Component-Based Language Implementation with Object-Oriented Syntax and Aspect-Oriented Semantics

Barrett Bryant

Software Composition & Modeling Laboratory

SoftCom

Department of Computer and Information Sciences

University of Alabama at Birmingham

UAB

Outline

- Background knowledge
- Problem statement
- Related work
- Framework overview
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- Conclusion

Outline

- **Background knowledge**
- **Problem statement**
- **Related work**
- **Framework overview**
- **Component-based language development**
- **OOS and AOS**
  - **Object-oriented syntax**
  - **Aspect-oriented semantics**
- **Framework usage**
- **Future work**
- **Conclusion**

Background knowledge

- Syntax and semantics
- Component-Based Software Engineering (CBSE)
  - Promote software reuse
  - Essential properties
    - Information hiding
    - Explicit interface
    - Context Independency
- Object-oriented programming
- Aspect-Oriented Programming (AOP) and AspectJ
  - Aspects: special language constructs to modularize crosscutting concerns.
  - Introduction (inter-type declarations)
  - Interception (join-points)

Outline

- Background knowledge
- **Problem statement**
- Related work
- Framework overview
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- Conclusion

Compiler construction vs. cooking a wedding cake

- Cooking facilities: YACC, JavaCC, CUP, ...
- Cooking complexity
  - Compiler design is known as a “dragon” task
  - Good modularity enables you to divide-and-conquer the complexity
  - As long as the pieces can be assembled together

No decomposition of language definitions

Most parser generators don't support modular grammar definitions at all

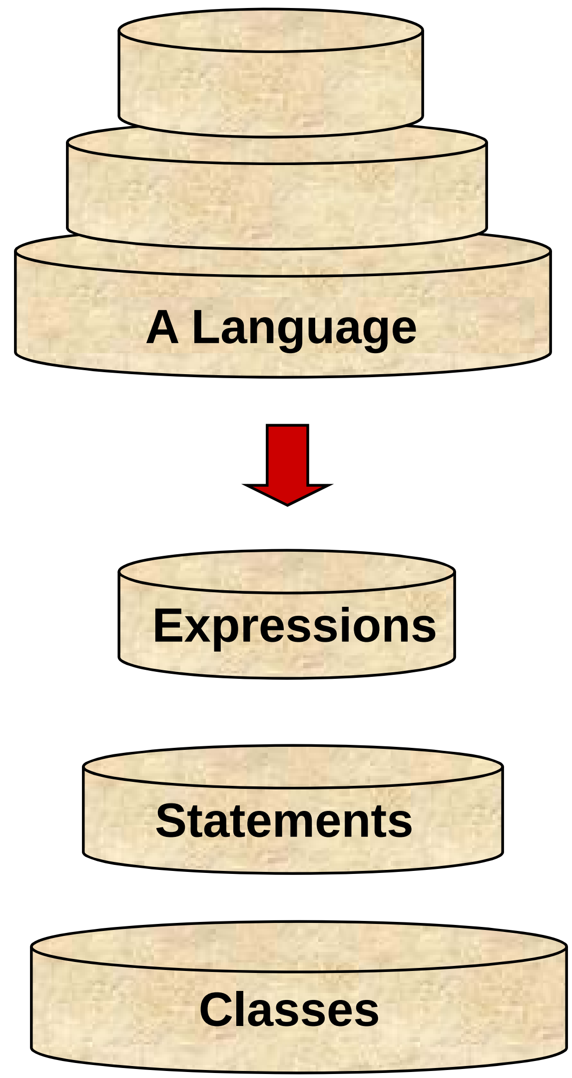
Cobol 85 is 2500 lines of specification, more than 1000 variables

Comprehensibility

Changeability

Reusability

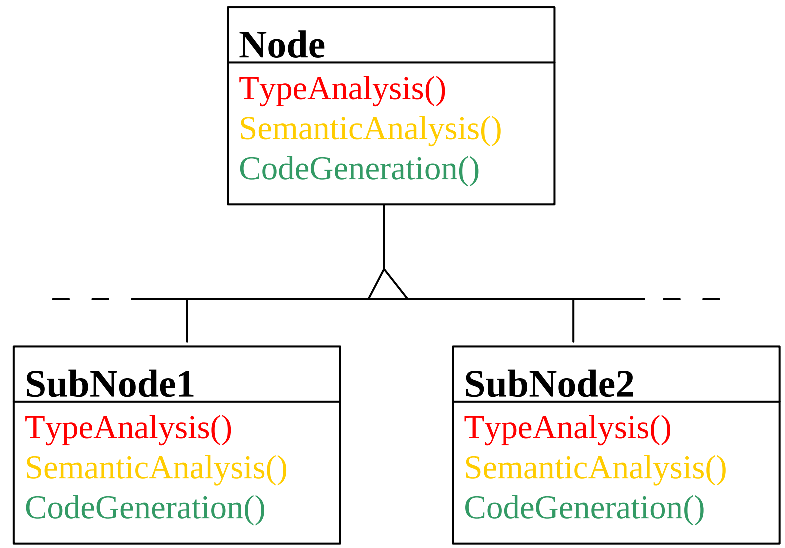
Independent development

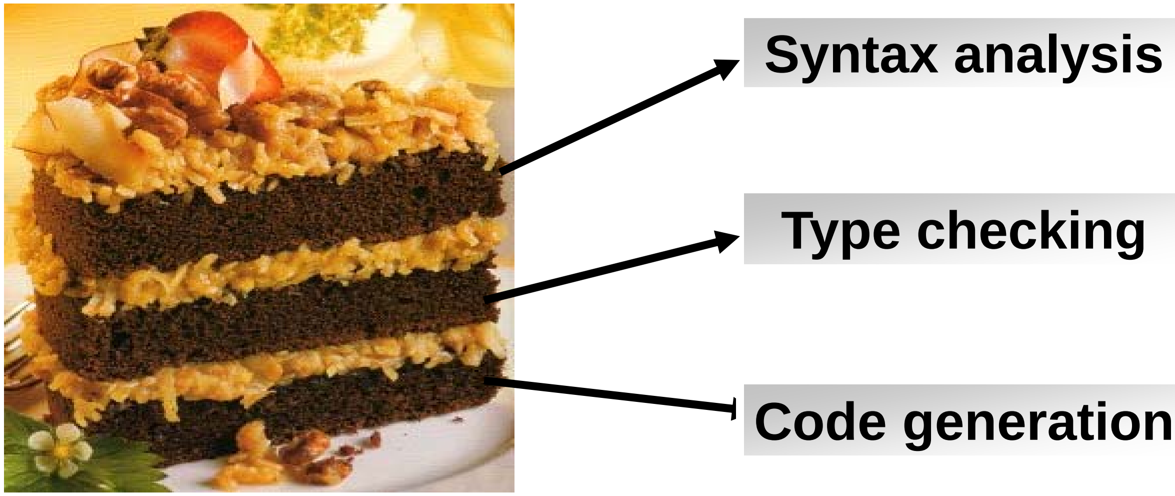


No clear separation of compiler construction phases

- Syntax and semantics
  - Syntax analysis -- formal specification
  - Semantic analysis -- programming languages
  - The communication between syntax and semantics makes the specification and code tangled together
- Among different semantic phases
  - Pure object-oriented design, code scatter all over the syntax tree class hierarchy

Hard to maintain and evolve!!





Ideal separation objectives

Syntax	⟷	**Semantics**
Semantic phase1	⟷	**Semantic phase2**
Auto-generated code	⟷	**Hand-written code**
Declarative formal specification	⟷	**Imperative programming language code**

Outline

- Background knowledge
- Problem statement
- **Related work**
- Framework overview
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- Conclusion

Related work – decomposition of language syntax

Modular grammar

- The nature is pure text copying
- Modules are still tightly coupled ➔ conflicts

Tools	Conflict solving solution
LISA,PPG	Manually
BtYacc	Backtracking
SDF,DMS	GLR

- Any update to a particular module requires a re-composition of all the modules and regeneration of a large parse table

Related work – separation of compiler phases

- Separation between syntax and semantics
  - Semantics by formal specification
    - Good separation but not rich enough to fully describe semantics
- Separation between semantic phases
  - The Visitor pattern
    - Introduces a lot of extra code
    - Forces all concrete visitors to share the same interface
    - New semantics are always introduced by traversal of the whole tree
    - Cannot access private members of a node class
  - Aspect-oriented semantics
    - JastAdd II – only supports static introduction

