Compiler Compiler Tutorial

CSA2010 – Compiler Techniques

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Introduction

- With so many Compilers around, do we need to write parsers/compilers in industry?

- FTP interface
- Translator from VB to Java
- EPS Reader
- NLP

Topics

- Prerequisites
- Compiler Architecture/Modules
- JavaCC
- Semantic Analysis
- Code Generation and Execution
- Examples
- The assignment (SFL)

Prerequisites

- Java
- Regular Expressions
  - ? + * …
- Production rules and EBNF
- Semantics

Regular Expressions

- Repetitions
  - \+ = 1 or more
  - * = 0 or more
  - ? = 0 or 1
- Examples
  - a+ - a, aa, aaa
  - b* - , b, bb
  - c? - , c

- Alternative
  - a | b = a or b
- Examples
  - a | b - a, b

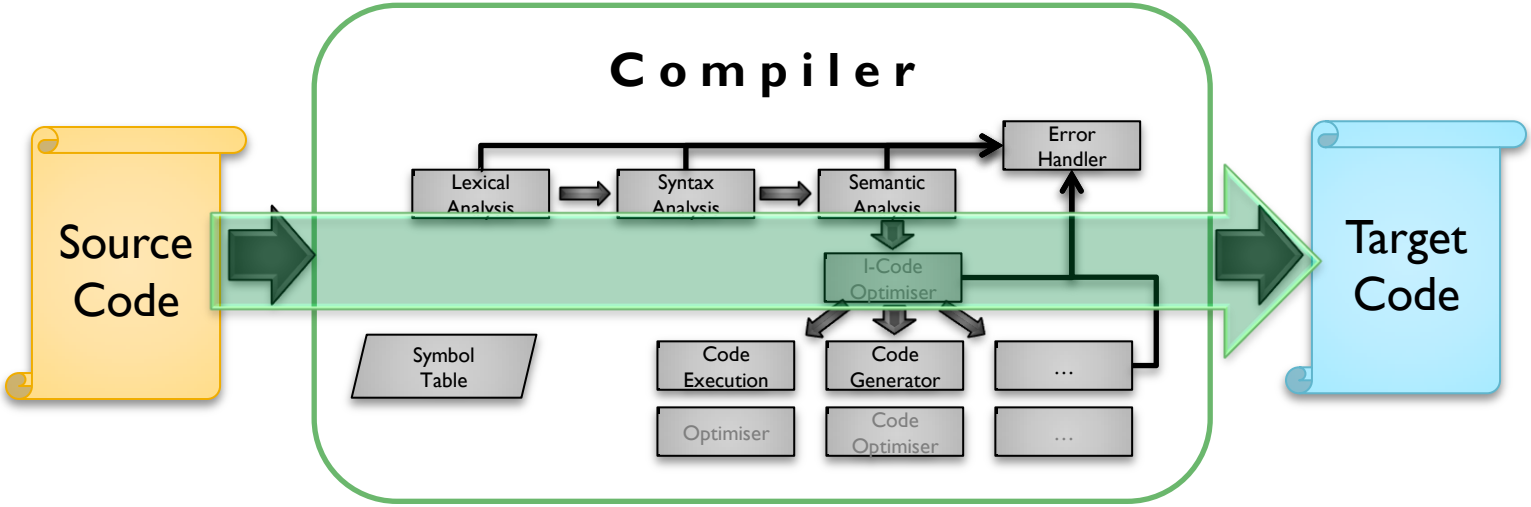
- Ranges
  - [a-z] = a to z - a,b,c,d,e,f,g,…,y,z
  - [fls] = f, l and s - f,l,s
  - [^cde] = not c,d,e - a,b,f,g,…,y,z

Compiler

- What is a compiler?
  - Where to start from?
  - Design / Architecture of a Compiler

Compiler

- Is essentially a complex **function** which **maps** a program in a **source** language onto a program in the **target** language.



Translation

Source Code

```
function Sqr( x : int ) : int
{
    let n : int = x;
    n <- n * n;
    return n;
}
```

Target Code

```
push        ebp
mov         ebp,esp
sub         esp,0CCh
push        ebx
push        esi
push        edi
lea         edi,[ebp-0CCh]
mov         ecx,33h
mov         eax,0CCCCCCCCh
rep stos    dword ptr es:[edi]
mov         eax,dword ptr [x]
mov         dword ptr [n],eax
mov         eax,dword ptr [n]
imul        eax,dword ptr [n]
mov         dword ptr [n],eax
mov         eax,dword ptr [n]
pop         edi
pop         esi
pop         ebx
mov         esp,ebp
pop         ebp
ret
```

Translation

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function Sqr( x:int ): int
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Compiler

Translation

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push        ebp
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mov         ecx,33h
mov         eax,0CCCCCCCCh
rep stos    dword ptr es:[edi]

mov         eax,dword ptr [x]
mov         dword ptr [n],eax

mov         eax,dword ptr [n]
imul        eax,dword ptr [n]
mov         dword ptr [n],eax

mov         eax,dword ptr [n]

