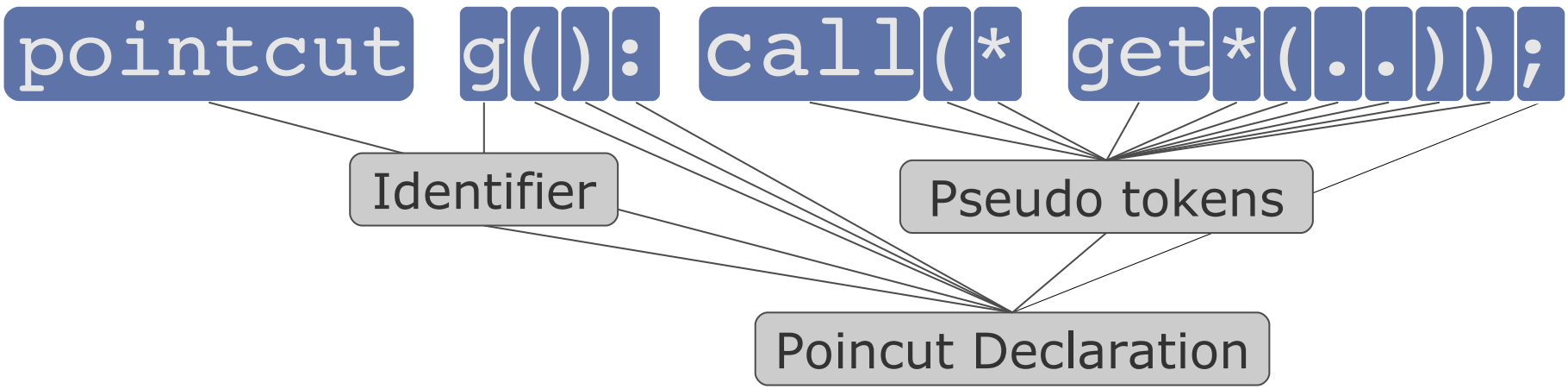
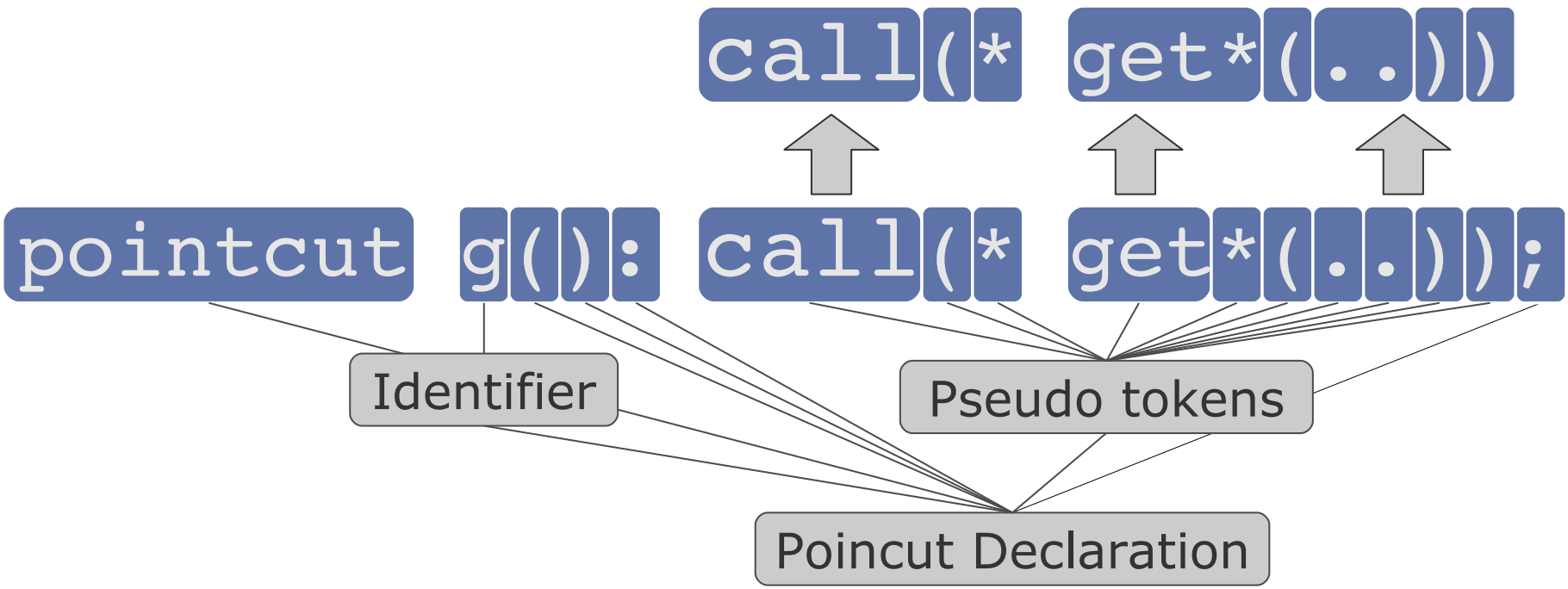
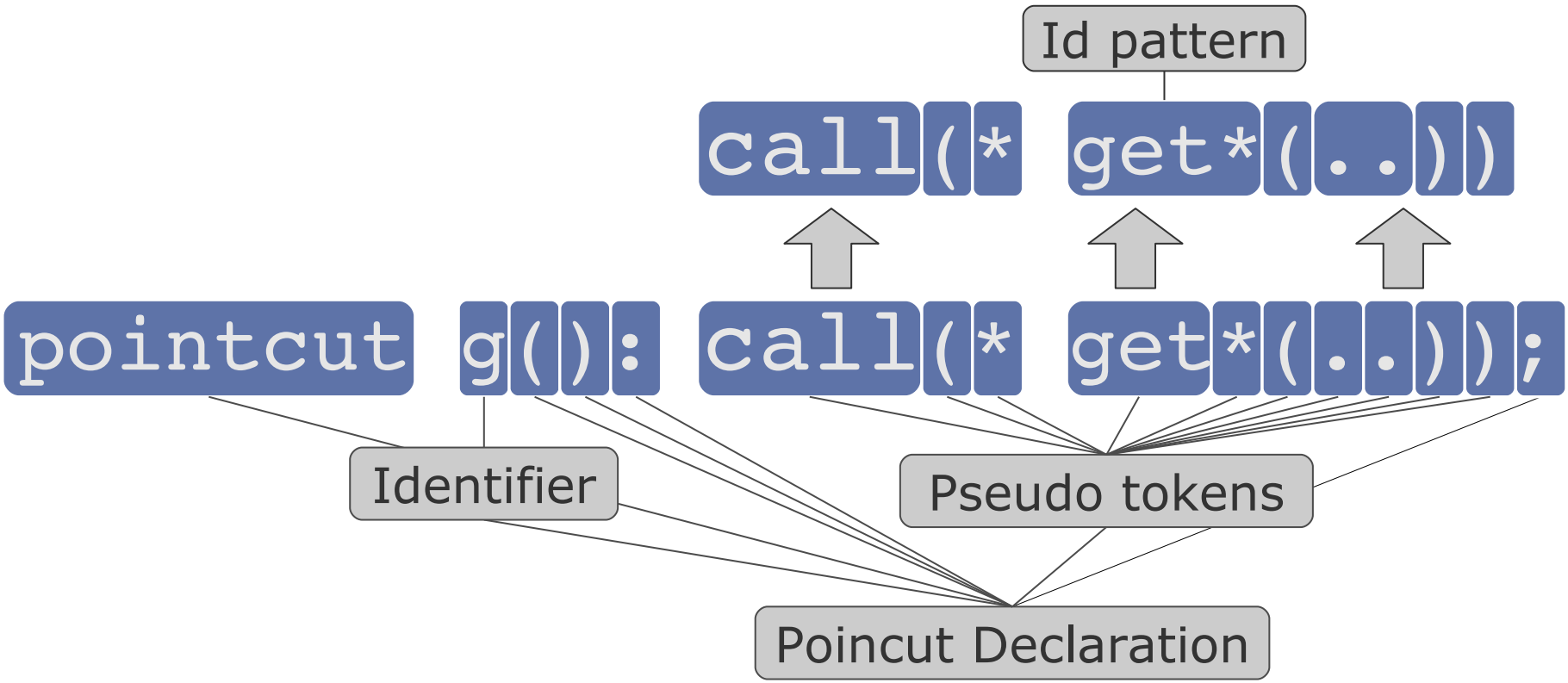
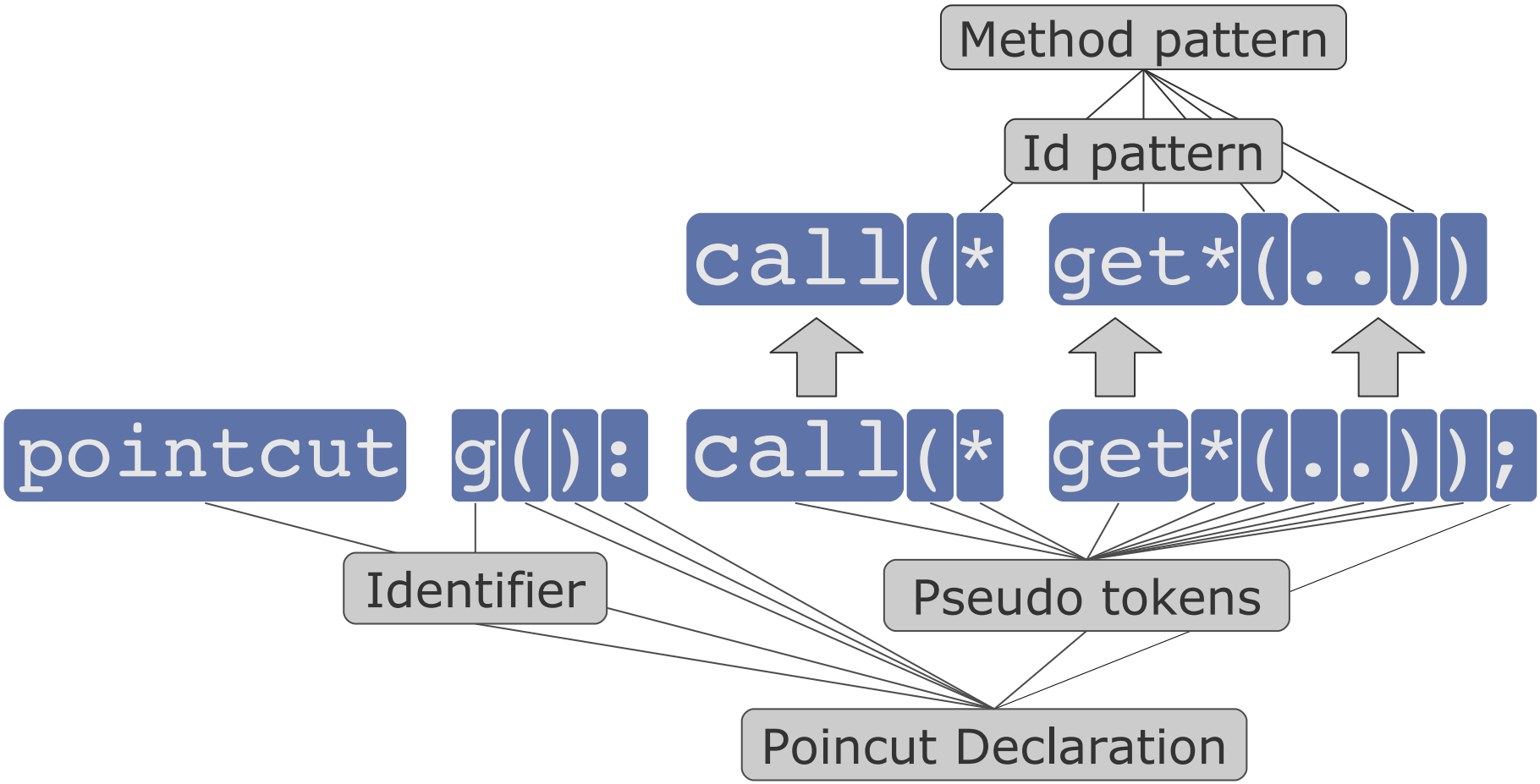
```

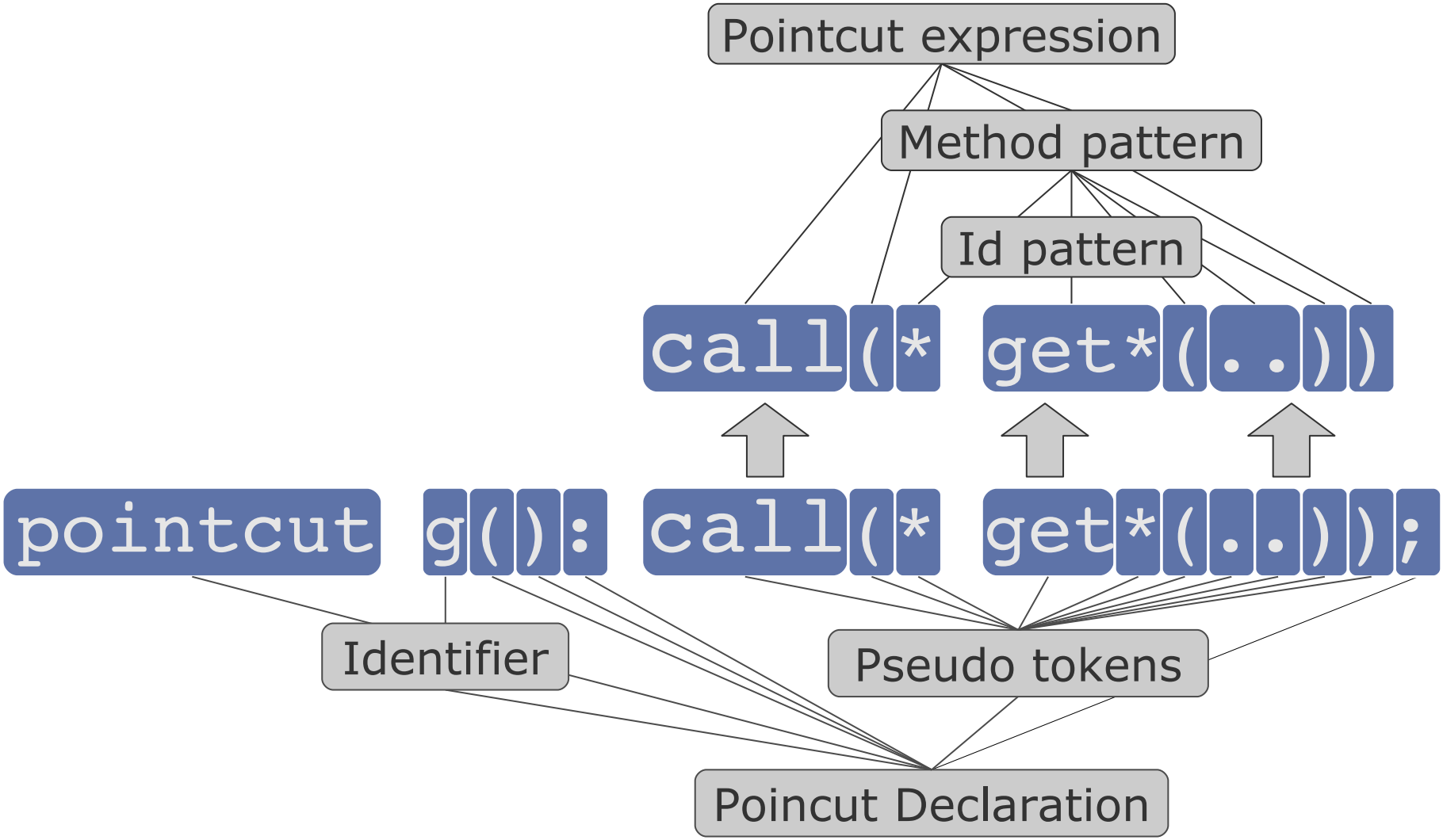

pointcut g(): call(* get*(..));
Identifier
Pseudo tokens

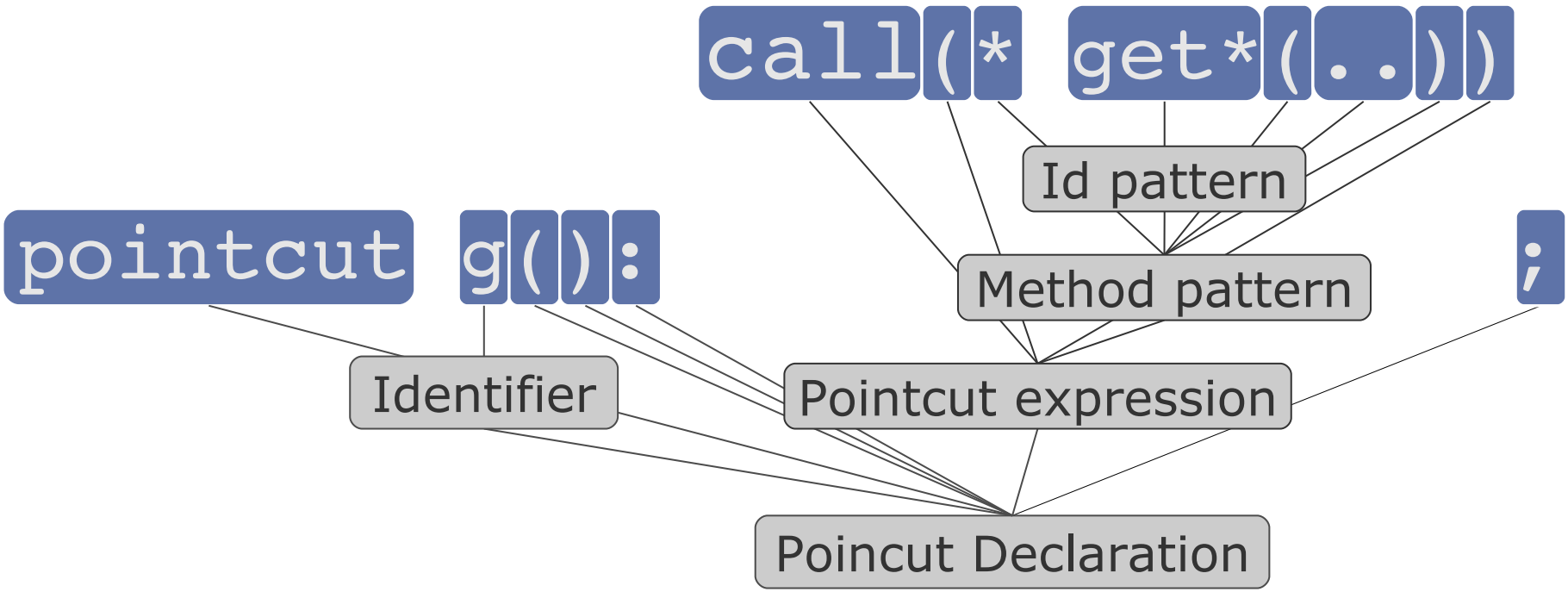

pointcut g(): call(* get*(..));
Identifier
Pseudo tokens
Poincut Declaration

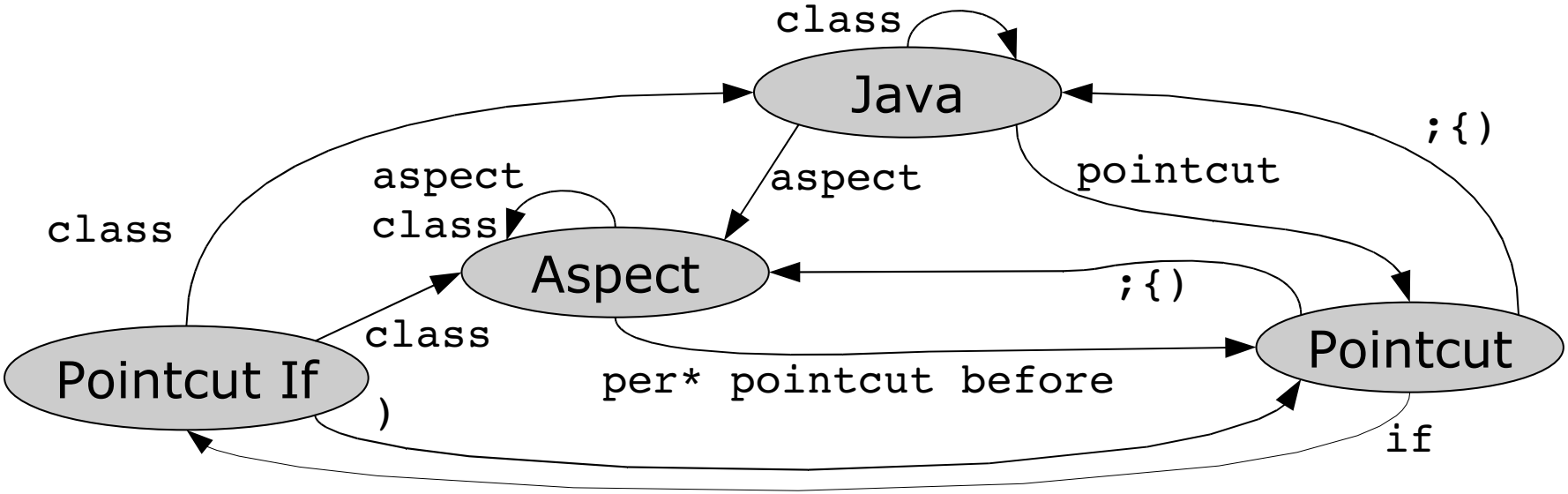

call(*
get*(..))
pointcut
g():
call(*
get*(..));