Outline

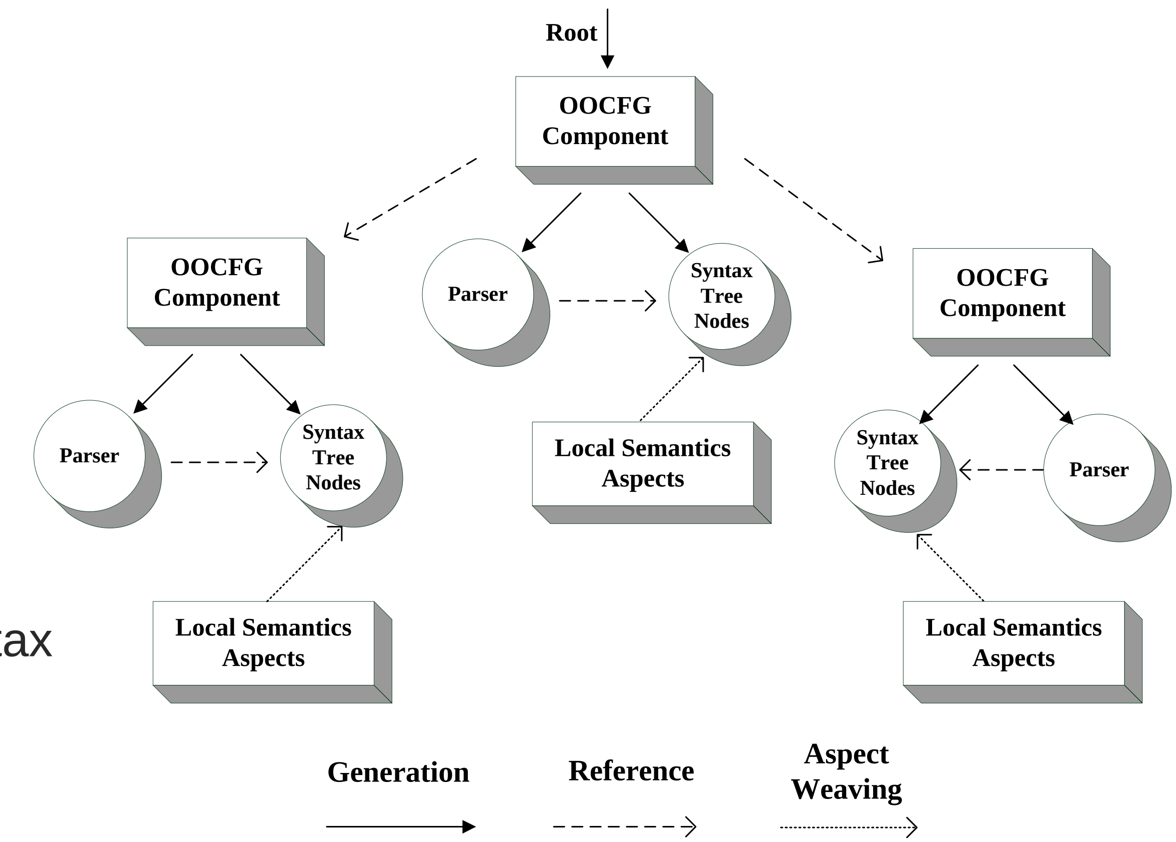
- Background knowledge
- Problem statement
- Related work
- **Framework overview**
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- Conclusion

Framework overview

Structure

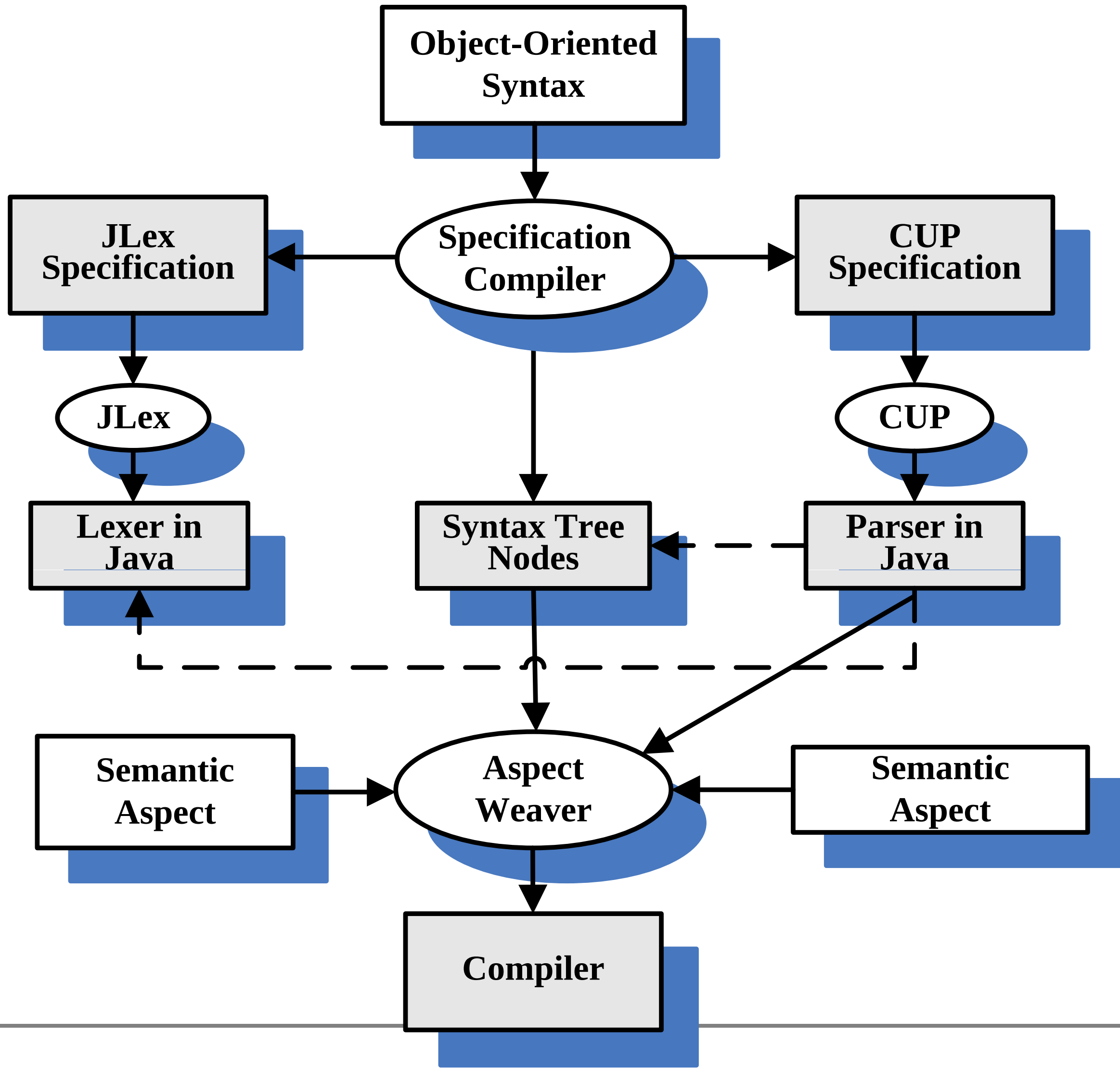
Function

Component-based LR (CLR) parsing decomposes a large language into a set of smaller languages



Object-Oriented Syntax (OOS) and Aspect-Oriented Semantics (AOS) facilitate separation of different phases

OOS + AOS implementation



Contribution

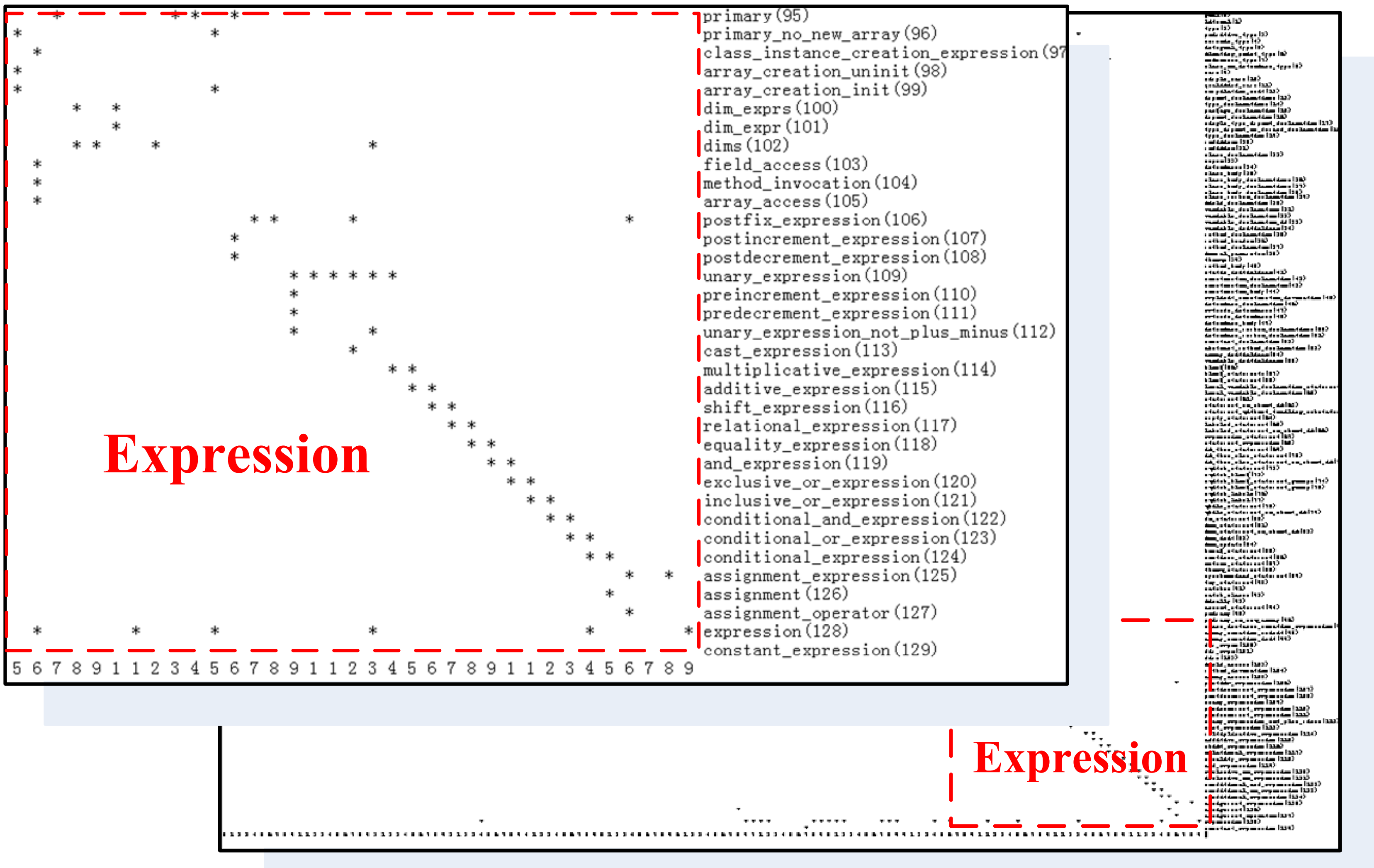
- CLR decreases the development complexity by reducing the granularity of a language
  - Syntax composition at the parser level ➔ reduced coupling between grammar modules
  - More expressive than regular LR parsing
- OOS + AOS isolates syntax and semantics as well as semantic phases themselves into different modules
  - Separation of declarative and imperative behavior
  - Separation of generated code and handwritten code
  - OOS - generation of both parser and syntax tree
  - AOS - transparent to node classes, flexible in tree walking and phase composition.