pop         edi
pop         esi
pop         ebx
mov         esp,ebp
pop         ebp
ret
```

Production Rules

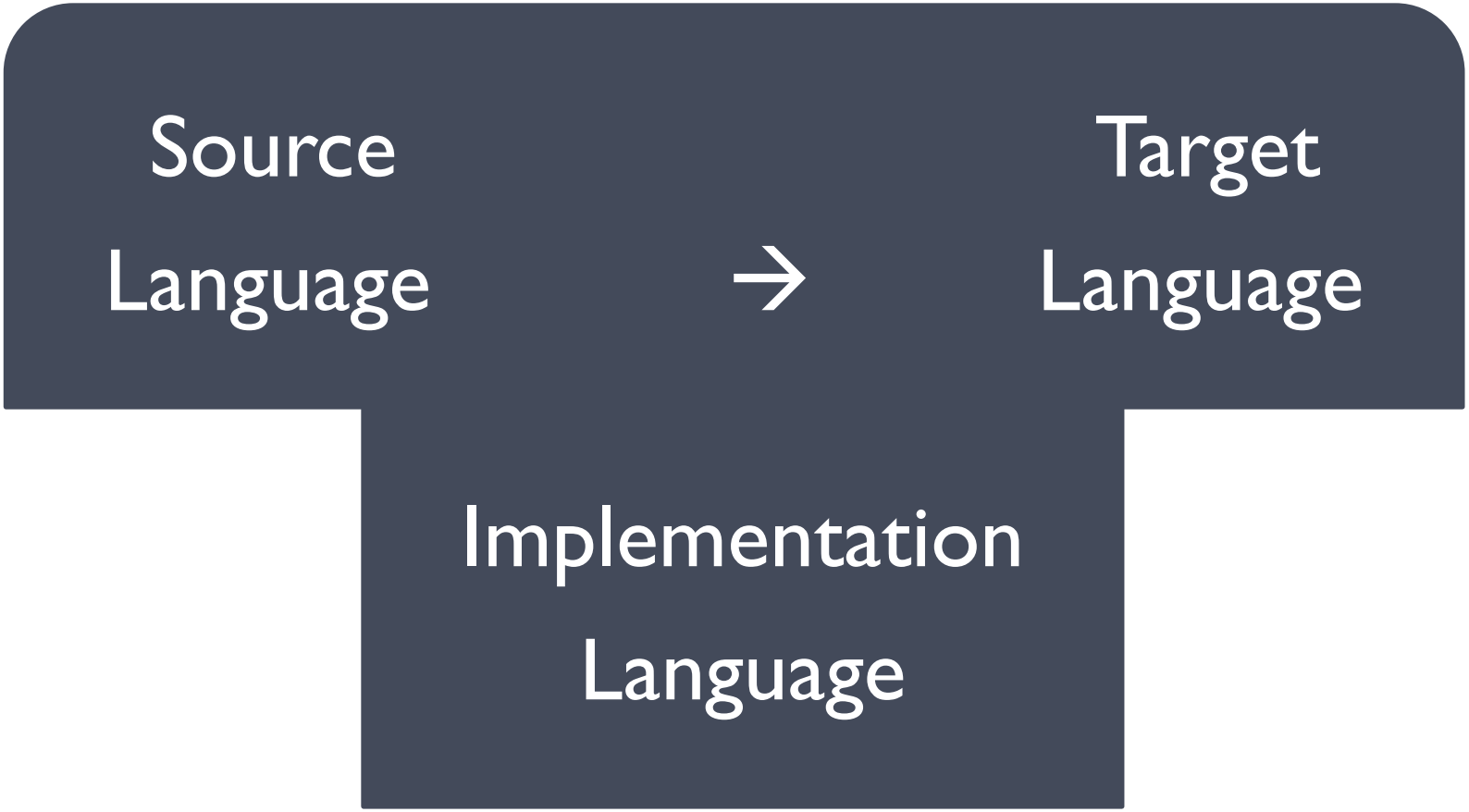
- Context Free Grammars
  - A → B “c” D
- BNF
  - A ::= B “c” D
- EBNF
  - A ::= B* “c”? D+

The Language game

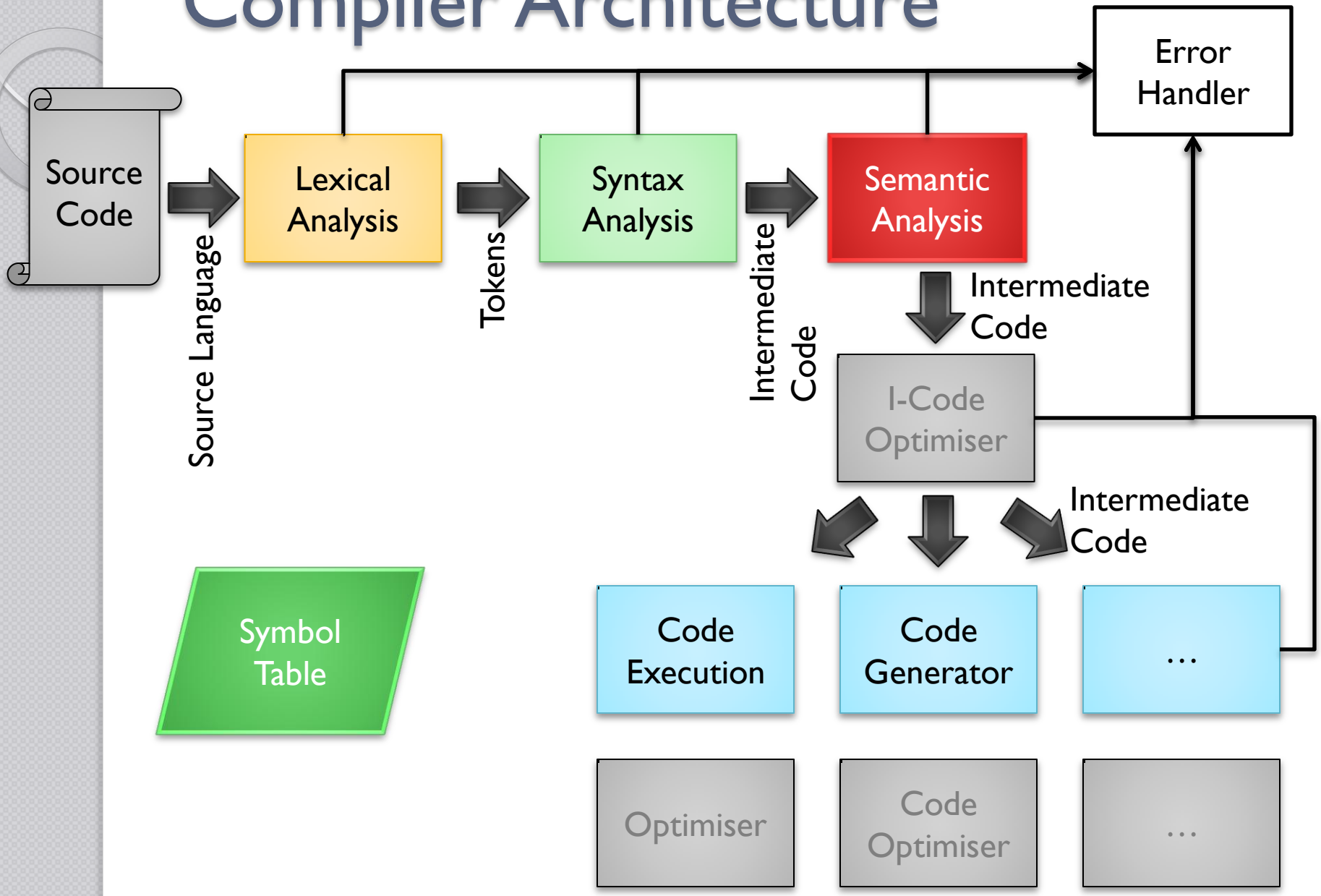
- Source Language
- Target Language
- Implementation Language

…

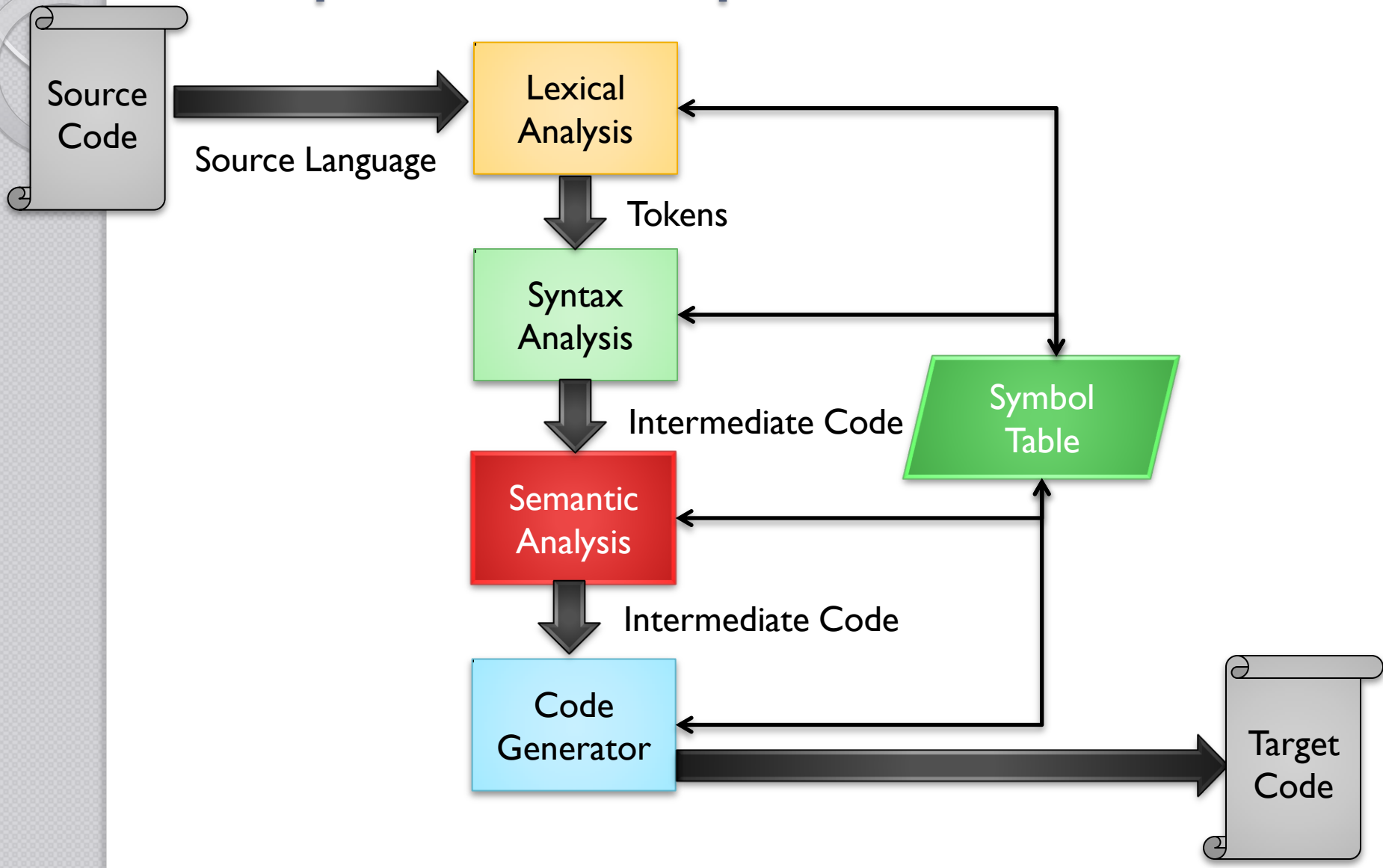
Tombstone Diagram



Compiler Architecture



Simplified Compiler Architecture



Lexical Analysis

- Tokenises the source file
  - Removes whitespace
  - Tokens
  - Keywords

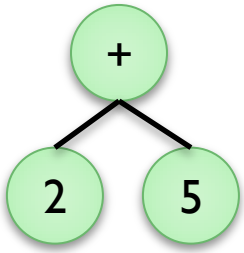
Source Code

```
function Sqr( x : int ) :
int
{
    let n : int = x;
    n <- n * n;
    return n;
}
```

```
Function    (Keyword)
Sqr         (Identifier)
(           (Lparen)
X           (Identifier)
:           (Colon)
Int         (Keyword)
)           (Rparen)
:           (Colon)
Int         (Keyword)
{           (Lbrace)
Let         (Keyword)
N           (Identifier)
:           (Colon)
Int         (Keyword)
=           (Eq)
X           (Identifier)
;           (Semicolon)
...
```

Syntax Analysis (Parser)

- Checks that the source file conforms to the language grammar
  - E.g. FunctionCall ::= “function” identifier “(“ …
- Creates intermediate code
  - ParseTree



Source Code ✓