Identifier
Pseudo tokens
Poincut Declaration

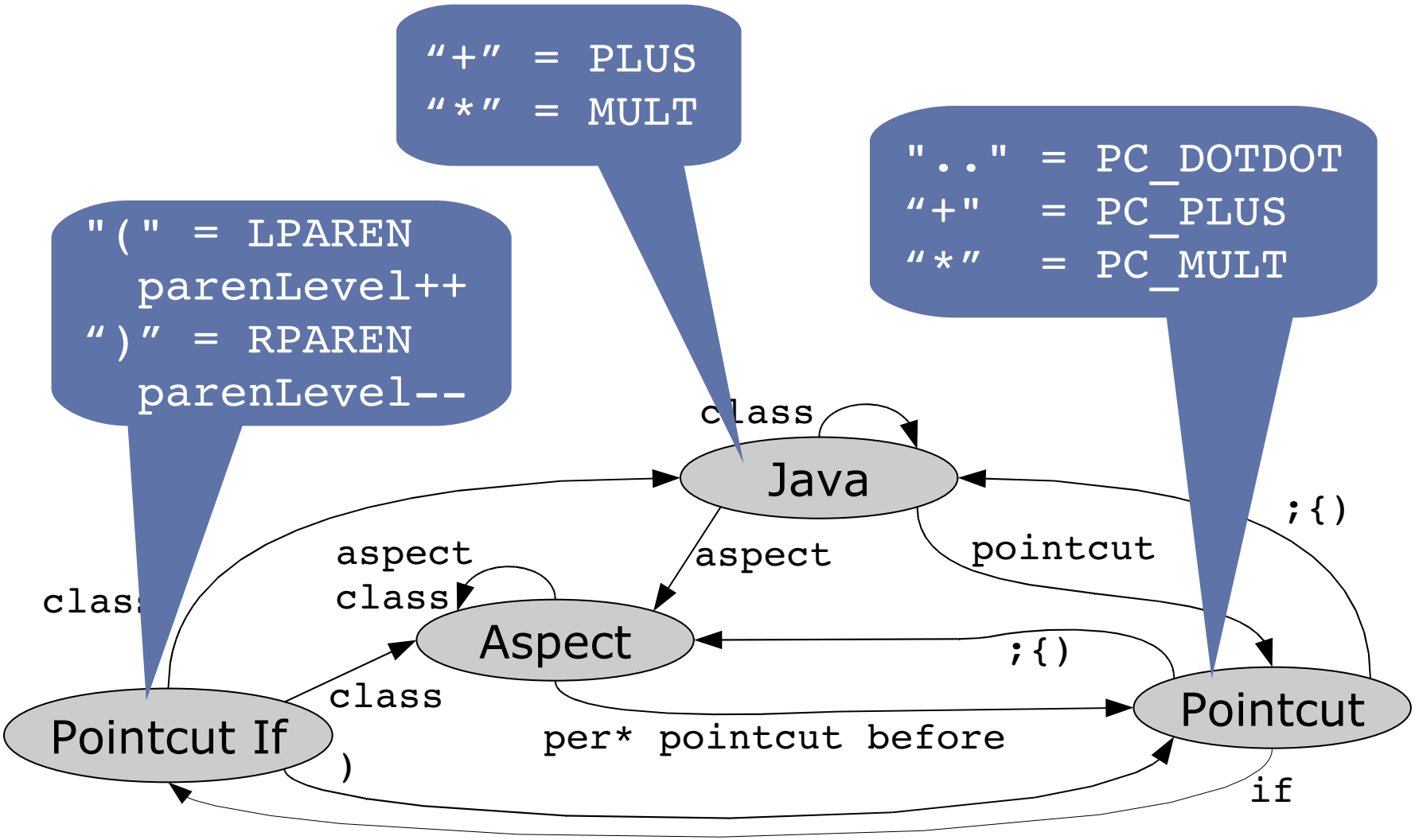

Id pattern
call(*
get*(..))
pointcut
g():
call(*
get*(..));
Identifier
Pseudo tokens
Poincut Declaration


Method pattern
Id pattern
call(*
get*(..))
pointcut
g():
call(*
get*(..));
Identifier
Pseudo tokens
Poincut Declaration

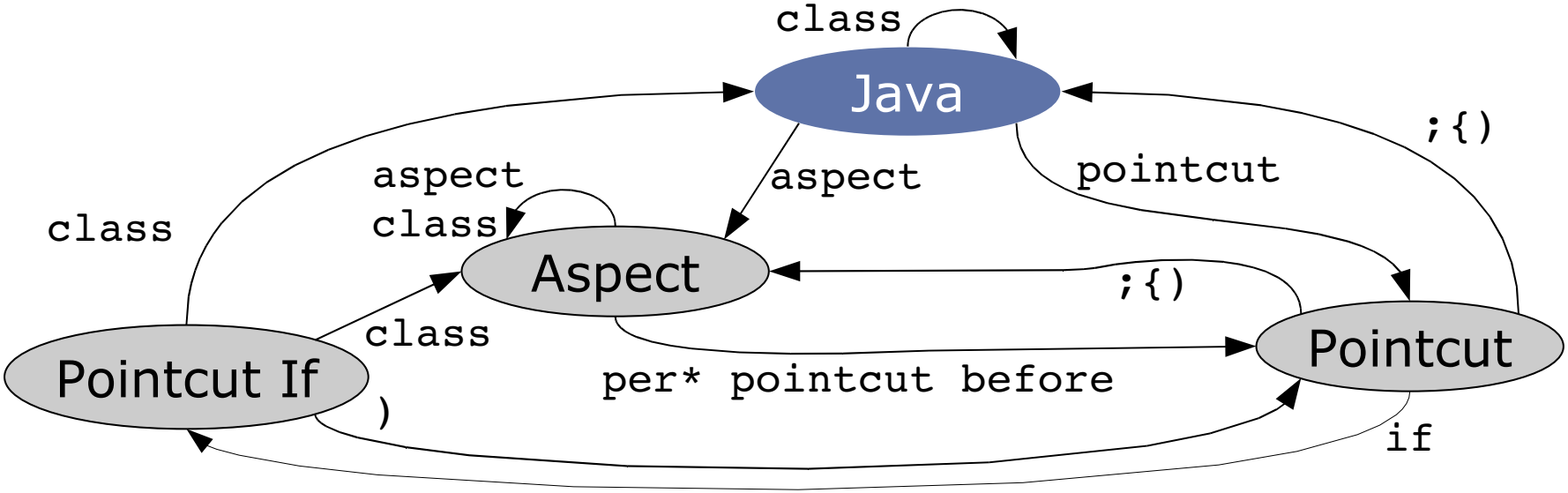

Pointcut expression
Method pattern
Id pattern
call(*
get*(..))
pointcut
g():
call(*
get*(..));
Identifier
Pseudo tokens
Poincut Declaration


call(* get*(..))
Id pattern
pointcut g():
Method pattern
;
Identifier
Pointcut expression
Poincut Declaration


class
Java
;{)
aspect
class
aspect
pointcut
class
Aspect
;{)
class
Pointcut If
per* pointcut before
Pointcut
)
if


"+" = PLUS
"*" = MULT
".." = PC_DOTDOT
"+" = PC_PLUS
"*" = PC_MULT
"(" = LPAREN
parenLevel++
")" = RPAREN
parenLevel--
class
Java
aspect
class
aspect
pointcut
;{}
clas
Aspect
;{}
class
Pointcut If
per* pointcut before
Pointcut
)
if