The overall paradigm increases the comprehensibility, reusability, changeability, extendibility and independent development ability of the syntax and semantic analysis with less development workload required from compiler designers.

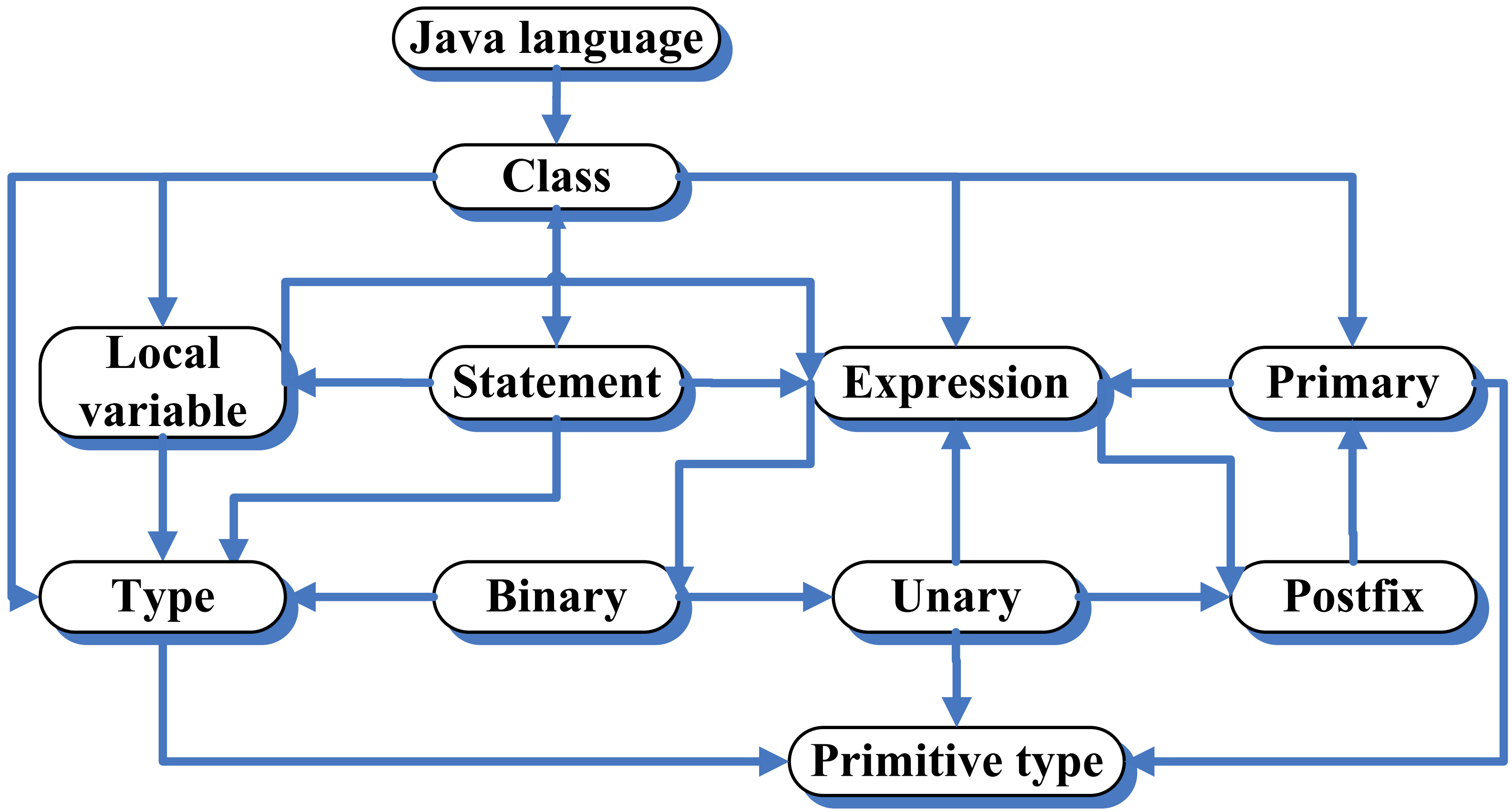
Outline

- Background knowledge
- Problem statement
- Related work
- Framework overview
- **Component-based language development**
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
  - Demo
- Future work
- Conclusion

Component-based Context-Free Grammar (CCFG)



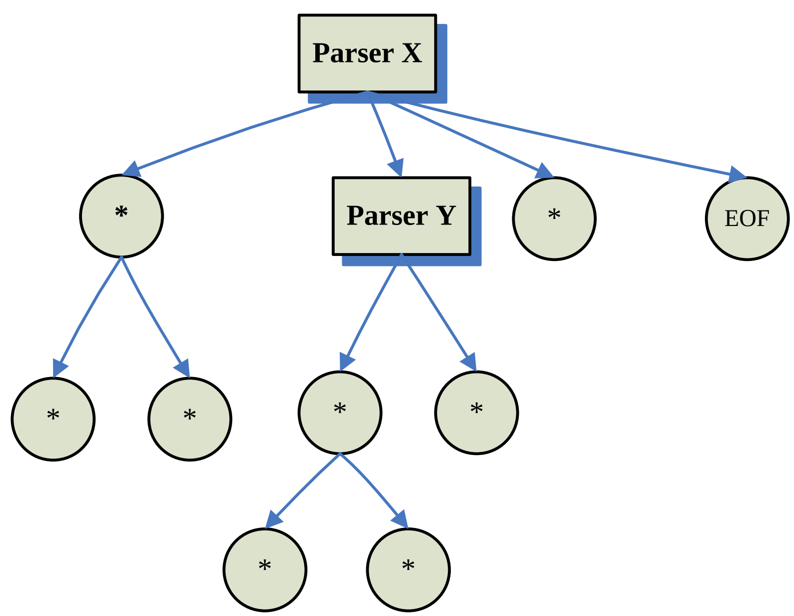
Java language components (11 components)