```
function Sqr( x : int ) …
```

Source Code ✗

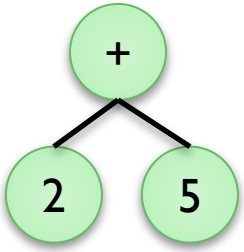
```
function 1.5( x : int )
…
```

Semantic Analysis

- Checks that the meaning behind the syntax makes sense, according to the type-system
  - E.g. let x : int = 3;
    x:int, 3:int 
  - E.g. let x : int = 3.2;
    x:int, 3.2:Real 

Code Generation / Execution

- Traverses the Intermediate Code representation and generates or executes the code




```
PlusNode.Execute()
{
        return leftChild.Execute() +
                rightChild.Execute() ;
}
```

```
IntLiteralNode.Execute()
{
        return Integer.parseInt(this.getValue());
}
```

Symbol Table

- Important Data Structure
  - Keeps information about every identifier in the source
    - Variables
    - functions
    - Labels …
  - Keeps the scope information
  - Entry Properties
    - Name
    - Type
    - Value
    - Scope

Symbol Table

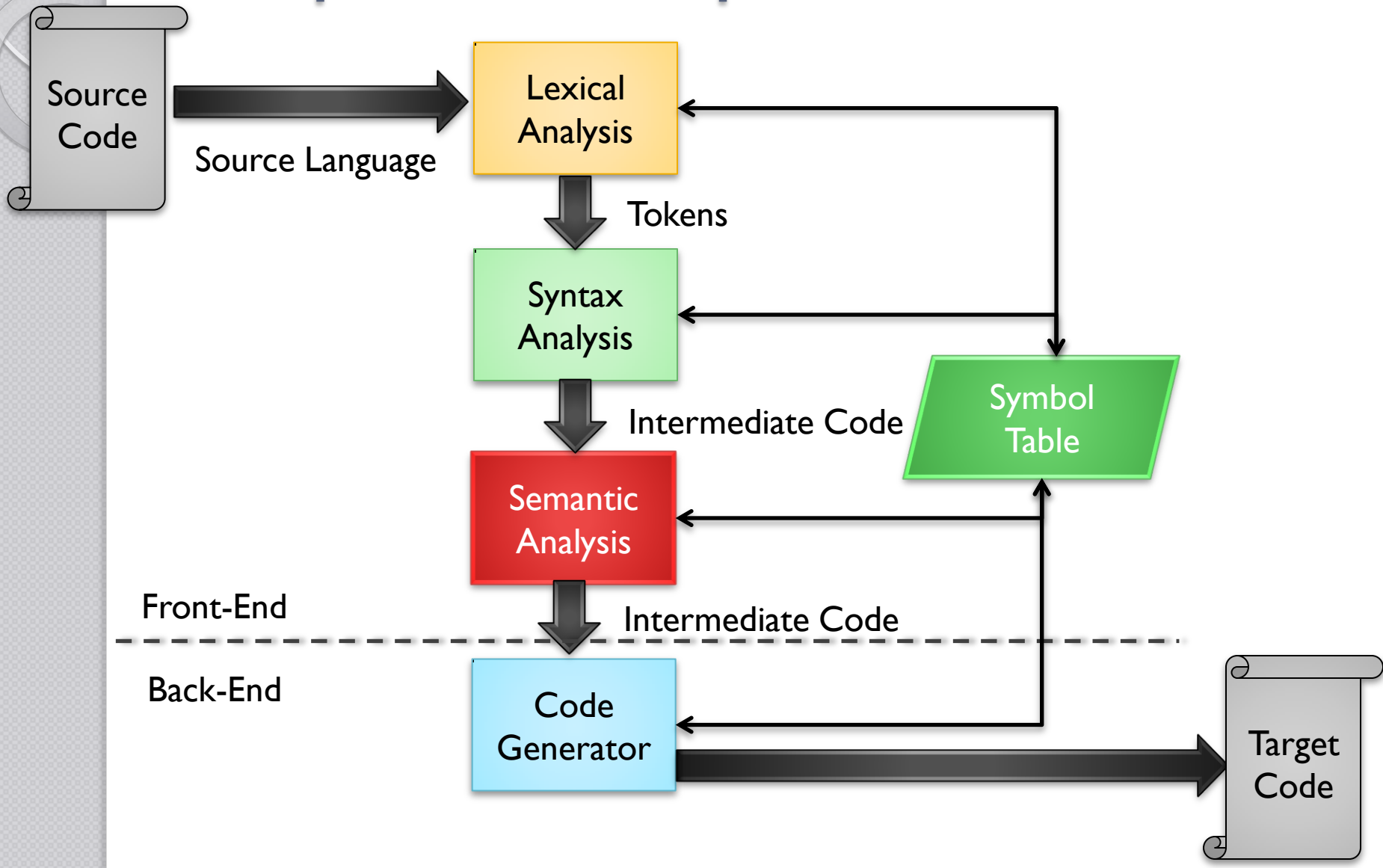
A data structure that maps an Identifier's name onto a structure that contains the identifier's information

Name → (Name, Type, Value, Scope)

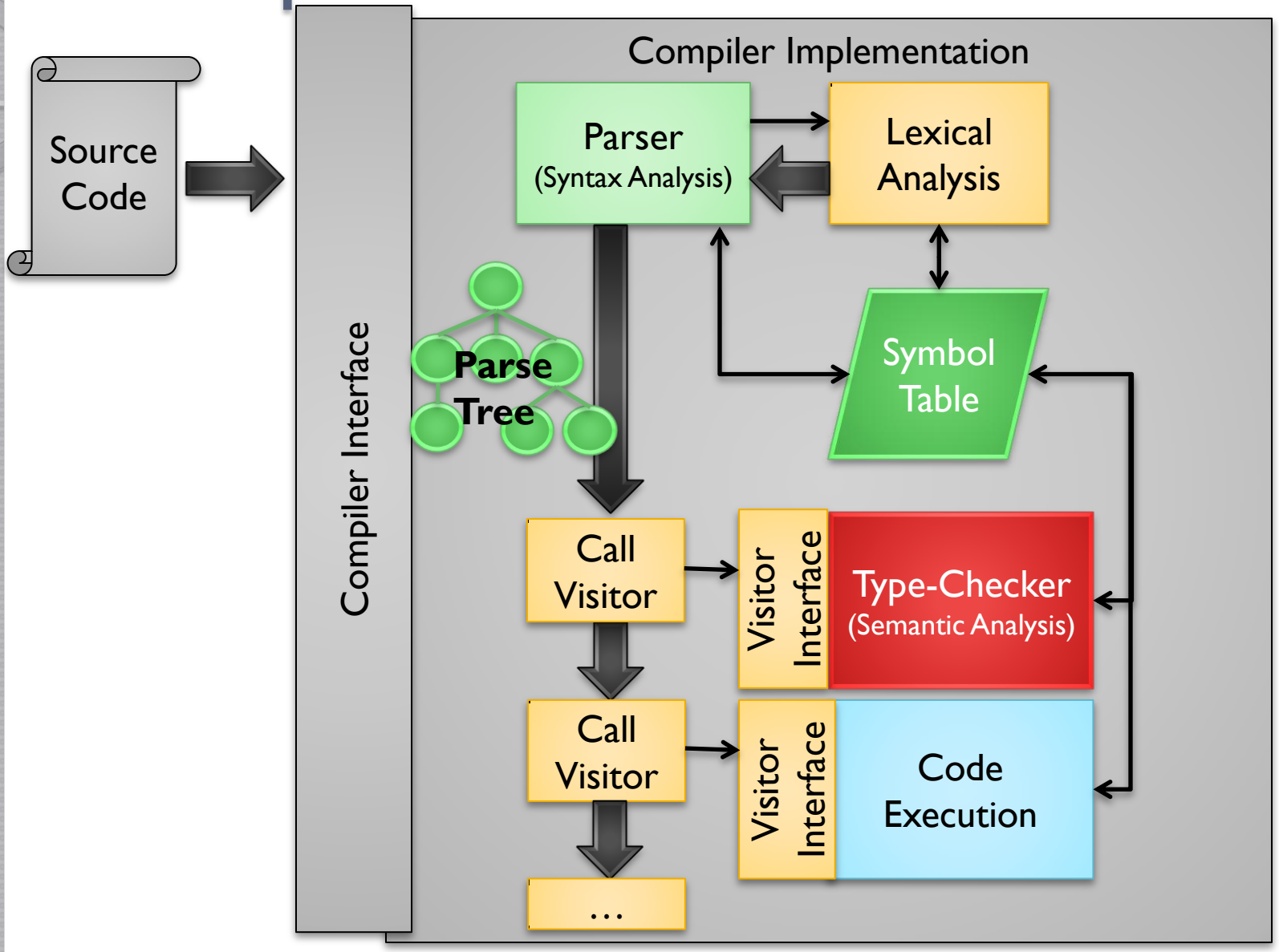
Symbol Table

- Easiest way is to make use of a hash-table / hash-map
- Create a new Hash-map for each new scope

Simplified Compiler Architecture



Compiler Architecture



Java Interfaces

- Interface is a contract
- Class implements interface
  - Honours the contract
  - Implements the methods of the interface
- Interface variable can hold instance of a class that implements that interface

Java Interfaces