```
public aspect LogFoo {
  pointcut logCalls() : call(* Foo.*(..));
  before() : logCalls() && if(isEnabled()) {
    System.out.println("Enter " + thisJoinPoint);
  } ...
```



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  pointcut logCalls() : call(* Foo.*(..));
  before() : logCalls() && if(isEnabled()) {
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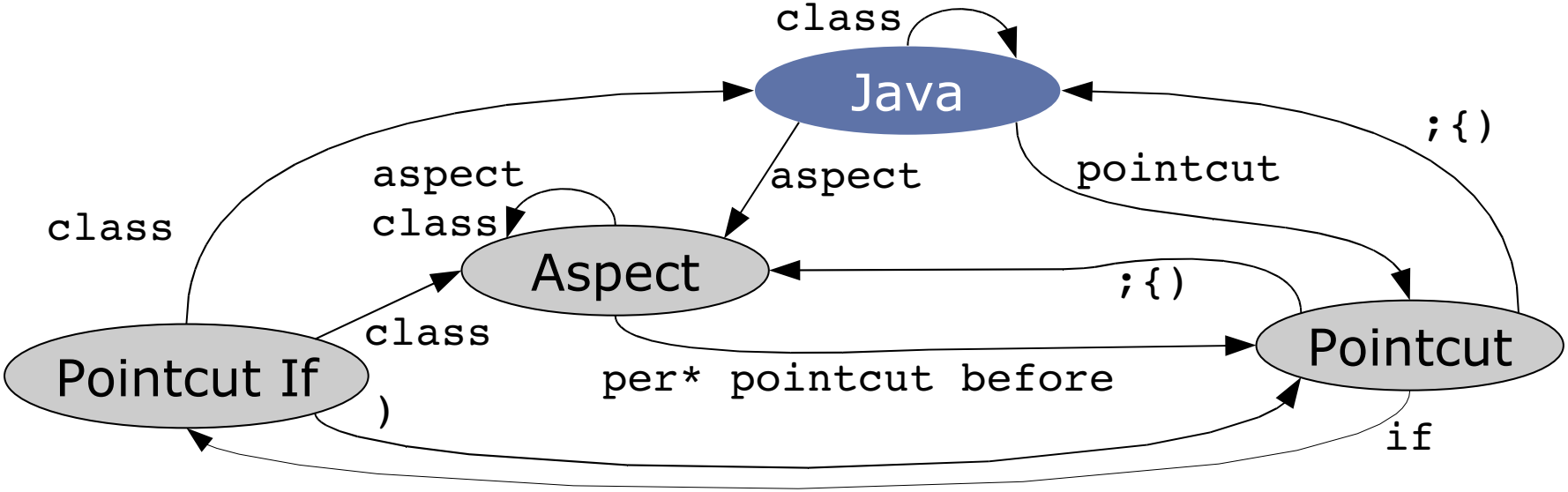

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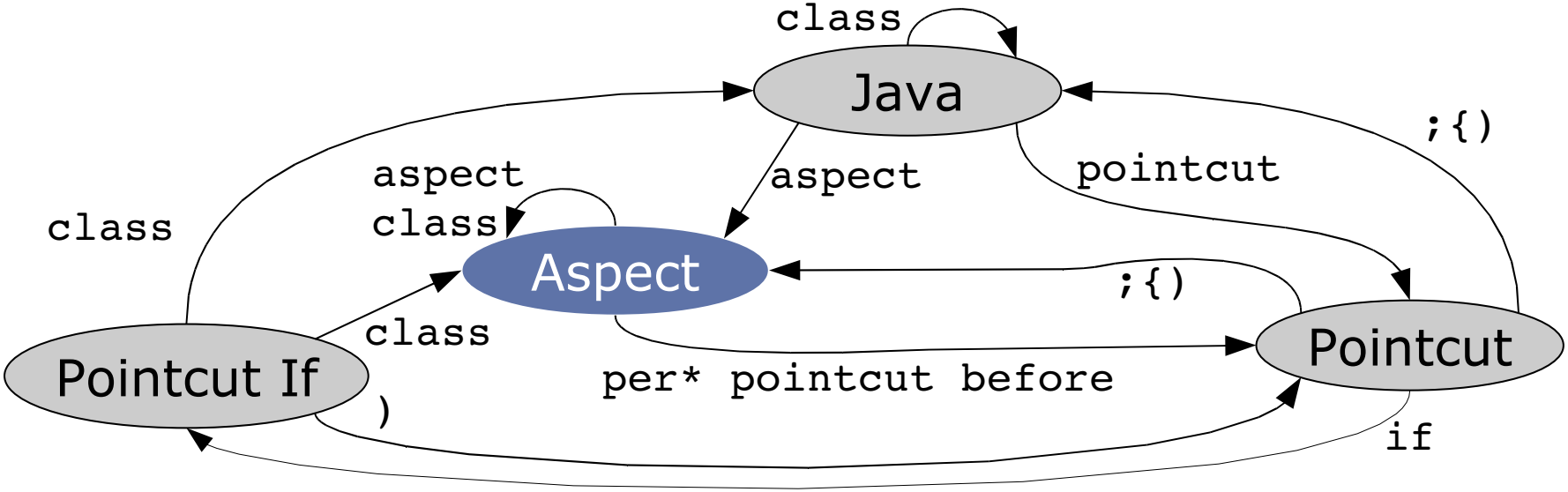

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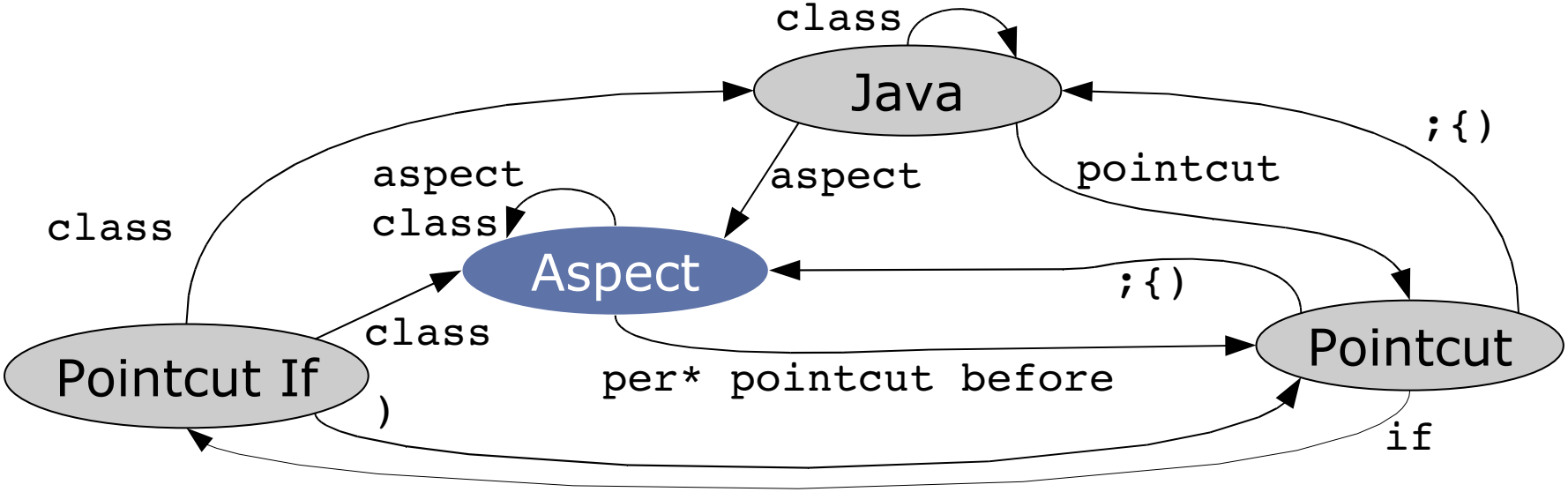
```