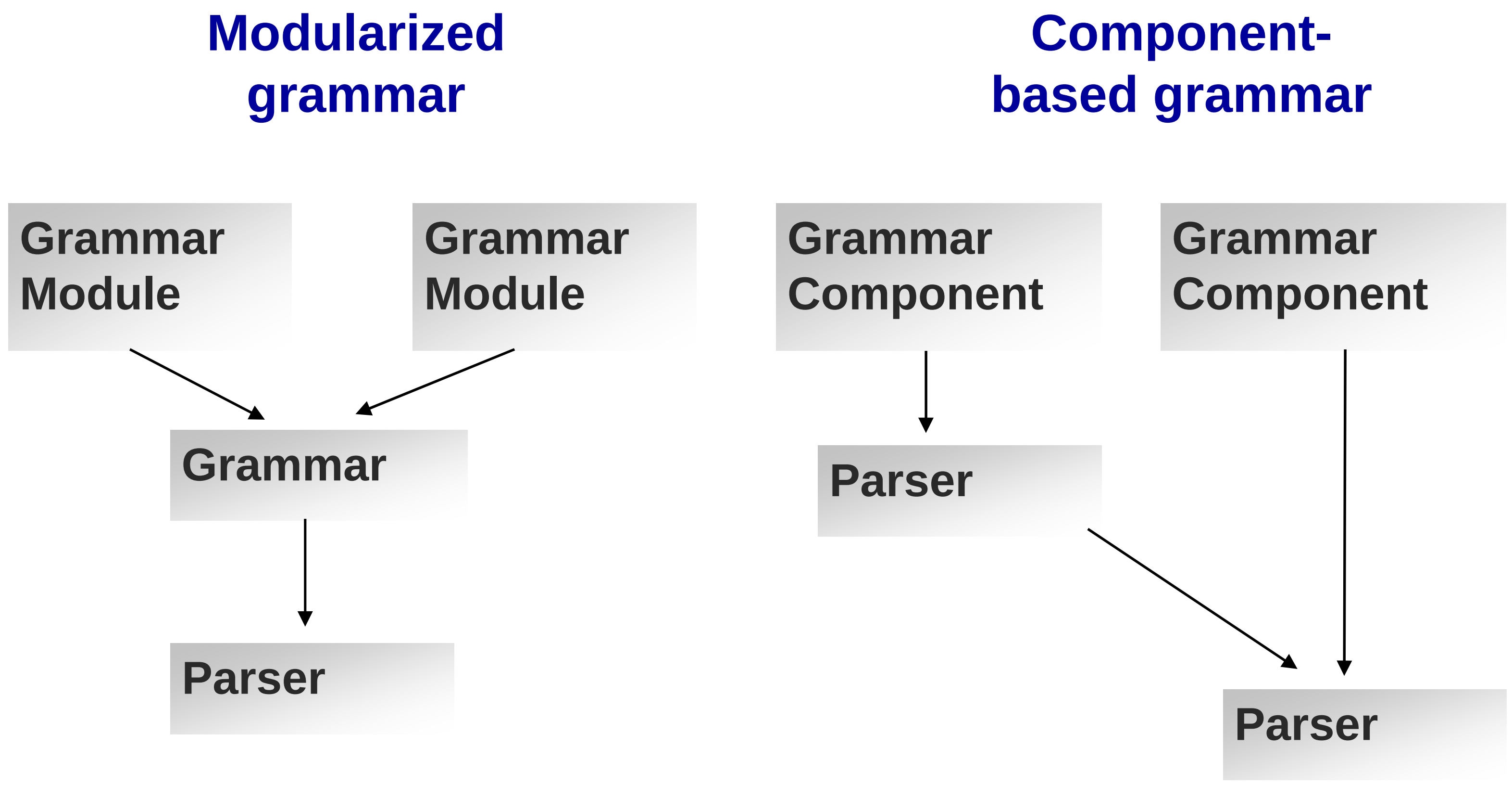
CCFG & CCFL & parser components

- A CCFG component G is a quintuple (N, T, C, P, S)
  - N: a set of nonterminal symbols
  - T: a set of terminal symbols
  - C: a set of symbols representing other grammar components
  - $P \subseteq N \times (N \cup T \cup C)^*$ is a finite set of production rules, a production of the form $A \rightarrow \alpha$ means A derives α.
  - $S \in N$: the start symbol
- CCFL
  - Let $\sigma \in (N \cup T \cup C \cup L(C))^*$, $\tau \in (N \cup T \cup C \cup L(C))^*$, $\gamma 1=\sigma\, B\, \tau$ and $\gamma 2=\sigma\, \beta\, \tau$, then $\gamma 1$ directly derives $\gamma 2$, denoted $\gamma 1 \Rightarrow \gamma 2$, if one of the two conditions is met: 1) $B \rightarrow \beta$ is a production in P; 2) $B \in C$ and $\beta \in L(B)$
  - $L(G) = \{x|\ S \Rightarrow^* x,\ x \in (T \cup L(C))^*\})$

- Parser components
  - Grammar component ➔ parser component.
  - The root parser invokes its sub-parsers that will recursively invoke other parsers as needed.



Component-based grammar vs. modularized grammar

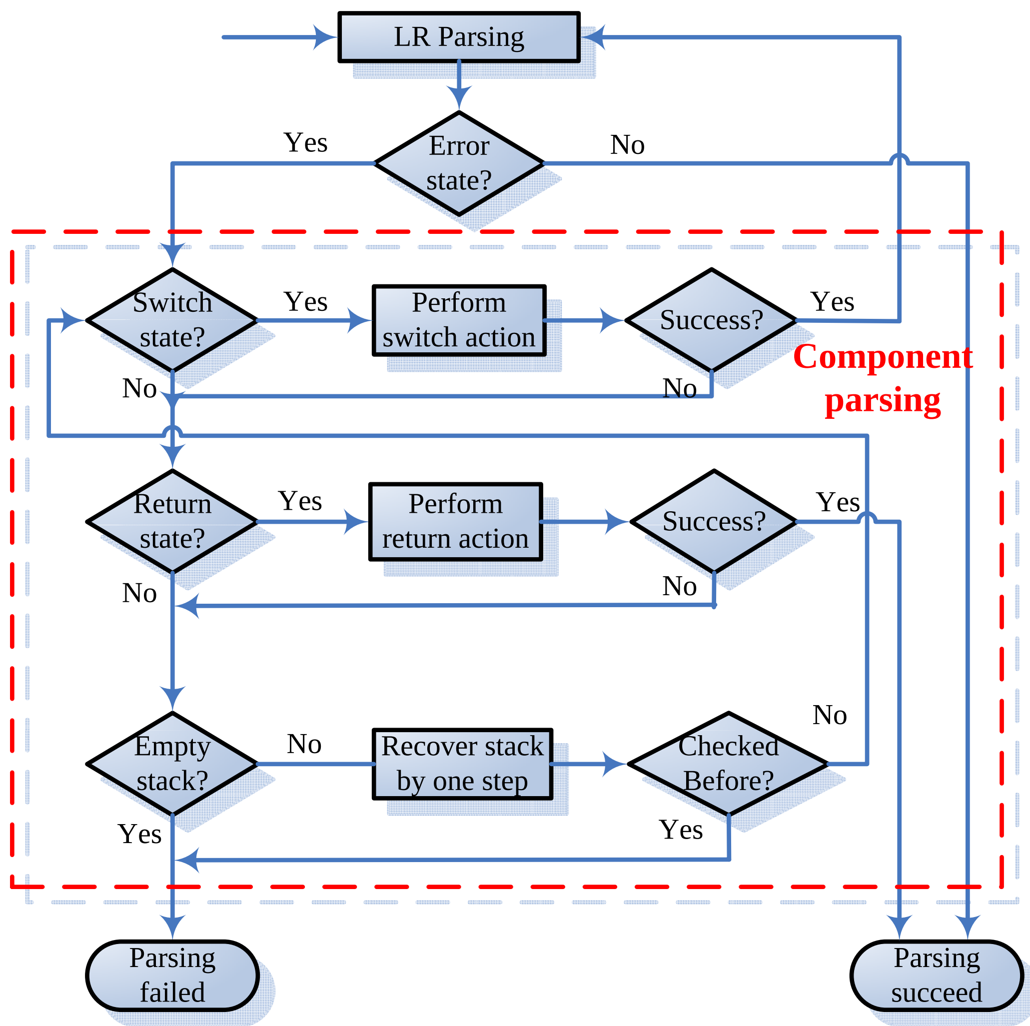


Code-level composition, less coupled definition, smaller parsing table, multiple lexers, etc ...

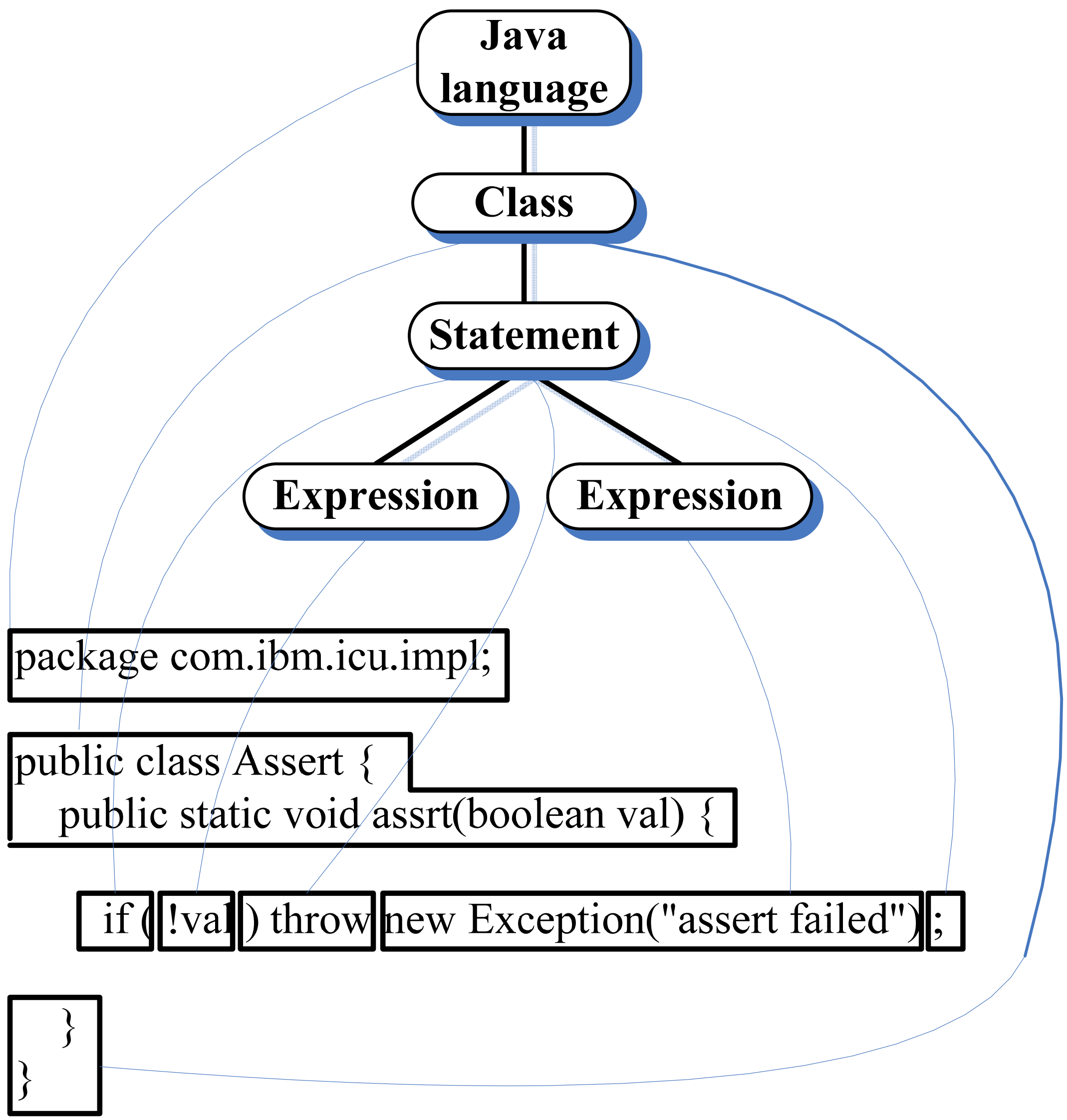
CLR parsing algorithm – switch and return