```
public interface IAdder
{
    int add(int n, int m);
}
```

```
public interface IMinus
{
    int subtract(int n, int m);
}
```

```
public class SimpleMath
implements IAdder, IMinus
{
    public int add(int n, int m)
    { … }

    public int subtract(int n, int m)
    { … }
}
```

```
public static void main(…)
{
    IAdder a = new SimpleMath();
    IMinus s = new SimpleMath();

    a.add(1,2);
    s.subtract(4,2);
}
```

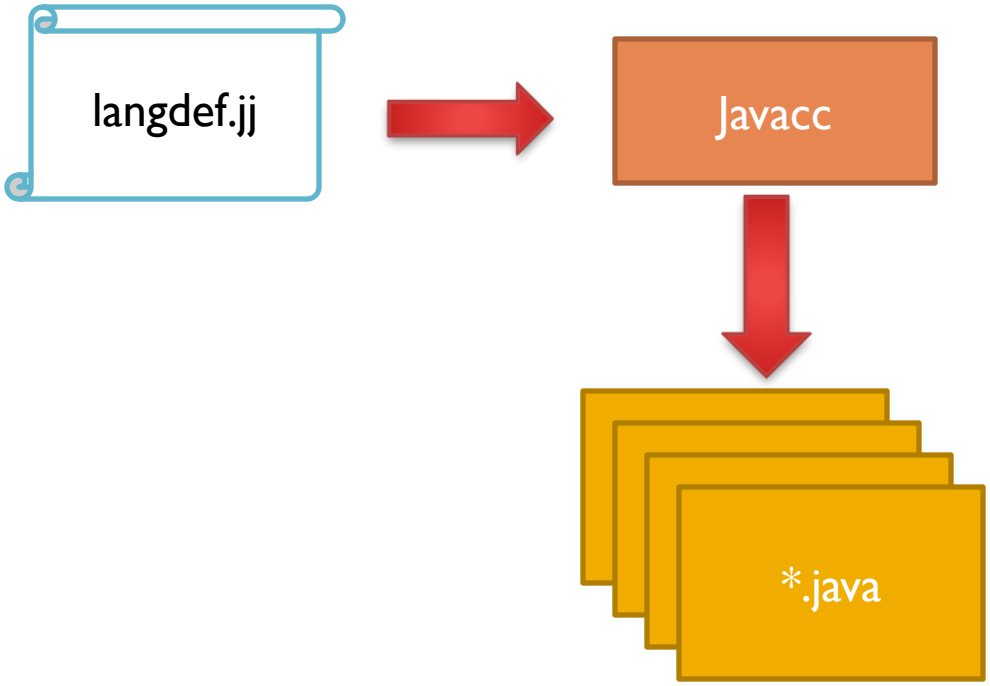
Program Generators?

- Source-to-Executable
  - Compiler
- Reverse Polish Notation
  - 2 + 3 - 4 → 2 3 + 4 -
- Source-to-Source
  - Preprocessors

Javacc

- A program that creates parsers
- The source code(input) is a definition file
  - Grammar definition
  - Inline Java code
- The target(output) is java-based parser
- Recognizer?

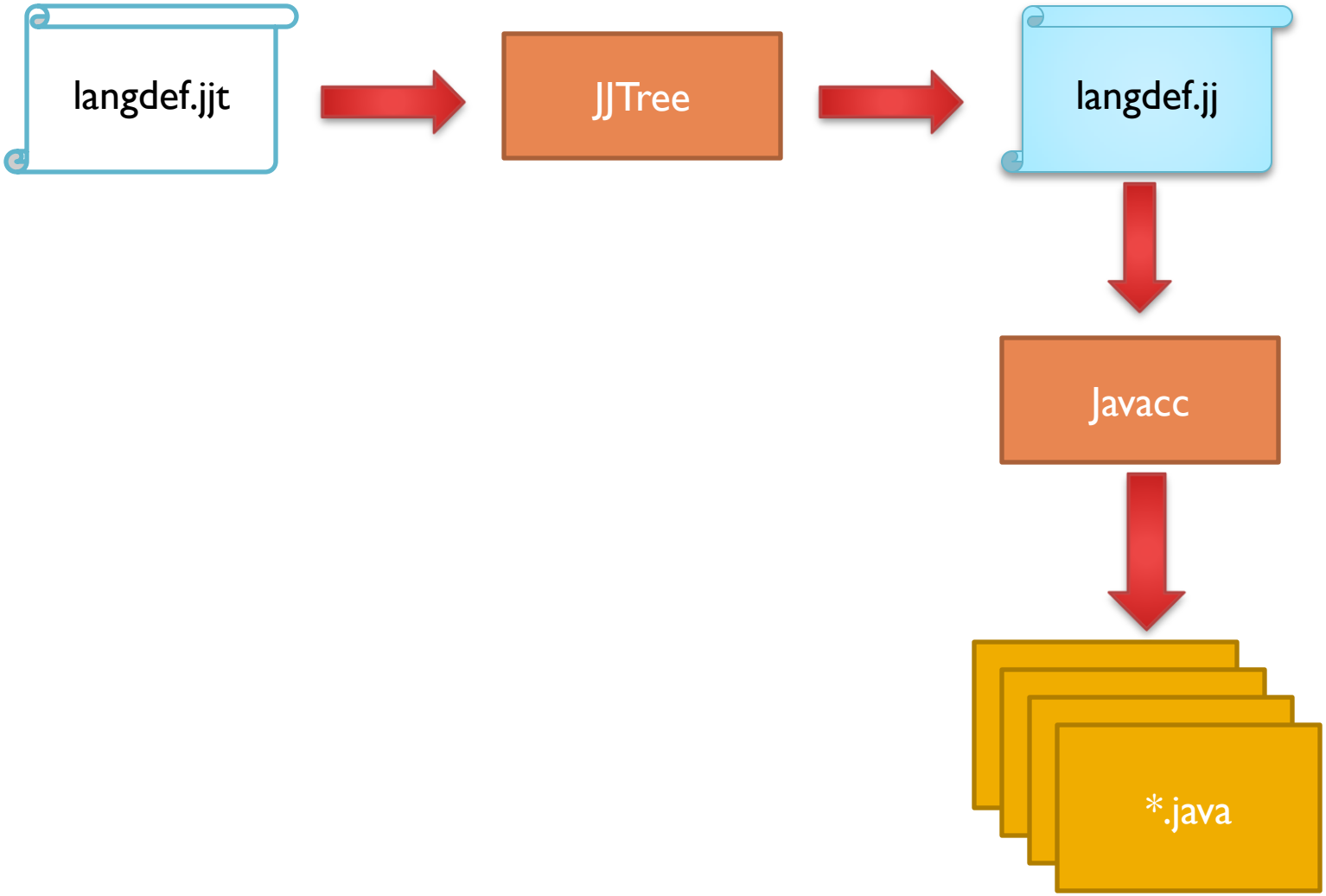
Javacc



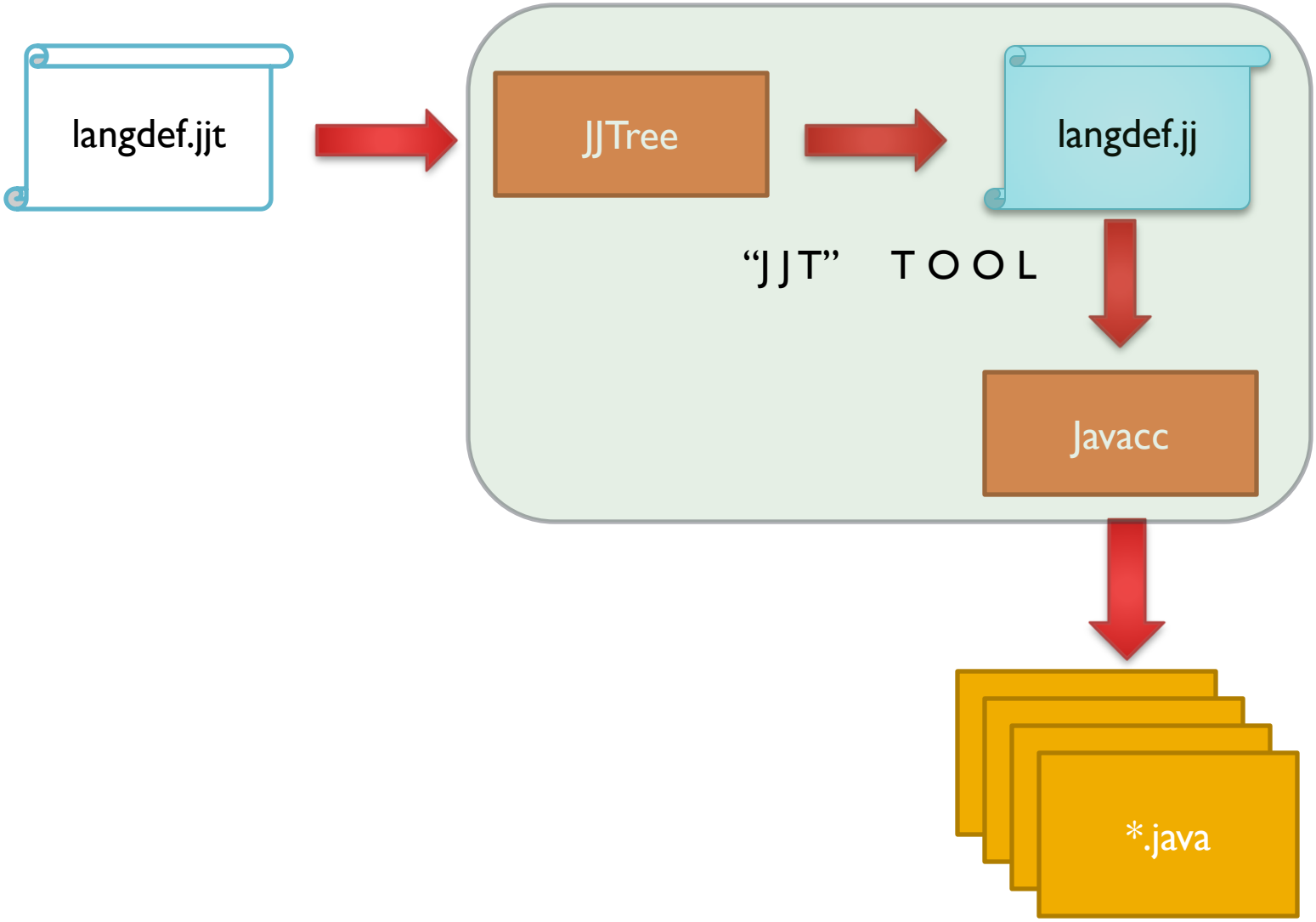
JJTree

- From a recognizer to a parser
- Preprocessor to Javacc
- Produces Parse Tree building actions
- Creates ".jj" files from ".jjt" files

JJTree



JJTree



Installing Javacc

- https://javacc.dev.java.net/
  - Javacc.zip / Javacc.tar.gz
- Eclipse plugin
  - Preferences->Install/Update->Add
    - http://eclipse-javacc.sourceforge.net/
  - Help->New Software

.jjt Grammar Files

- Four (4) sections
  - Options
  - Parser
  - Tokens
  - Production Rules

.jjt Options

