

4. Parsing in Practice

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Thanks to Jens Palsberg and Tony Hosking for their kind permission to reuse and adapt the CS132 and CS502 lecture notes.

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Roadmap



- > Bottom-up parsing
- > LR(k) grammars
- > JavaCC, Java Tree Builder and the Visitor pattern
- > Example: a straightline interpreter

See, Modern compiler implementation in Java (Second edition), chapters 3-4.

Roadmap



- > **Bottom-up parsing**
- > LR(k) grammars
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Some definitions

Recall:

- > For a grammar G , with start symbol S , any string α such that $S \Rightarrow^* \alpha$ is called a *sentential form*
 - If $\alpha \in V_t^*$, then α is called a *sentence* in $L(G)$
 - Otherwise it is just a sentential form (not a sentence in $L(G)$)
- > A *left-sentential form* is a sentential form that occurs in the leftmost derivation of some sentence.
- > A *right-sentential form* is a sentential form that occurs in the rightmost derivation of some sentence.

Bottom-up parsing

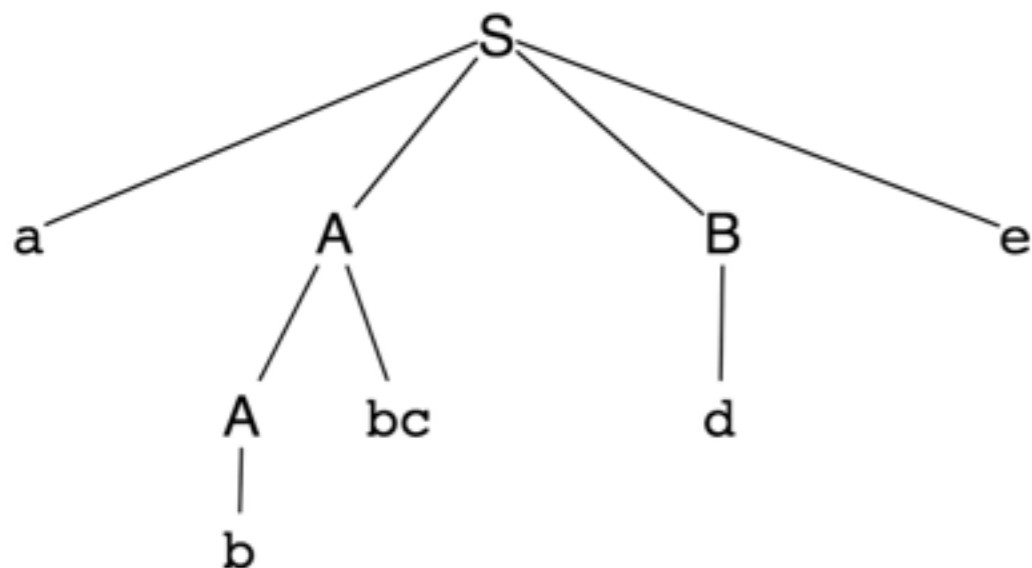
Goal:

- Given an input string w and a grammar G , construct a parse tree by starting at the leaves and working to the root.
- > The parser repeatedly matches a *right-sentential form* from the language against the tree's upper frontier.
- > At each match, it applies a *reduction* to build on the frontier:
 - each reduction matches an upper frontier of the partially built tree to the RHS of some production
 - each reduction adds a node on top of the frontier
- > The final result is a *rightmost derivation*, in reverse.

Example

Consider the grammar:

- | | | | |
|----|-----|---------------|--------|
| 1. | S | \rightarrow | $aABe$ |
| 2. | A | \rightarrow | Abc |
| 3. | | $ $ | b |
| 4. | B | \rightarrow | d |



and the input string: abbcde

Sentential Form	Action
abbcde	shift a
<u>a</u> bbcde	no match; shift b
a <u>b</u> bcde	match; reduce (3)
a <u>A</u> bcde	no match; shift b
aA <u>b</u> cde	lookahead \Rightarrow shift c
aA <u>bc</u> de	match; reduce (2)
aA <u>d</u> e	shift d
aA <u>B</u> e	match; reduce (4)
<u>aAB</u> e	shift e
S	match; reduce (1)

Handles

> A *handle* of a right-sentential form γ is a production $A \rightarrow \beta$ and a position in γ where β may be found and replaced by A to produce the previous right-sentential form in a rightmost derivation of γ