Pseudo code:

```
flag component_parse(program, stack):
 repeat
   state := stack.top()
   if switch_map (state) ≠ ∅
     for ∀ component ∊ switch_map (state)
       if component.lr_parse(program) == true
         record stack configuration
         return continue_flag
       end if
     end for
   end if
   if return_map (state) == true
     if return action success
       return termination_flag
     end if
   end if
   if stack ≠ ∅
     recover stack by one step
   else
       return error_flag
   end if
 until reach the stack configuration when
     last switch action happened
 return error_flag
```



CLR parsing example (4 components)



Software engineering benefits

Comprehensibility

Intertwined symbols and productions are reduced

Changeability

Changes are isolated inside individual components
Only local recompilation needed

Reusability

Components can be plugged and played

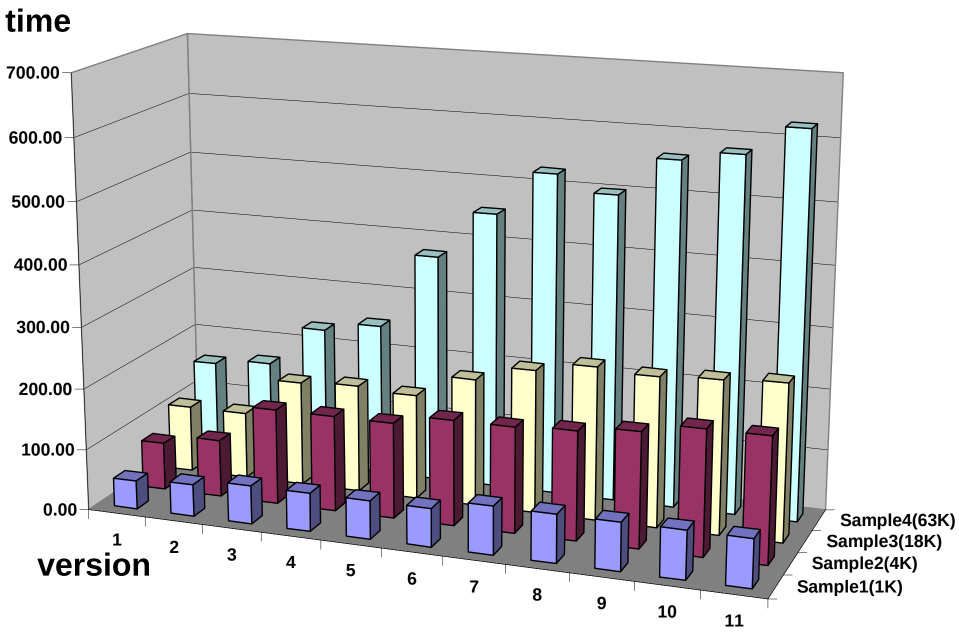
Independent development

Dependencies are handled at the code-level instead of the grammar level

Language description ability

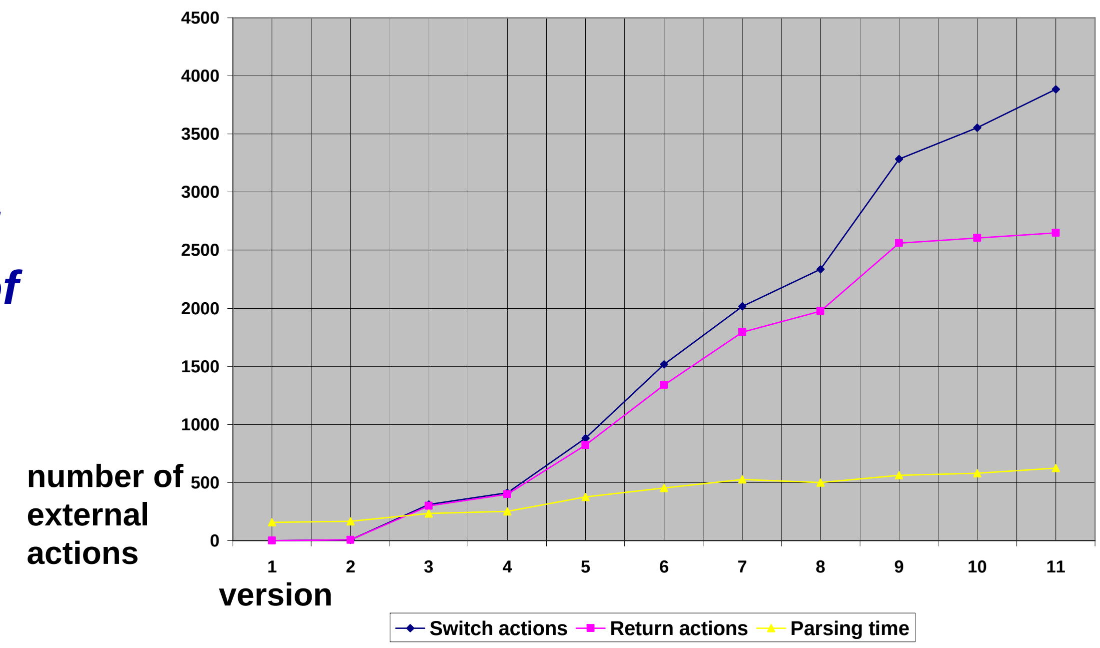
- **Expressive power**
  - CLR's backtracking can resolve the traditional shift-reduce or shift-shift conflicts in LR parsers
- **Ambiguous tokens**
  - Benefited by multiple lexers
  - Useful for embedded languages, languages with no reserved words, etc.
    - SQLJ: **`count`**
    - PL/I example **`IF IF = THEN THEN IF = THEN;`**

Performance measurement



Parsing speed comparison among 11 versions of CLR implementation of JLS

The increase of external actions as the number of components increases



Outline

- Background knowledge
- Problem statement
- Related work
- Framework overview
- Component-based language development
- **OOS and AOS**
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- Conclusion

Design principle

Object-orientation → Data structures → Syntax analysis

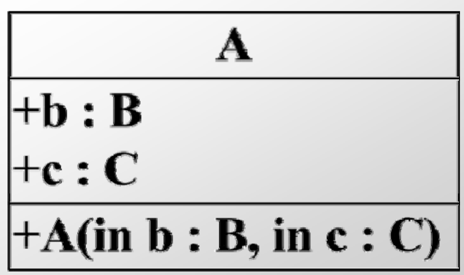
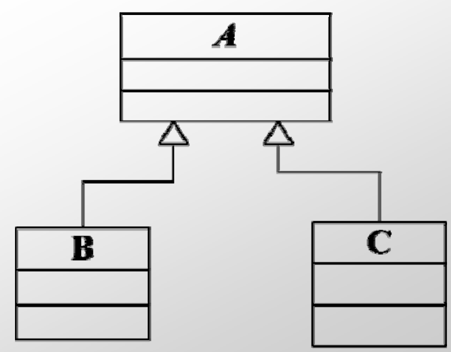
Aspect-orientation → Crosscutting behaviors → Semantic analysis

Syntax can be easily specified by formal specification but semantics cannot due to its arbitrary nature

	Object-orientation	Aspect-orientation
Formal specification	Syntax analysis	
Programming language		Semantic analysis

Object-oriented syntax

A ::= B C | D; ✗

OOS specification	A ::= B C	A::= B | C
LHS and RHS relationship	Aggregation	Inheritance
Generated Cup specification	CUP: A ::= B : B C : C {:Result = new A(B,C);:}	A ::= B : B {: Result = B; :} | C : C {: Result = C; :}
Node class diagram		