```
options
{
   BUILD_NODE_FILES=false;
   STATIC=false;
   MULTI=true;
   …
}
```

.jjt Parser block

PARSER_BEGIN(**parser_name**)

…

public class **parser_name**

{

…

}

…

PARSER_END(**parser_name**)

.jjt Tokens

- Lexeme to ignore

```
SKIP :
{
  " "
  | "\t"
  | "\n"
  | "\r"
  | <"//" (~["\n","\r"])* ("\n"|"\r"|"\r\n")>
}
```

.jjt Tokens

- Tokens that are to be returned

```
TOKEN :
{
  <PLUS:“+”>
  |<TRUE: "true" >
  | <FALSE: "false" >
  | <LETTER: (["A"-"Z"] | ["a"-"z"]) >
  | <STRING_LITERAL: "\"" (~["\"","\r","\n"])* "\"" >
  | <#DIGIT: [“0”-”9”]>
}
```

.jjt Production Rules

- Assume the following:

Header → "**Script**" <STRING_LITERAL>

or

Header ::= "**Script**" <STRING_LITERAL>

.jjt Production Rules

- Assume the following:

Header ::= “Script” <STRING_LITERAL>

```
void Header():
{
  <SCRIPT> <STRING_LITERAL>
}
```

.jjt Production Rules

Header ::= “Script” <STRING_LITERAL>

```
void Header(): { int n = 0; n++;}
{
  <SCRIPT> <STRING_LITERAL>
  { n++; }
}
```

.jjt Production Rules

- Calling Non-Terminals

```
void Integer(): {}
{ … }

void Header(): { }
{
   <SCRIPT>
   Integer()
}
```

.jjt Production Rules

- Token matching - Actions

```
void Header(): { int n = 0; n++; }
{
  <SCRIPT>{ n = 1; }
  <STRING_LITERAL>
  { n++; }
}
```

.jjt Production Rules

- Getting Token value

```
void Number()
{ Token t;
  int n = 0; }
{
  t=<DIGIT>{ n = integer.parseInt(t.image);
  }
}
```

Lookahead

- Consider the following java statements
  - public int name;
  - public int name[];
  - public int name() { … }

Building the AST

```
options
{
   STATIC=false;
   MULTI=true;
   BUILD_NODE_FILES=true;
   NODE_USES_PARSER=false;
   NODE_PREFIX="";
   …
}
```

Building the AST

```
SimpleNode Start() : {}
{
  Expression()
  ";"
  <EOF>
  {
      return jjtThis;
  }
}
```

Parsing

```
PARSER_BEGIN(MyParser)
...
MyParser parser = new MyParser(System.in);
try {
   SimpleNode n = parser.Start();
   System.out.println(“Parsed!");
} catch (Exception e) {
      System.out.println("Oops!");
      System.out.println(e.getMessage());
}
...
PARSER_END(MyParser)
```

Example

Digit ::= [“**0**” - “**9**”]

Number ::= Digit+

Plus ::= “+”

Minus ::= “**-**”

Op ::= Plus | Minus

Expression ::= Number { Op Number }

Example

```
TOKEN:
{
< NUMBER: <DIGIT>+ >
| < Digit: [“0” - “9”] >
| < PLUS:“+” >
| < MINUS:“-” >
}
```

Digit ::= [“0” - “9”]
Number ::= Digit+
Plus ::= “+”
Minus ::= “-”

Example

```
void Op() :{}
{
   < PLUS > | < MINUS >
}

void Expression(): {}
{
   < Number >
   (Op() < Number >)*
}
```

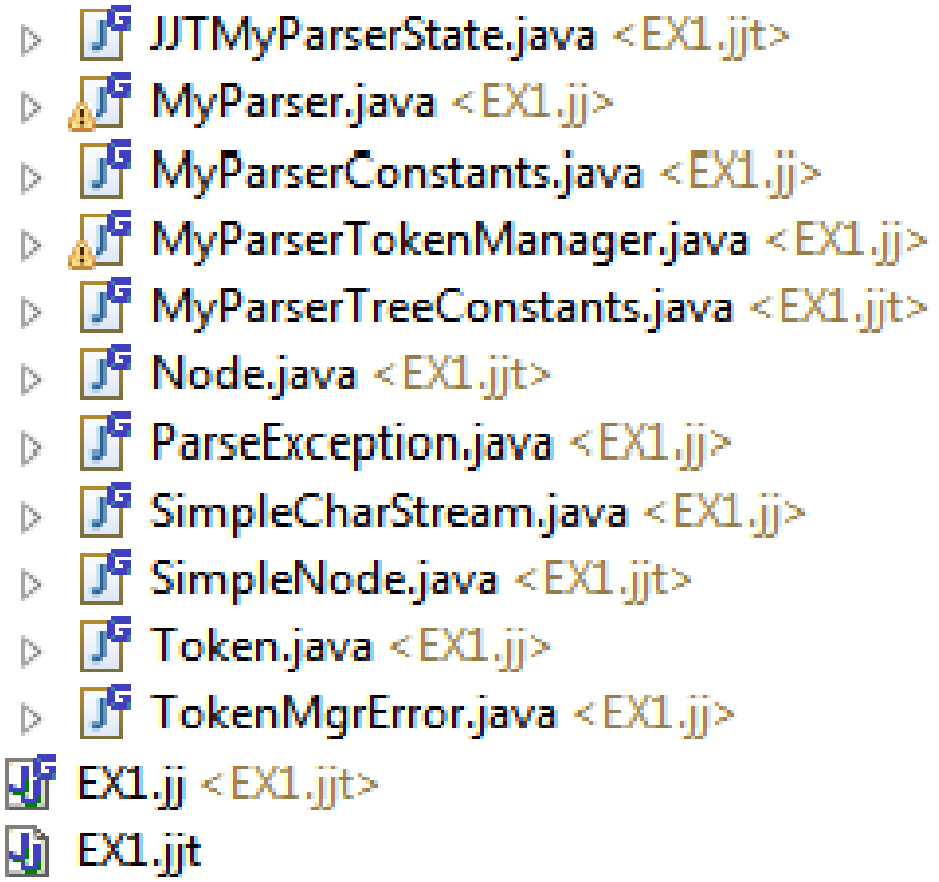
Op ::= Plus | Minus

Expression ::=
Number { Op Number }

Example

```
PARSER_BEGIN(MyParser)
...
MyParser parser = new MyParser(System.in);
try {
   parser.Expression();
   System.out.println(“Parsed!");
} catch (Exception e) {
      System.out.println("Oops!");
      System.out.println(e.getMessage());
}
...
PARSER_END(MyParser)
```

Generated Sources



Example – Evaluating