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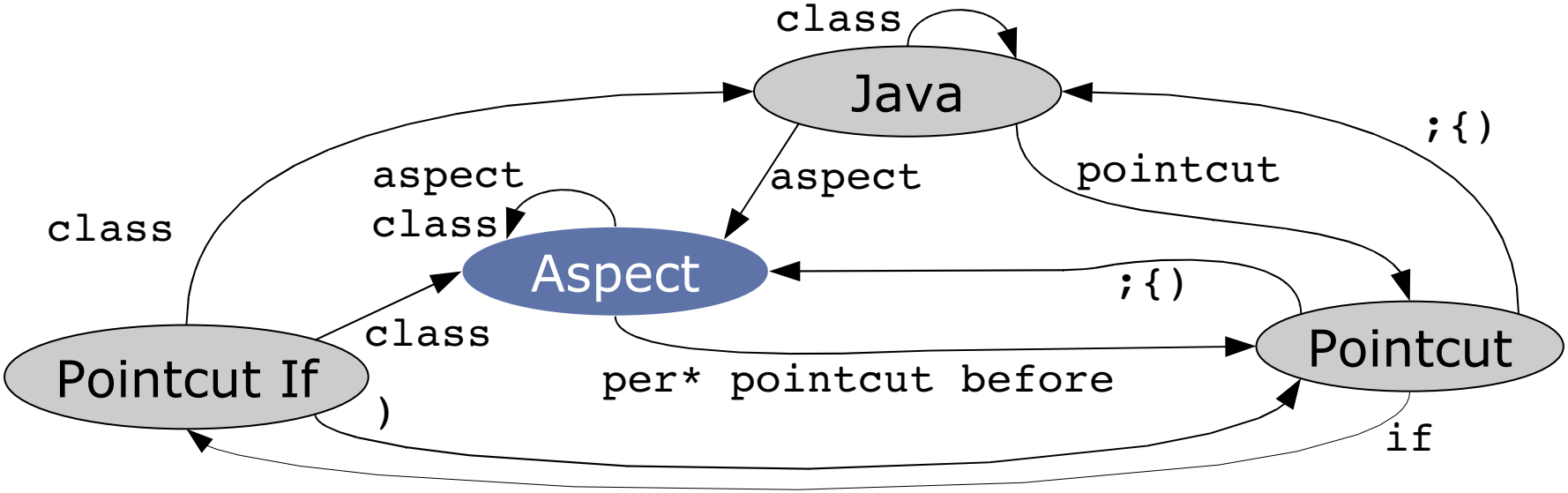
  } ...
```



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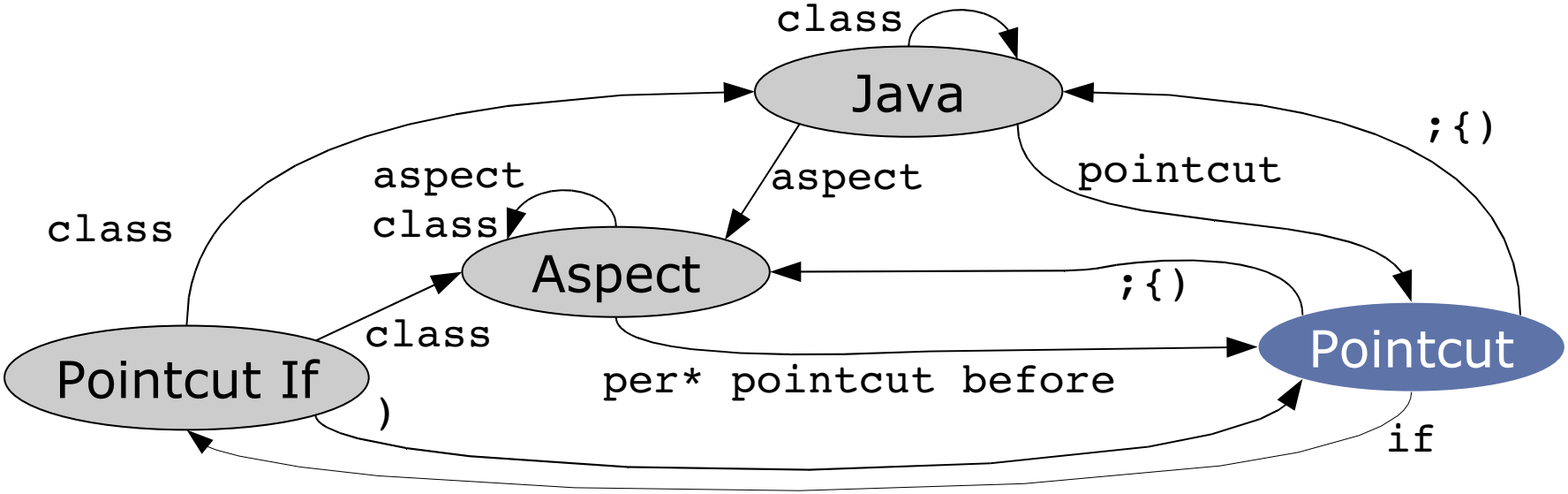
  pointcut logCalls() : call(* Foo.*(..));
  before() : logCalls() && if(isEnabled()) {
    System.out.println("Enter " + thisJoinPoint);
  } ...
```