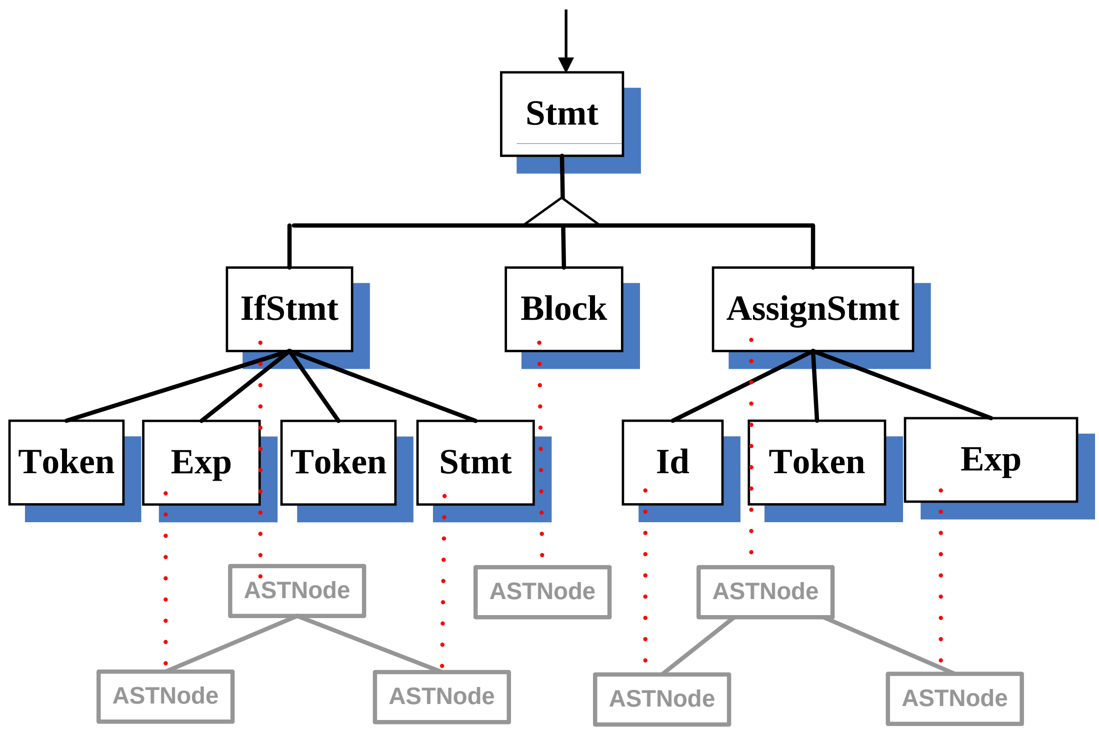
```
// Syntax definition
Stmt ::= Block
         | “if” Expr “then” Stmt
         |  Id “:=” Exp
```

JastAdd specification

```
// Tree definition
abstract Stmt;
BlockStmt : Stmt ::= Block;
IfStmt : Stmt ::= Exp Stmt;
AssignStmt : Stmt ::= Id Exp;
```

Object-oriented syntax

```
Stmt ::= Block | IfStmt | AssignStmt.
IfStmt ::= “if” Exp “then” Stmt.
AssignStmt ::= Id “:=” Exp.
```



OOCFG specification features and their usage

- Object-oriented grammar definition
  - Enabling an object-oriented relationship between LHS symbol and RHS symbols, therefore removing the need to provide a separated specification for syntax tree construction.
- AST and CST
  - Providing semantic analysis the flexibility in tree selection and ensuring all analysis needs can be easily computed
- Typed LHS symbol – no node class generation
  - Promoting the reuse of existing node classes
- Macros – only occur in syntax trees, transparent to parser
  - Reducing parsing conflicts while providing richer description of the grammar and distinct syntax tree nodes
- Templates – generic production definitions
  - Facilitating OOCFG to support generic production definition in a grammar specification

Abstract syntax tree vs. concrete syntax tree

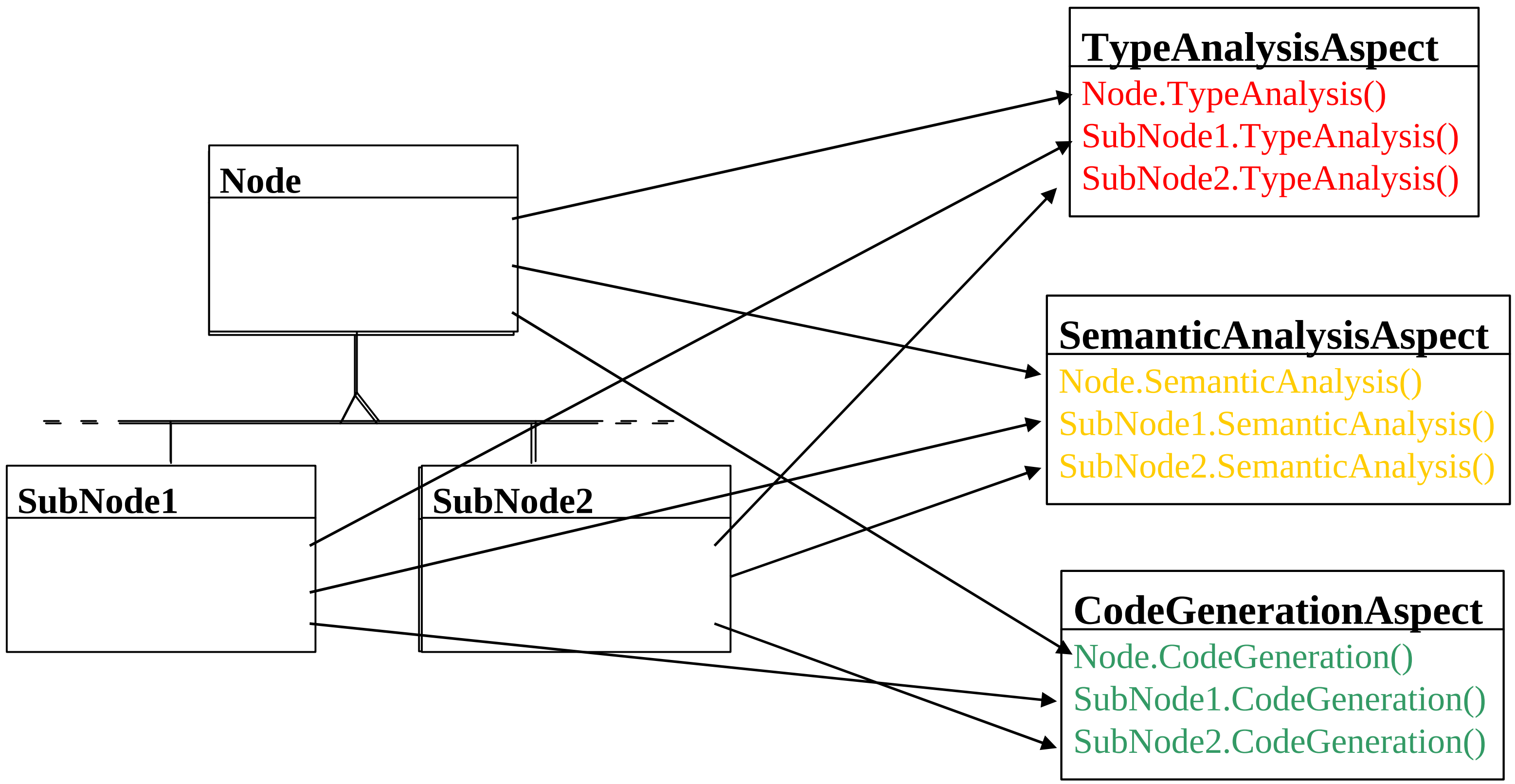
	Concrete Syntax Tree	Abstract Syntax Tree
Co-relation to syntax and semantics	Syntax-oriented	Semantics-oriented
Level of details	Low level syntax details.	High level abstraction
Type of tree nodes	Strongly-typed	Weakly-typed
Type of tree links	Immutable	Programmable
Usage mode	Read-only	Read and write enabled

OOS specification generates both concrete syntax tree and abstract syntax tree to fully satisfy various semantic analysis requirements

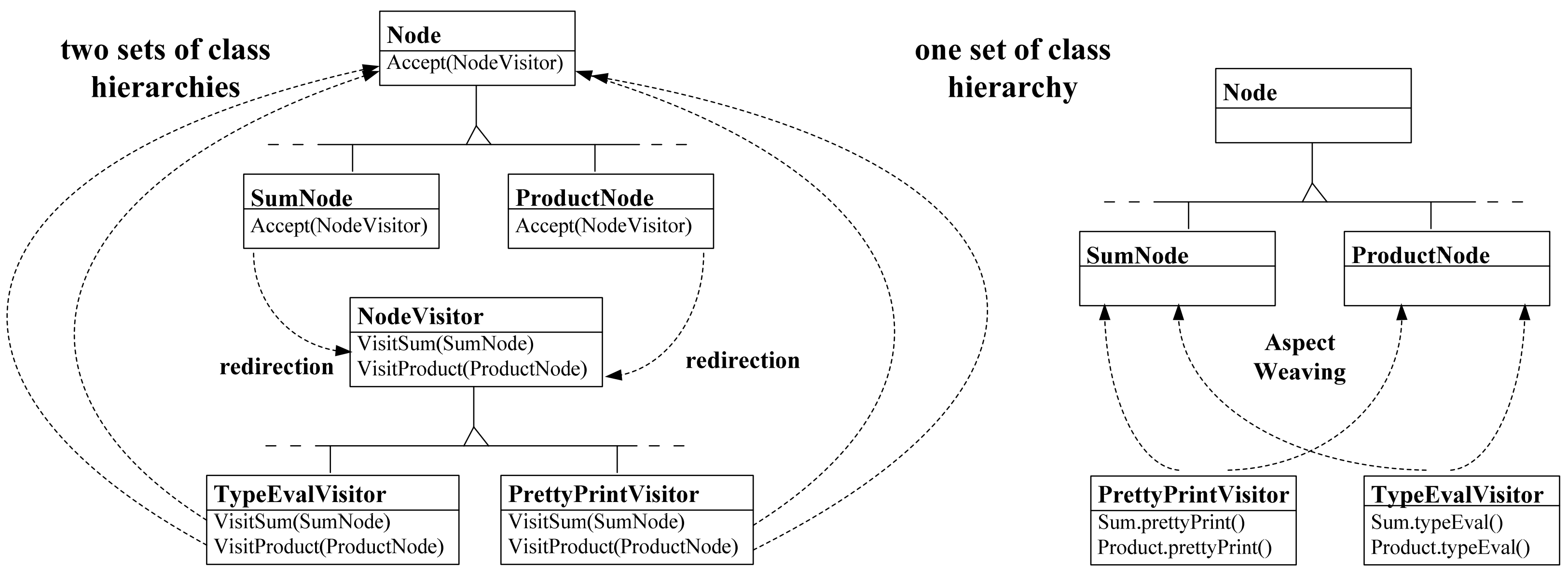
Aspect-oriented semantics implementation