```
Token Op() :{ Token t; }
{
   (t = < PLUS > | t = < MINUS >)
   { return t; }
}
```

Example

```
int Expression(): { Token t, op; int n;}
{
    t = < NUMBER >
    {
        n = Integer.parseInt( t.image );
    }
    ( op=Op()
    t = < NUMBER > {
    if(op.image.equals("+"))
            n += Integer.parseInt( t.image );
    else
            n -= Integer.parseInt( t.image ); }
    )*
    { return n; }
}
```

Example

```
PARSER_BEGIN(MyParser)

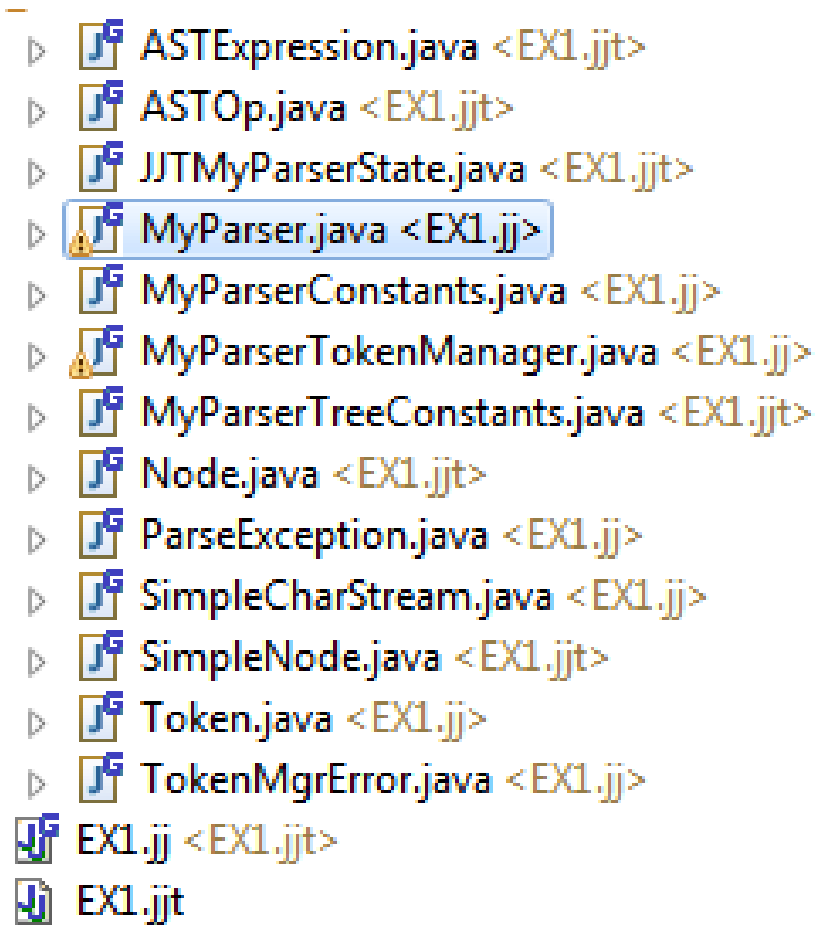
public class MyParser
{
...
    MyParser parser = new MyParser(System.in);
    try
    {
      int n = parser.Expression();
...

PARSER_END(MyParser)
```

Example - Building the AST

```
options
{
   STATIC=false;
   MULTI=true;
   BUILD_NODE_FILES=true;
   NODE_USES_PARSER=false;
   NODE_PREFIX="AST";
   …
}
```

Generated Code



Example

```
void Op() :{}
{
   < PLUS > | < MINUS >
}

SimpleNode Expression(): {}
{
   < Number >
   (Op() < Number >)*
   { return jjtThis; }
}
```

Op ::= Plus | Minus

Expression ::=
Number { Op Number }

Example

```
PARSER_BEGIN(MyParser)

public class MyParser
{
...
    MyParser parser = new MyParser(System.in);
    try
    {
      SimpleNode rootNode = parser.Expression();
...

PARSER_END(MyParser)
```

Example Grammar 2

Digit ::= [“**0**” - “**9**”]

Number ::= Digit+

Factor ::= Expression | Number

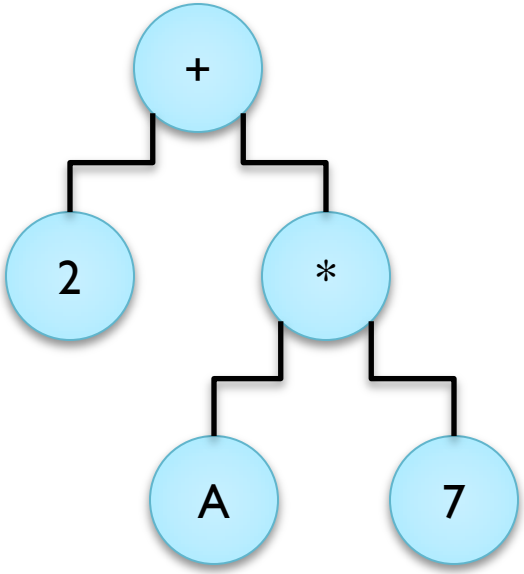
Term ::= Factor [“*” | “/” Factor]

Expression ::= Term { “**+**” | “**-**” Term }

Start ::= Expression

The Visitor Design Pattern

- The Problem



  - Number of operations to be performed on each node

  - Options

- Implement each operation inside each node
- Make use of visitor pattern

The Visitor Design Pattern

- Consider one Node
  - Printing Operation

- We can implement the operation in a separate class e.g. PrintVisitor

```
PrintVisitor

 void PrettyPrint( Plus )
{
   …
}
```

- This can be done for all type of nodes

The Visitor Design Pattern

- Modification on node

```
Plus

void Print( Visitor  p_visitor)
{
    p_visitor.PrettyPrint( this );
}
```



```
PrintVisitor

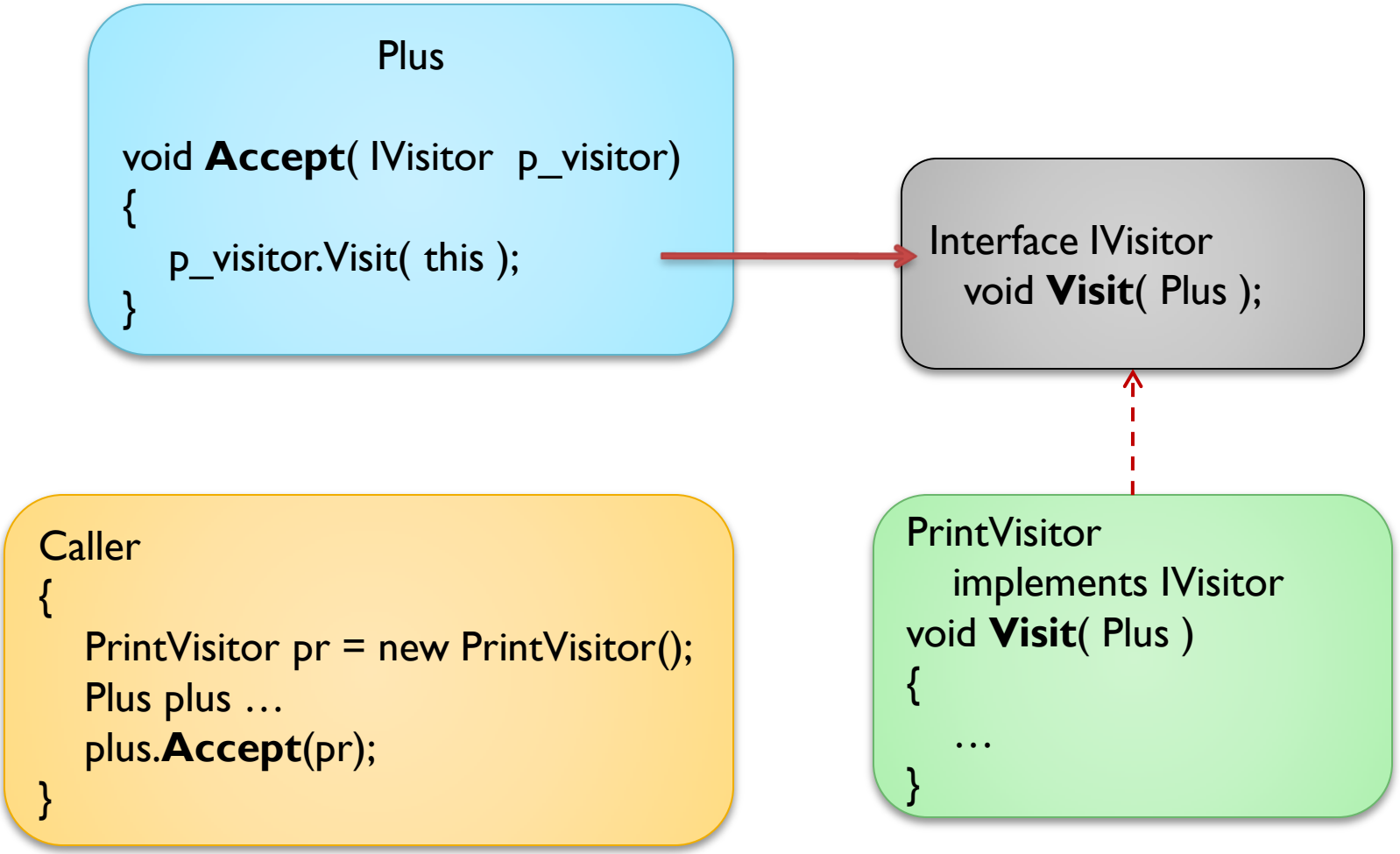
void PrettyPrint( Plus )
{
    …
}
```

- Client