Scannerless parsing elegantly deals with these issues

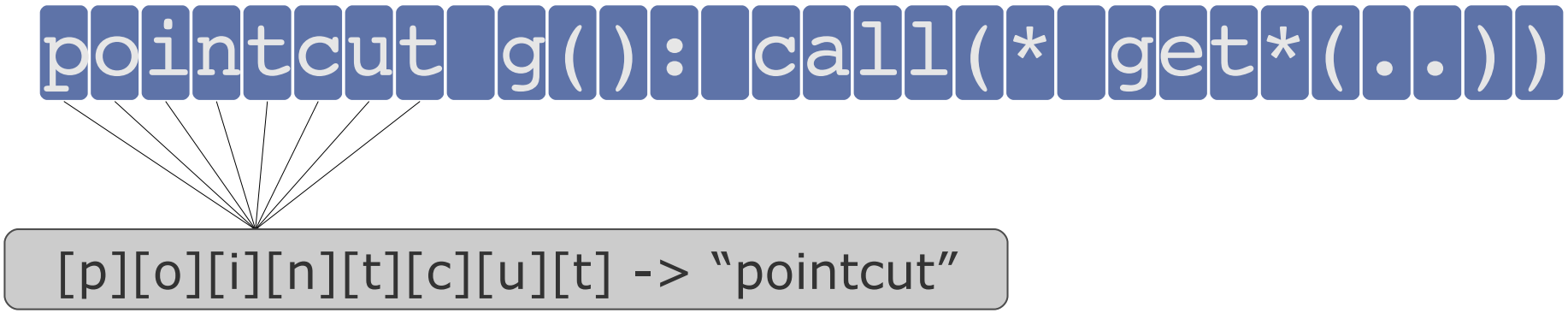
- no separate lexical analysis
- parser operates on individual characters
- scannerless parsing needs generalized LR parsing

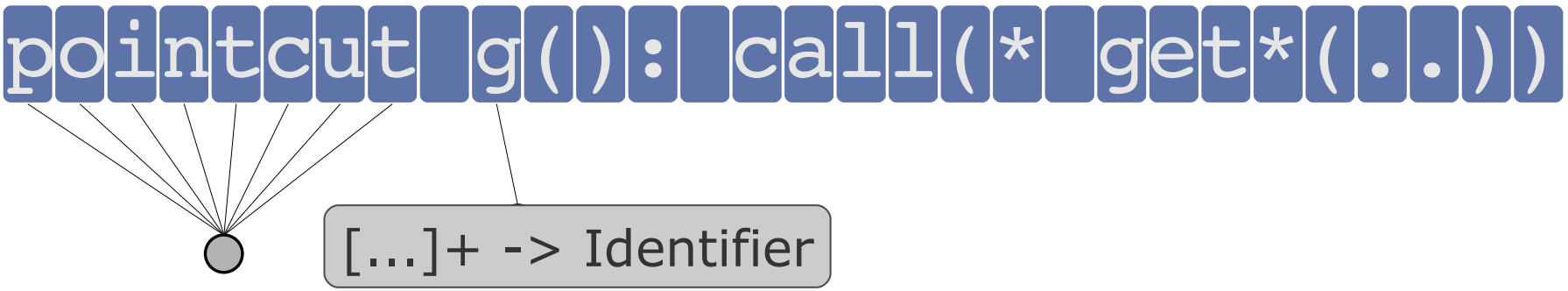
SDF – Syntax Definition Formalism

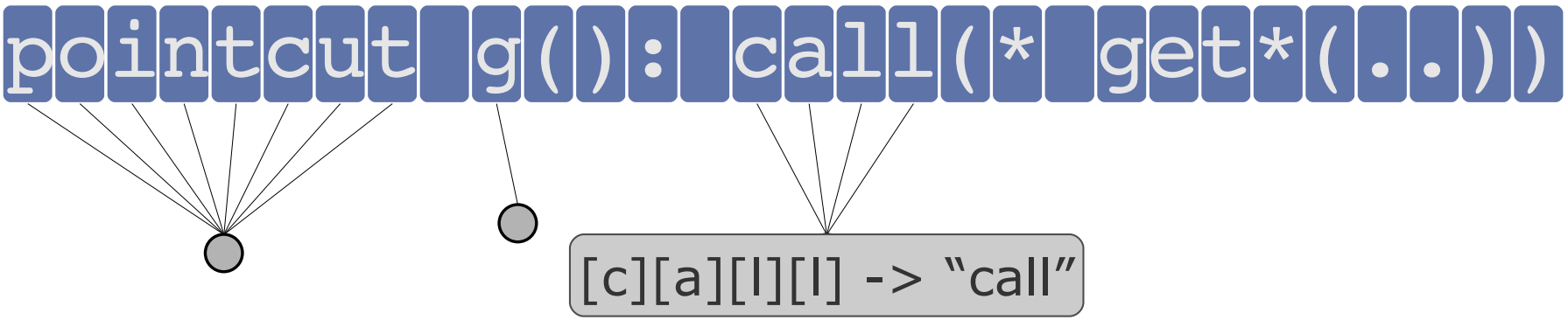
- declarative
- modular
- context-free and lexical syntax
- declarative disambiguation
- all context-free grammars