- Each semantic concern is modularized as an aspect
  - An independent semantic pass
  - A group of action codes
- Semantic pass
  - Implemented as introductions to the syntax tree classes
- Crosscutting actions applied to a group of nodes
  - Weaved into syntax tree classes as interceptions

Introductions



Aspect-oriented introduction vs. object-oriented Visitor pattern



```java
class UnparseVisitor extends Visitor{
   protected PrintStream out = System.out;
   public Object print(Node node){
      // ...
   }
   // Other utility routines
   // ...
   public Object visit(Node node){
     return print(node);
   }
   public Object visit(CompilationUnit node){
     return print(node);
   }
   // same visit methods for another 83 nodes.
   // ...
}
```

```java
aspect Unparse{
   protected PrintStream out = System.out;
   public static void print(Node node){
      // ...
   }
   // other utility routines
   // ...
   public void Node.unparse(){
      Unparse.print(this);
   }
}
```

500 lines of redundant code have been removed !

Interception

```
pointcut scopeEvaluate(): target(ScopeNode+) && call (* *.evaluate()) ;

before() : scopeEvaluate(){
    symTabs.push(currentSymTab);
SymbolTable tmp = currentSymTab;
currentSymTab = new SymbolTable();
currentSymTab.parentScope = tmp;
}
```

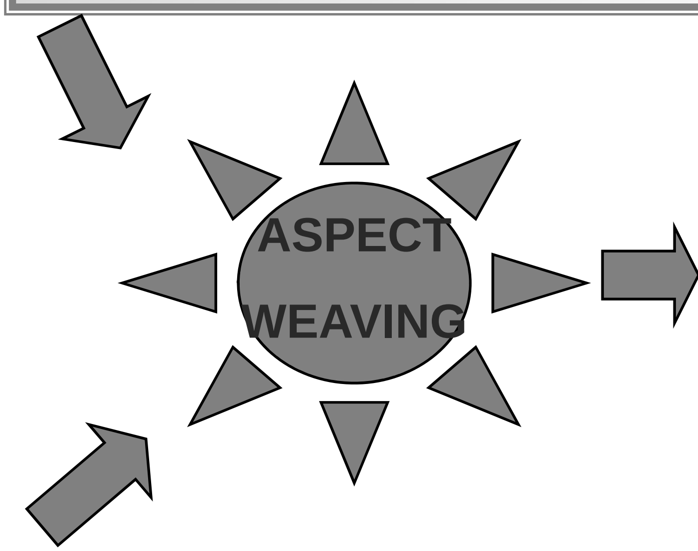
Executed each time entering a new scope

Occurred 46 times in a parser!

```
after() : scopeEvaluate(){
currentSymTab = (SymbolTable)symTabs.pop();
}
```

Executed each time leaving a scope

```
before() : scopeEvaluate(){
  symTabs.push(currentSymTab);
  SymbolTable tmp = currentSymTab;
  currentSymTab = new SymbolTable();
  currentSymTab.parentScope = tmp;
}
after() : scopeEvaluate(){
  currentSymTab = (SymbolTable)symTabs.pop();
}
```




```
…
// node is an instance of ScopeNode
node.evaluate();
…
```

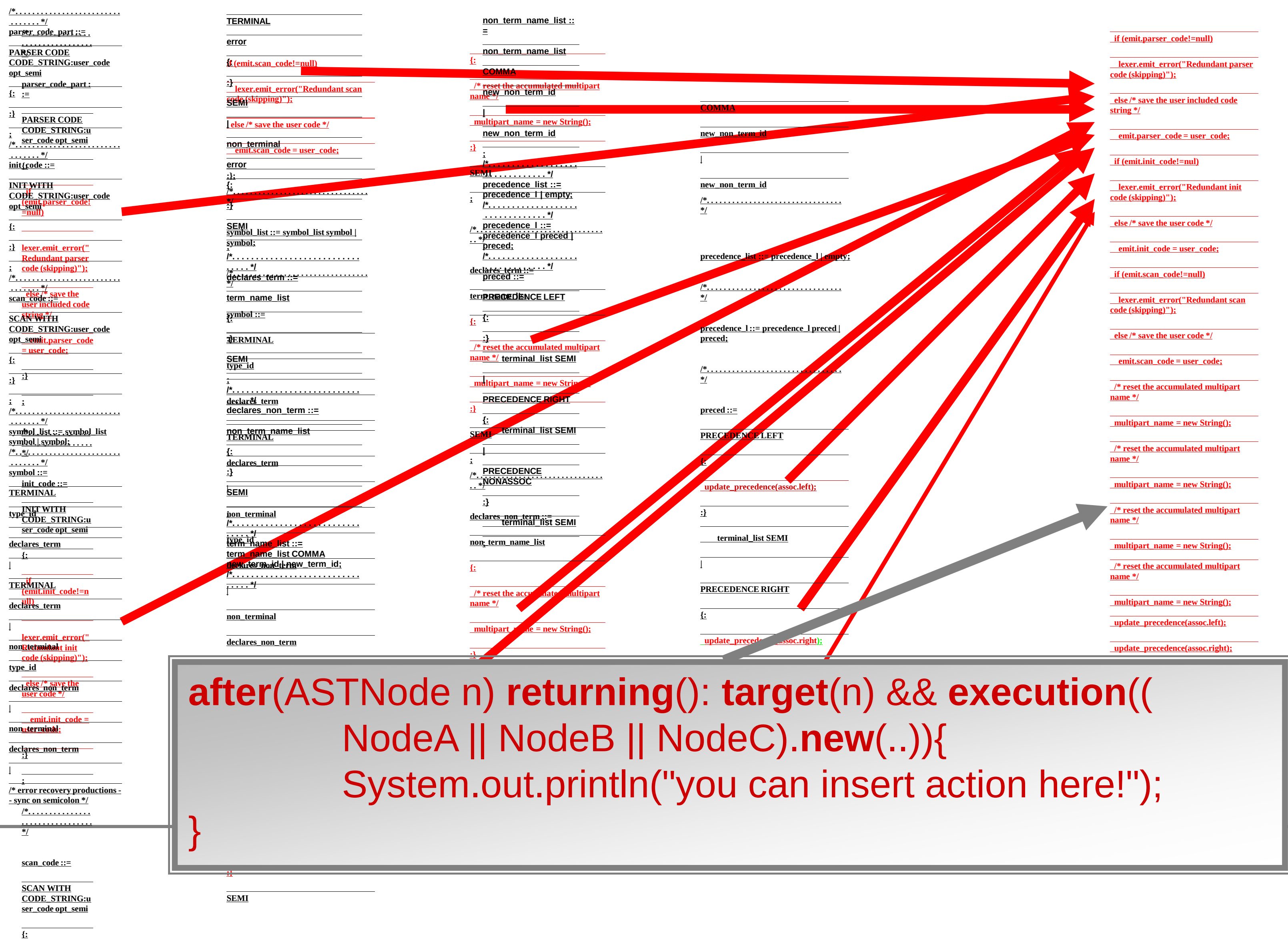
```
…
// node is an instance of ScopeNode
symTabs.push(currentSymTab);
SymbolTable tmp = currentSymTab;
currentSymTab = new SymbolTable();
currentSymTab.parentScope = tmp;

node.evaluate();

currentSymTab =
(SymbolTable)symTabs.pop();
…
```

Interception to parser

parser.cup **Action.aj**



```
after(ASTNode n) returning(): target(n) && execution((
        NodeA || NodeB || NodeC).new(..)){
        System.out.println("you can insert action here!");
}
```

AOS advantages

- Aspect-orientation can isolate crosscutting semantic behavior in an explicit way
  - Each semantic aspect can be freely attached to (generated) AST nodes without "polluting" the parser or AST node structure.
  - Different aspects can be selectively plugged in for different purposes at compile time.
  - Since each aspect is separated with other aspects, developers can always come back to the previous phase while developing a later phase.