```
Caller
{
    PrintVisitor pr = new PrintVisitor();
    Plus plus …
    plus.Print(pr);
}
```

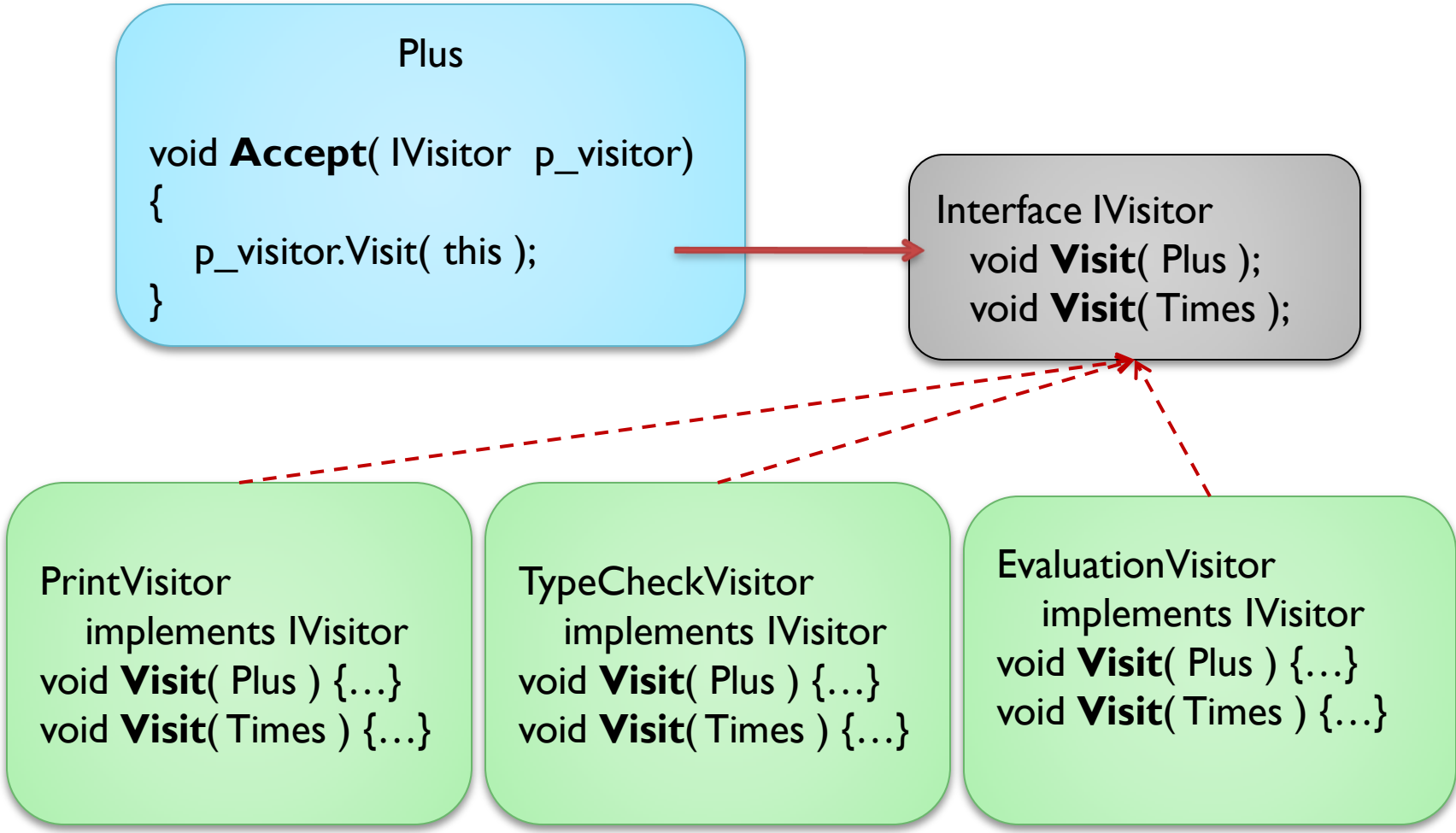
The Visitor Design Pattern

- Finally

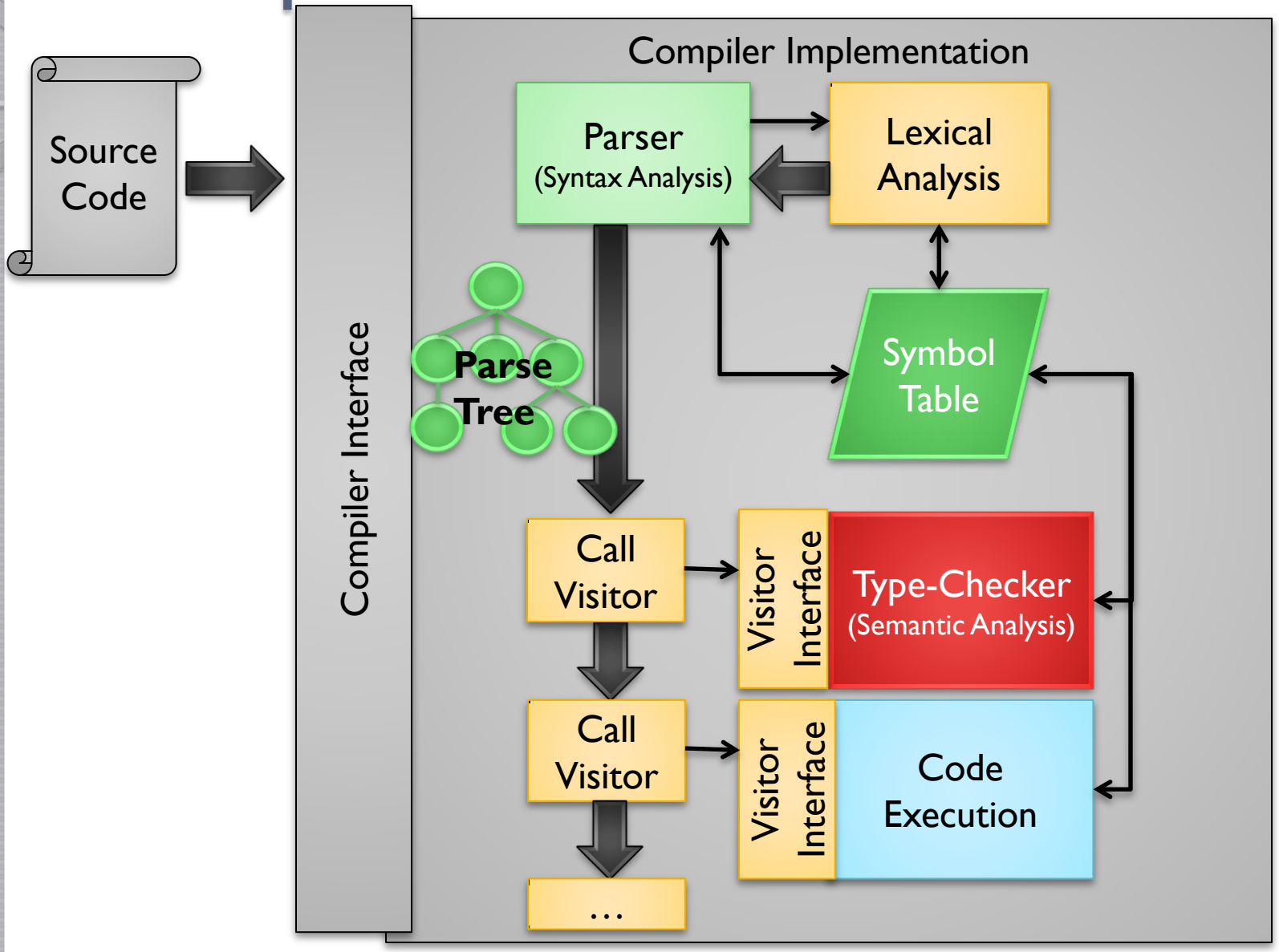


The Visitor Design Pattern

- Benefits



Compiler Architecture



JJTree and the Visitor Pattern