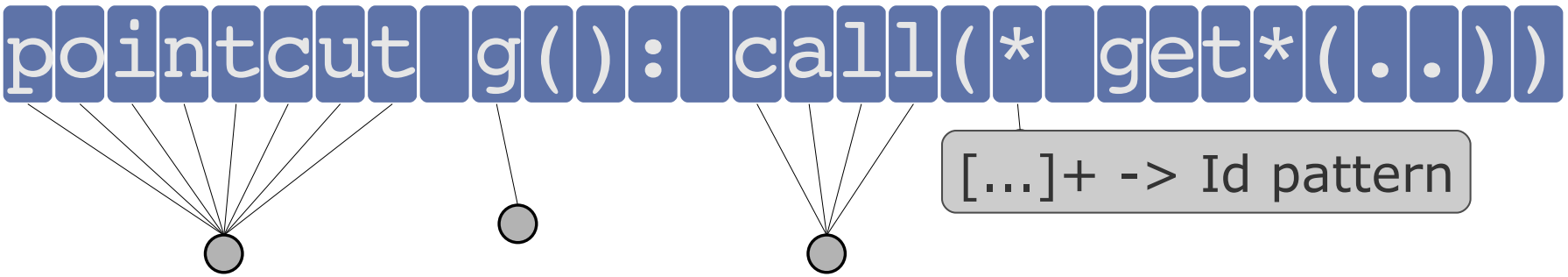
```
pointcut g(): call(* get*(..))
```

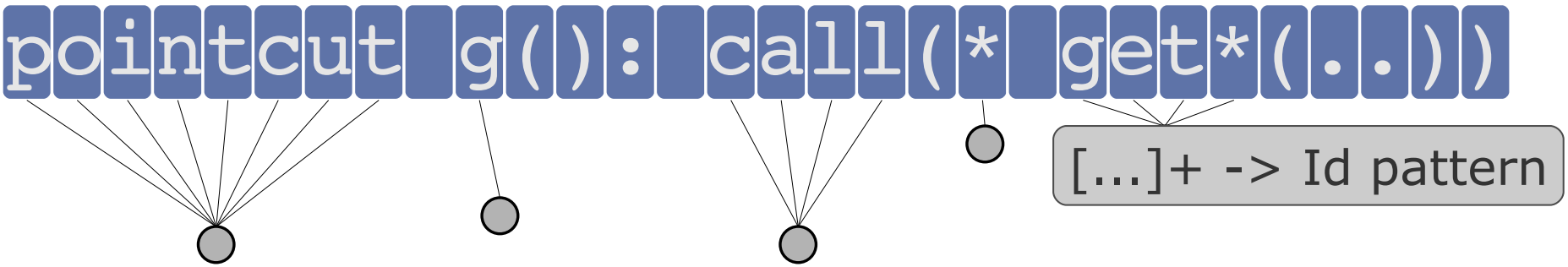
```
pointcut g(): call(* get*(..))
```

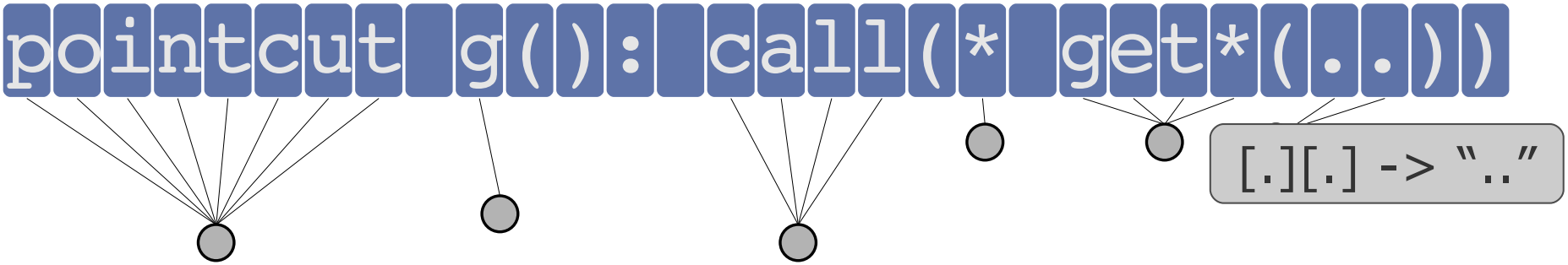

pointcut g(): call(* get*(..))
[p][o][i][n][t][c][u][t] -> “pointcut”

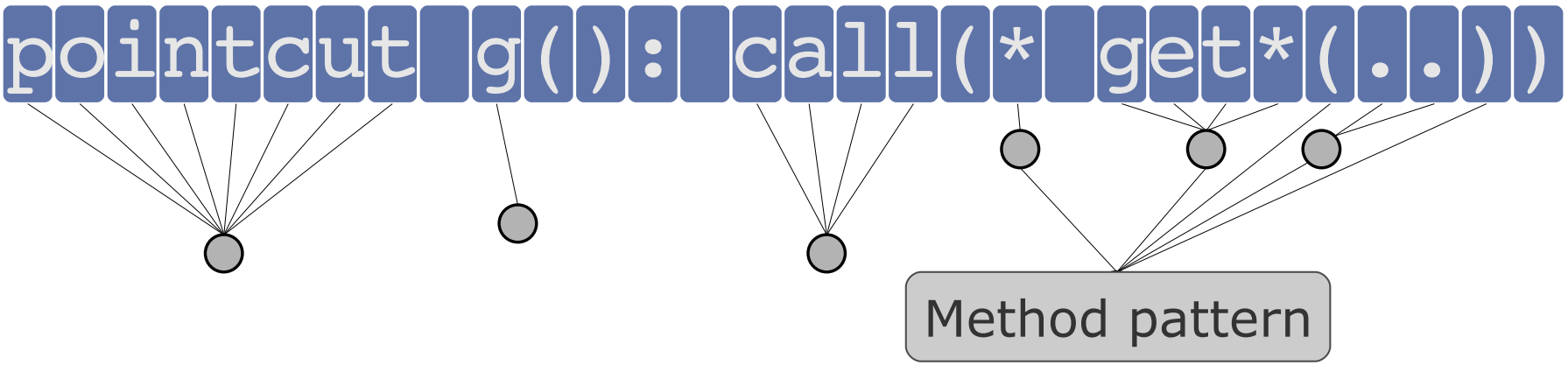

pointcut g(): call(* get*(..))
[...]+ -> Identifier

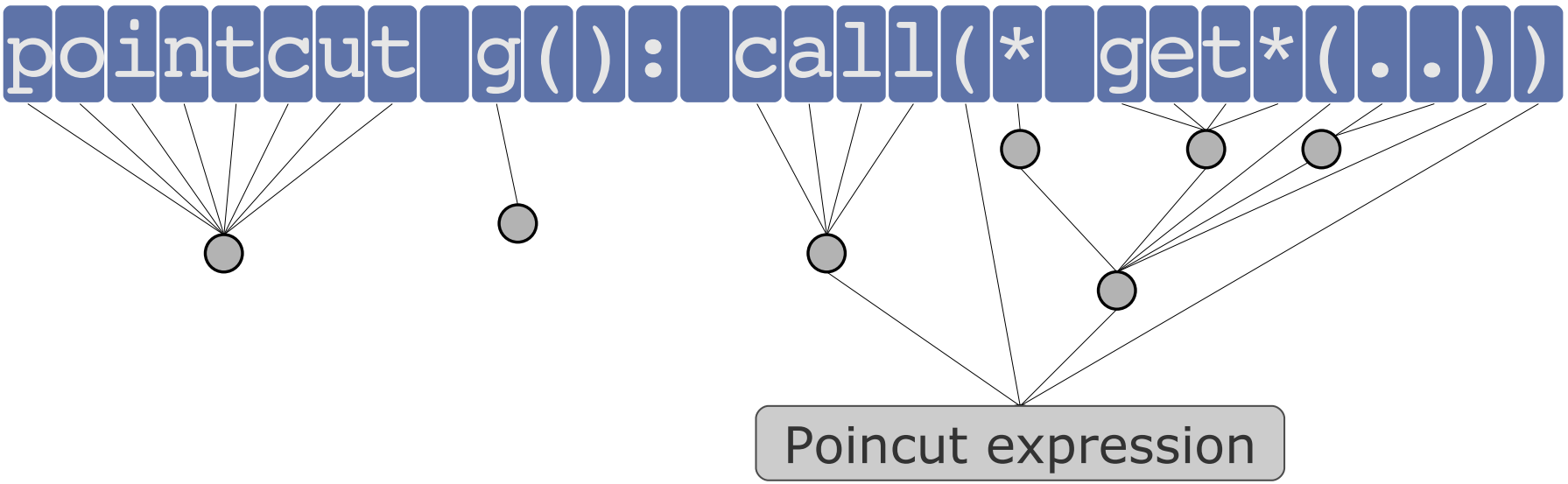

pointcut g(): call(* get*(..))
[c][a][l][l] -> “call”