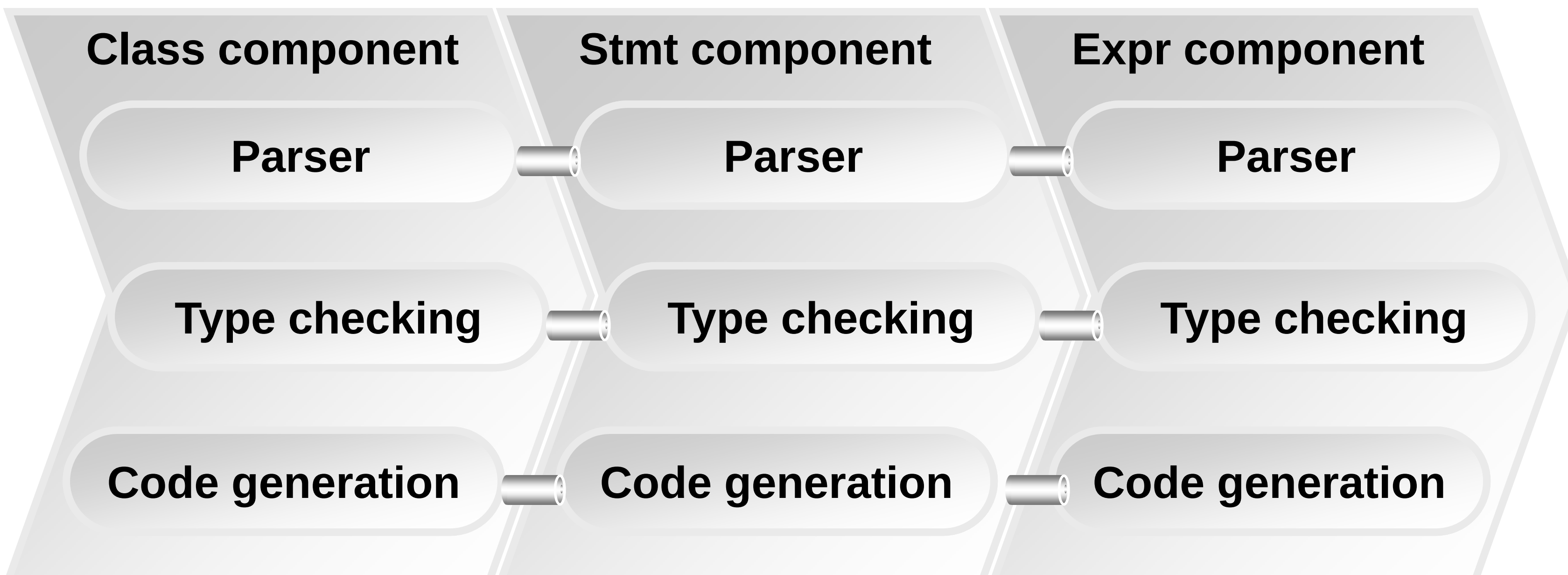
AOS advantages (cont'd)

- Inter-type dec
  - Defined withi
    node class m
  - Extend the ol
    promote sem
- Join-point mo
  - Provide flexib
    nodes or parser
  - Avoid code duplication
  - Trace facility
- Introduction + Interception
  - Tree traversal
  - Phase combination

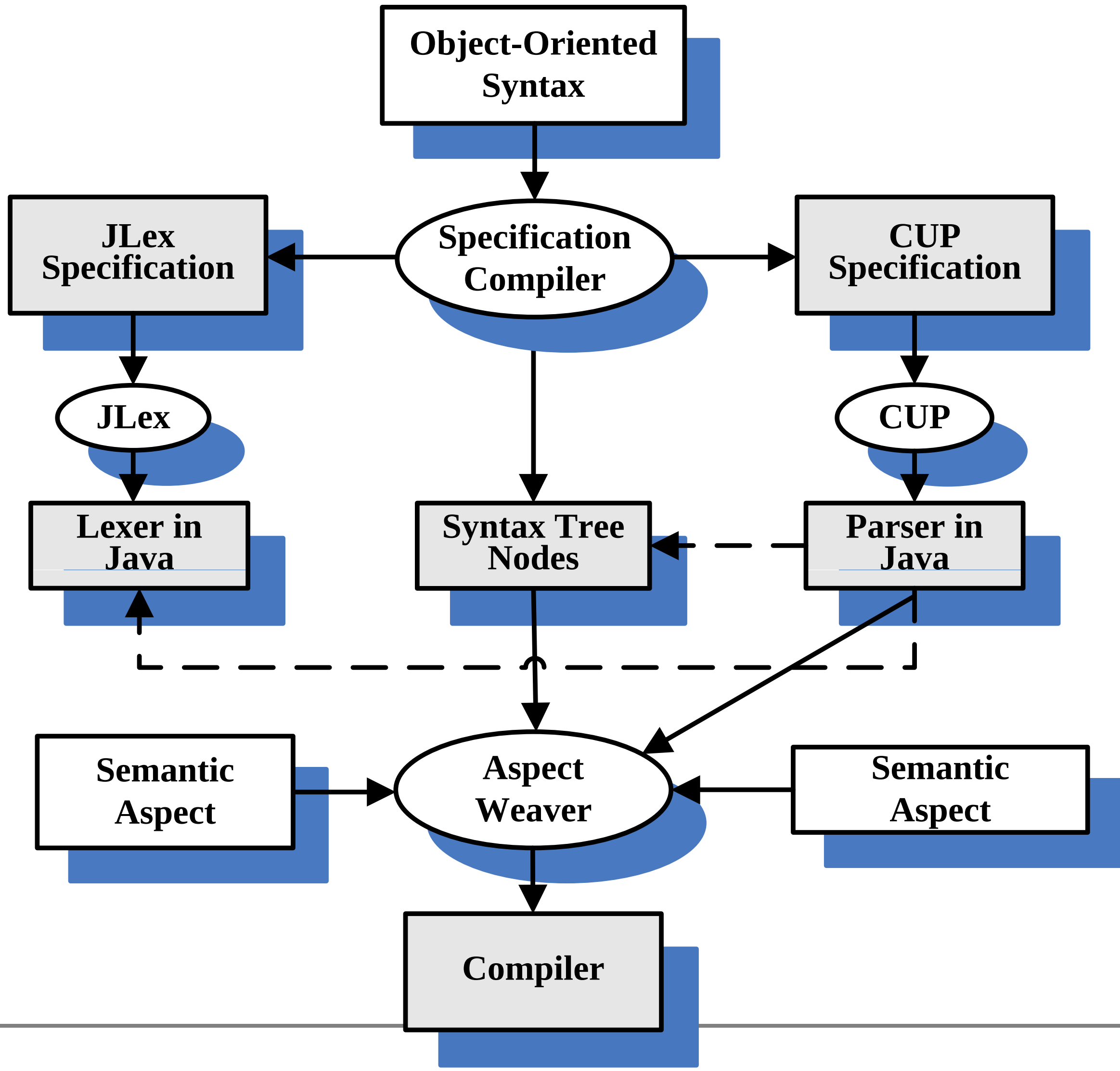
```
aspect PrintNodeCreation {
    pointcut construction(Node n): target(n)
        && execution((Node+ && !Node).new(..));
        after(Node n) returning():construction(n) {
            System.out.println(
                thisJoinPointStaticPart.getSignature()
                .getDeclaringType().getName()+"is created");
        }
}
```

Integration with CLR parsing

- Syntax specification ➔ The restrictions of OOS can be applied to CCFG without generating any side-effects
- Syntax tree construction ➔ CLR's parse tree generation process is inlined with OOS tree generation
- Semantic analysis ➔ Semantic composition follows syntax tree composition



OOS + AOS implementation



Outline

- Background knowledge
- Problem statement
- Related work
- Framework overview
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- **Framework usage**
- Future work
- Conclusion

Case studies

- Pam and BasicM
- RelationJava
- OOCFG Converter
- Bootstrap Implementation
- Google Query Language
- Java

- Changeability
- Reusability
- Independent development ability
- Readability
- Flexible semantics
- Flexible syntax/tree

Outline

- Background knowledge
- Problem statement
- Related work
- Framework overview
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- Conclusion

Future work

- CLR backtracking
  - Time complexity
  - Error recovery
- Module inclusion
- Grammar aspects
- Support of other parsing paradigms
- Rich client platform based on eclipse platform

Outline

- Background knowledge
- Problem statement
- Related work
- Framework overview
- Component-based language development
- OOS and AOS
  - Object-oriented syntax
  - Aspect-oriented semantics
- Framework usage
- Future work
- **Conclusion**

Conclusion

- Compiler design is an intricate task because it is hard to be modularized (structure wise and function wise).
- The presented framework presents a solution that can attack the modularity problems in two dimensions
  - CLR decreases the complexity of building a large language by constructing a set of smaller language parsers from grammar components
  - OOS + AOS provides a clean separation of concerns between syntax and semantics as well as semantic phases themselves
  - The framework also supersedes conventional language implementation practices by its description power, reduced specification, and support to describe crosscutting semantic behaviors, etc.
- Various experiments prove that the methodology increases the comprehensibility, reusability, changeability, extendibility and independent development ability of both syntax and semantics specification with less development workload required from compiler designers.

Further Information

Contact:

bryant@cis.uab.edu

Web Page:

http://www.cis.uab.edu/softcom/cde