```
Options
{
…
VISITOR=true;
…
}
```

Visitor interface

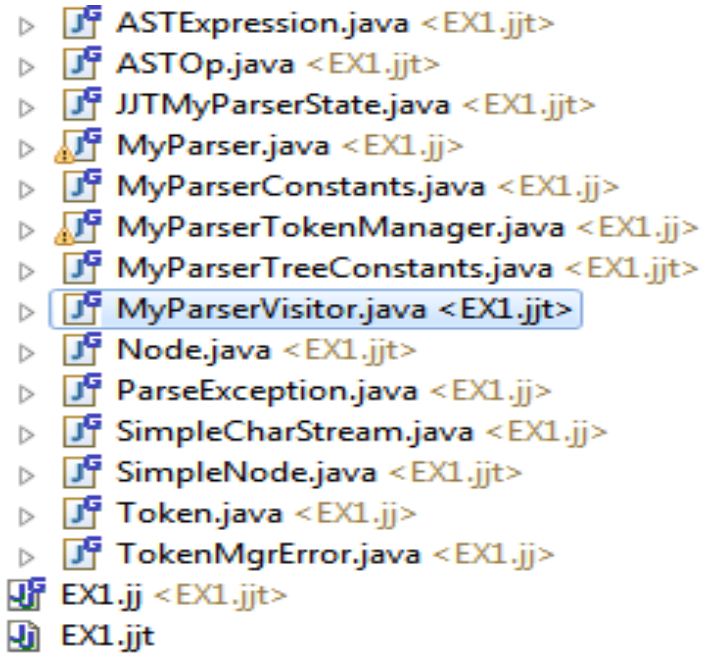
```
public interface MyParserVisitor
{

  public Object visit(SimpleNode node, Object data);

  public Object visit(ASTOp node, Object data);

  public Object visit(ASTExpression node, Object data);

}
```



Visitor - Node modification

```
Public class ASTExpression extends SimpleNode {
  public ASTExpression(int id) {
    super(id);
  }

  public ASTExpression(MyParser p, int id) {
    super(p, id);
  }

  /** Accept the visitor. **/
  public Object jjtAccept(MyParserVisitor visitor, Object data) {
    return visitor.visit(this, data);
  }
}
```

JJTree and the Visitor Pattern

```
Options
{
…
VISITOR=true;
VISITOR_DATA_TYPE="SymbolTable";
VISITOR_RETURN_TYPE="Object";
…
}
```

Visitor - return type

- We need a return-type generic enough to accommodate the results returned by all the visitor implementations
- By default jjt uses the Object class
  - Can easily be used however
    - class-casts
    - instanceof
- A generic container can be designed to hold the results

Visitor - return type

- Types –
  - Create an enumeration containing the types of the language's type-system.

```
enum DataType
{
    Unknown,
    Error,
    Boolean,
    Integer,
    Function,
    …
    Void
}
```

Visitor - return type

- Result class

```
Class Result
{
    DataType   type;
    Object     value;

    …
    Getter & Setter
    Conversion
    …
}
```

Type-Checking – (Semantic Analysis)

- Consider the following decision rule
  - IfStatement ::= “if” “(“ Expression “)” …

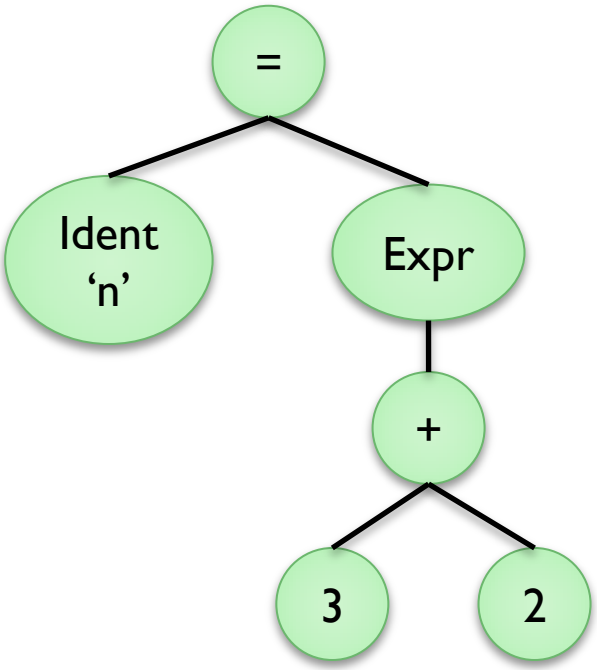
```
if( 3 + 2 )
{
   …
}
```

Type-Checking – (Semantic Analysis)

- Consider the following assignment rule
  - Assignment ::= Identifier = Expression
  - n = 3 + 2;

Type-Checking – (Semantic Analysis)

- n = 3 + 2;



visit(AssignmentNode)

```
if(LHS.visit.type == RHS.visit.type)
        return new Result(RHS.visit.type);
    else
         return new Result(DataType.Integer);
```

visit(PlusNode)

```
    if(LHS.visit.type == RHS.visit.type)
        return new Result(RHS.visit.type);
    else
         return new Result(DataType.Integer);
```

visit(IntLiteral)

```
            return new Result(DataType.Integer)
```

Identifier.visit()

```
    result = SymbolTable.get( node.value )
    return result;
```

Type-Checking – (Semantic Analysis)

- Implement the call to the visitor:

```
Public class MyParser {
... main ...
Try
    {
      SimpleNode root = parser.Expression();

      MyParserVisitor visitor = new TypeChecker();
      Result result = root.jjtAccept(visitor, null );

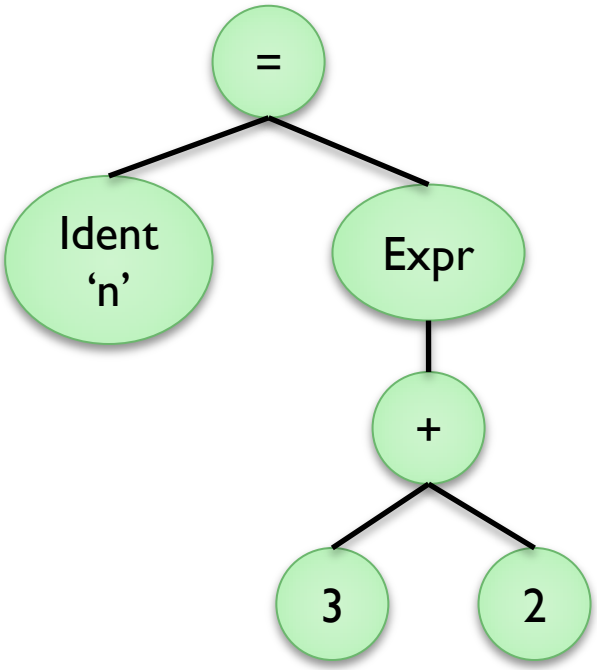
      System.out.println("DataType is " +
           result .getType().toString());
...
```

Interpreter – Code Execution

- In a similar way to Semantic Analysis, we can make use of the **visitor** pattern
- This time, we return values as well rather than type-information only
- We have to take special care about the difference in the semantics of the languages involved

Interpreter – Code Execution

- n = 3 + 2;



visit(AssignmentNode)

```
result =
((IdentifierNode)getChild(0)).jjtAccept(…)
result.value = getChild(1). jjtAccept(…).value
return result
```

visit(PlusNode)

```
Result result = new Result();
result.value = getChild(0). jjtAccept(…).value +
        getChild(1). jjtAccept(…).value;
```

visit(IntLiteral)

```
Result result = new Result();
result.type = DataType.Integer;
result.value = Integer.parseInt(node.value);
return result;
```

Interpreter – Code Execution

```
IfStatement ::=   "if" "(" Expression ")"
Statement ("else" Statement)?
```

```
visit(IfStatement  node, SymbolTable symTbl){
    value = node.jjtGetChild(0).jjtAccept(this, symTbl);

    boolean bCond = value.toBool();

    if( bCond )
        return node.jjtGetChild(1).jjtAccept(this, symTbl);
    else
    {
        if(node.jjtGetNumChildren() > 2 )
            return node.jjtGetChild(2).jjtAccept(this, symTbl);
    }

    return   VoidValue;
}
```

Interpreter – Code Execution

```
VariableDecl      ::=   "let" Identifier ":"
Type "=" Expression ";"
```

```
visit(VariableDecl node, SymbolTable SymTbl)
{
    String strVar = ((ASTIdentifier) node.jjtGetChild(0)).jjtGetValue().toString();

    valType = node.jjtGetChild(1).jjtAccept(this, SymTbl);

    value = node.jjtGetChild(2).jjtAccept(this, SymTbl);

    SymTbl.put(strVar, value);

    return value;
}
```

Code Generation

- Once again we make use of the visitor pattern
- We are translating portions of the source language into snippets of the target language
- We have to take special care about the difference in the semantics of the languages involved

Example

- Translate
  - Assignment ::= Identifier ‘=’ Expression
  - To
  - Assignment ::= Identifier ‘<-’ Expression

Code Generation

```
Visit( AssignmentNode )
{
//Source: Identifier = Expression;
//Target: Identifier <- Expression;

((IdentNode)getChild(0)).jjtAccept(…);

Emit( “<-” );

((ExprNode)getChild(1)).jjtAccept(…);

}
```

Questions?

The End