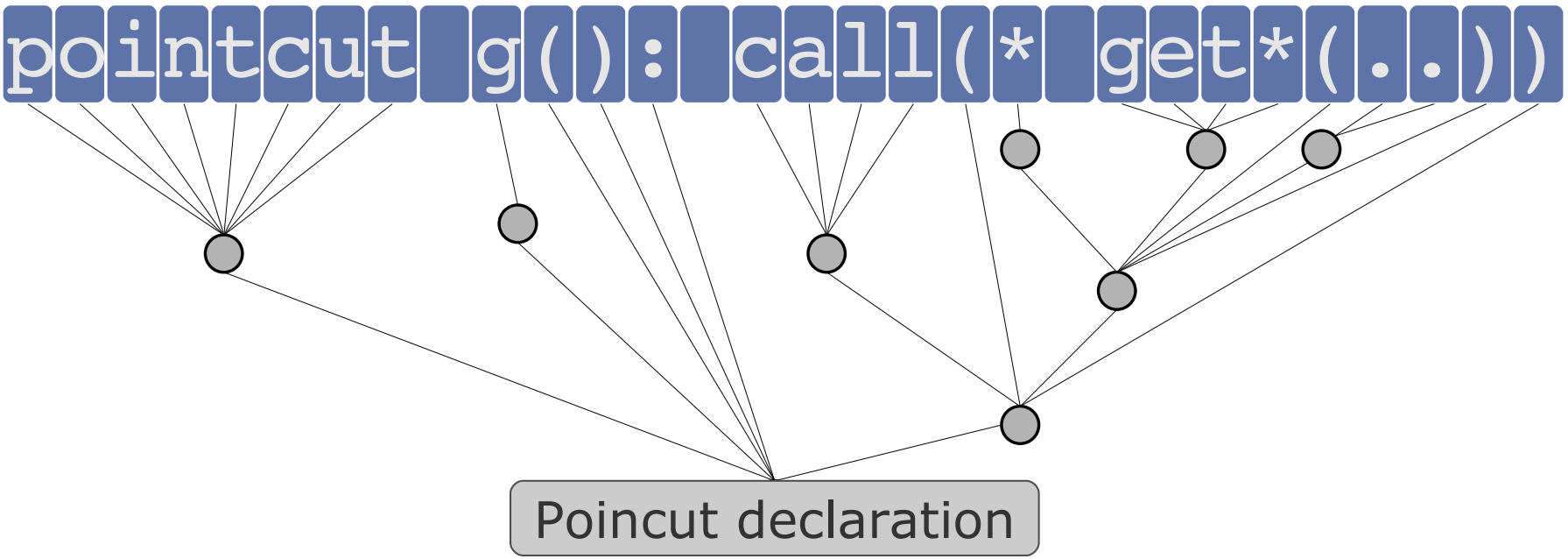

pointcut g(): call(* get*(..))
[...]+ -> Id pattern


pointcut g(): call(* get*(..))
[...]+ -> Id pattern


pointcut g(): call(* get*(..))
[.][.] -> “..”


pointcut g(): call(* get*(..))
Method pattern


pointcut g(): call(* get*(..))
Poincut expression


pointcut g(): call(* get*(..))
Poincut declaration

Part VI

Applications

```
entity-to-java-Entity :
  Entity(x_Class, x_super, props, functions) -> JavaFile(["src"],
  compilation-unit|[
    package pkgname;

    import java.util.*;
    import org.jboss.seam.persistence.*;
    import javax.persistence.*;

    @Entity
    public class x_Class extends x_super implements Serializable {
      public x_Class () {}

      public boolean equals(Object o) {
        return o != null && o instanceof x_Class
           && ((x_Class)o).getId().equals(getId());
      }
    }
  ]|)
```

```
email-to-xml(|call_from_page) :
  Define([Email()], x, fargs, elems1) ->
    XmlFile(["view"], <concat-strings>[template_name, ".xhtml"],
      %>
        <?xml version="1.0" encoding="UTF-8"?>

        <m:message xmlns="http://www.w3.org/1999/xhtml"
                   xmlns:m="http://jboss.com/products/seam/mail"
                   xmlns:h="http://java.sun.com/jsf/html">
          <%= elems3 ::*%>
        </m:message>
      <%)
```

```
php-prod2literal-method-dec(|grammar, cfg) :
  sym@lex(_) -> php:class-member |[
    public static function x($s) {
      if(!is_string($s)) {
        throw new Exception("Only strings ...");
      }

      $result = new y($s);
      $result->symbols[e] = true;
      return $result;
    }
  ]|
  where
    mod := <conc-strings> ("//", <write-to-string> sym)
    ; x := <conc-strings> ("literal_", <key-of-sym-sdf> sym)
    ; y := <php-class-name-string>
    ; e:= <write-to-string; string-to-php-asfix-string> sym
```

Stratego in Stratego

```
Desugar :
  |[ s => t ]| -> |[ s ; ?t ]|

Desugar :
  |[ <s> t :S]| -> |[ !t ; s ]|

Desugar :
  |[ f(as) : t1 -> t2 where s ]|
    ->
  |[ f(as) = ?t1 ; where(s); !t2 ]|

Desugar :
  |[ if s1 then s2 else s3 end ]| -> |[ where(s1) < s2 + s3 ]|
```

Transformation of Stratego programs in Stratego

```
ra2mathml(s) =
  !%>
    <?xml version="1.0"?>
    <math xmlns="http://www.w3.org/1998/Math/MathML">
      <% s %>
    </math>
  <%

ra-to-presentation-mathml(x) :
  Project(ps, r) ->
    %><mrow>
        <msub>
          <mo>&pi;</mo>
          <mrow>
            <mfenced open="" close="">
              <% <map(x)> ps :: * %>
            </mfenced>
          </mrow>
        </msub>
        <mfenced><% <x> r %></mfenced>
      </mrow><%
```

```
context-free syntax
  "type" "|[" Type "]|" -> MetaExpr {cons("ToMetaExpr")}

variables
  "e" [0-9]*     -> Expr          {prefer}
  "e" [0-9]* "*" -> {Expr ","}*   {prefer}
```

Assimilation rules for Eclipse JDT Core API

```
  Assimilate(r) :
    type |[ double ]| -> |[ ast.newPrimitiveType(PrimitiveType.DOUBLE) ]|

  Assimilate(r) :
    |[ y(e*) ]| -> |[
      {| MethodInvocation x = ast.newMethodInvocation();
         x.setName(ast.newSimpleName("~y"));
         bstm* | x |}
    ]|
    where <newname> "inv" => x
        ; <ExplodeArgs(r | x)> e* => bstm*
```

```
expr-to-box :
  Plus(b1, b2) -> H hs=1 [ b1 "+"  b2]

UglyPrint :
  If(b1, b2, b3) ->
    V vs=0 [
      H hs=0 [KW["if"] "(" b1 ")"]
      b2
      KW["else"] b3]

PrettyPrint :
  If(b1, b2, If(b3, b4, b5)) ->
    V vs=0 [
      H hs=0 [KW["if"] "(" b1 ")"]
      b2
      H hs=1 [KW["else"] H hs=0 [KW["if"] "(" b3 ")"]]
      b4
      KW["else"] b5]
```

```
function webpage(title : elt, body : elt) : elt =
  <html>
    <head>
      <title> $title </title>
    </head>
    <body>
       $body
    </body>
  </html>
```

Embed XML in a programming language

Part VII

Conclusion

What stops us from applying this immediately?

- limitations of parsing techniques
  - not interactive
  - not Java
  - no error recovery
  - poor error reporting
  - performance could be better
  - no unicode support
  - context-sensitive languages
- poor grammar engineering practices
  - need high-quality grammars
  - reliable migration of grammars
  - testing

Extend meta language with object language syntax

- combine arbitrary meta and object language
- meta-language does not need to be designed for this purpose
- limitation: language should have context-free syntax

Modular syntax definition is essential

- reuse existing syntax definitions – no changed needed

Scannerless Generalized LR parsing

- Only context-free grammars closed under composition
- No compositionality: regular grammars, LR, LL