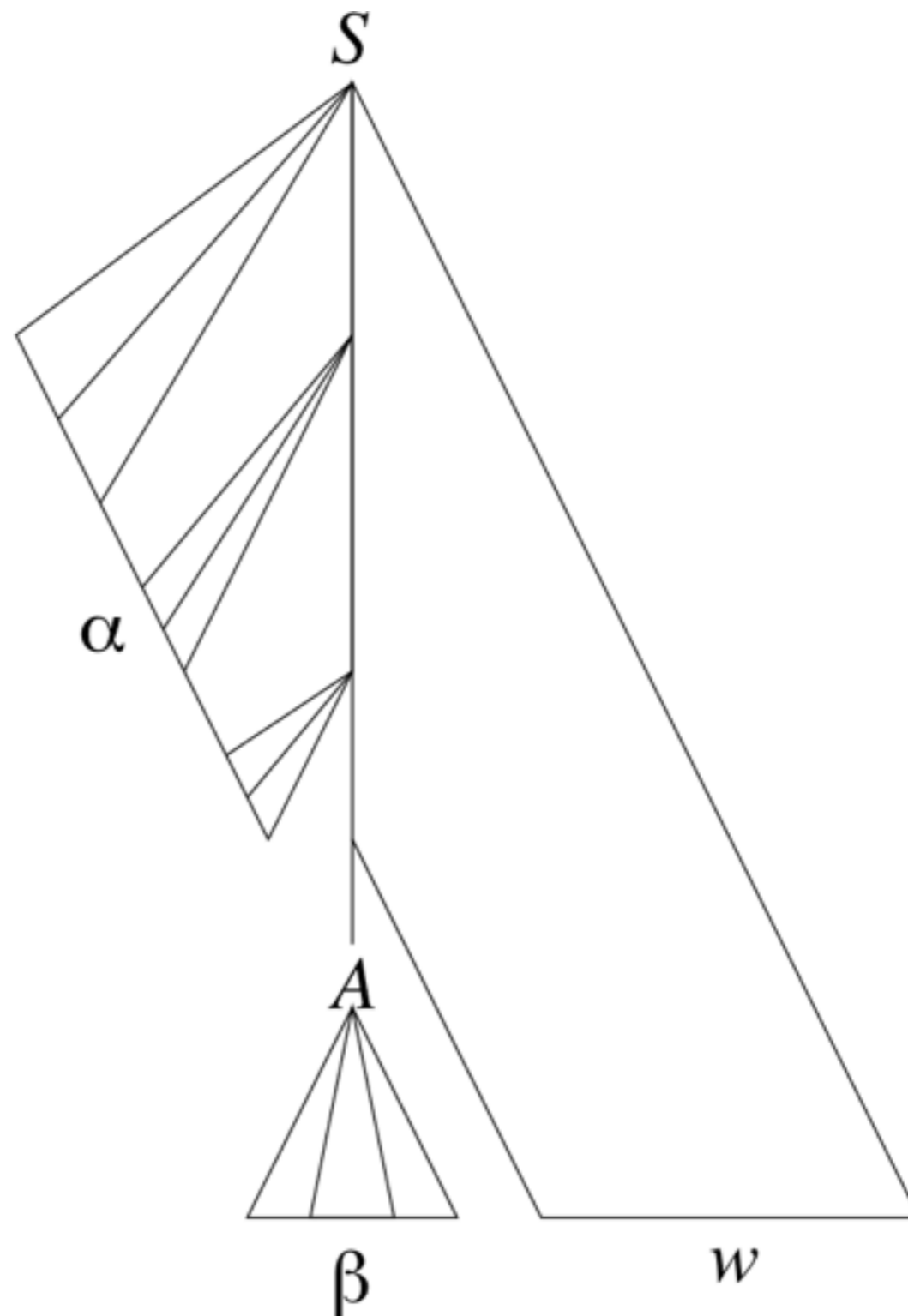
—Suppose: $S \Rightarrow^* \alpha A w \Rightarrow \alpha \beta w$

—Then $A \rightarrow \beta$ in the position following α is a *handle* of $\alpha \beta w$

NB: Because γ is a right-sentential form, the substring to the right of a handle contains *only terminal symbols*.

Handles

The handle $A \rightarrow \beta$ in the parse tree for $\alpha\beta w$



Handles

> **Theorem:**

—If G is unambiguous then every right-sentential form has a unique handle.

> **Proof:** (by definition)

1. G is unambiguous \Rightarrow rightmost derivation is unique
2. \Rightarrow a unique production $A \rightarrow \beta$ applied to take γ_{i-1} to γ_i
3. \Rightarrow a unique position k at which $A \rightarrow \beta$ is applied
4. \Rightarrow a unique handle $A \rightarrow \beta$

Example — rightmost derivation

The left-recursive expression grammar (*original form*)

- | | |
|----|---|
| 1. | $\langle \text{goal} \rangle ::= \langle \text{expr} \rangle$ |
| 2. | $\langle \text{expr} \rangle ::= \langle \text{expr} \rangle + \langle \text{term} \rangle$ |
| 3. | $\quad \quad \quad \quad \langle \text{expr} \rangle - \langle \text{term} \rangle$ |
| 4. | $\quad \quad \quad \quad \langle \text{term} \rangle$ |
| 5. | $\langle \text{term} \rangle ::= \langle \text{term} \rangle * \langle \text{factor} \rangle$ |
| 6. | $\quad \quad \quad \quad \langle \text{term} \rangle / \langle \text{factor} \rangle$ |
| 7. | $\quad \quad \quad \quad \langle \text{factor} \rangle$ |
| 8. | $\langle \text{factor} \rangle ::= \text{num}$ |
| 9. | $\quad \quad \quad \quad \text{id}$ |

Prod'n.	Sentential Form
—	$\langle \text{goal} \rangle$
1	$\underline{\langle \text{expr} \rangle}$
3	$\underline{\langle \text{expr} \rangle - \langle \text{term} \rangle}$
5	$\langle \text{expr} \rangle - \underline{\langle \text{term} \rangle * \langle \text{factor} \rangle}$
9	$\langle \text{expr} \rangle - \langle \text{term} \rangle * \underline{\text{id}}$
7	$\langle \text{expr} \rangle - \underline{\langle \text{factor} \rangle} * \text{id}$
8	$\langle \text{expr} \rangle - \underline{\text{num}} * \text{id}$
4	$\underline{\langle \text{term} \rangle} - \text{num} * \text{id}$
7	$\underline{\langle \text{factor} \rangle} - \text{num} * \text{id}$
9	$\underline{\text{id}} - \text{num} * \text{id}$

How do we parse (bottom-up) to arrive at this derivation?

$x - 2 * y$

Handle-pruning

The process to construct a bottom-up parse is called handle-pruning

To construct a rightmost derivation

$$S = \gamma_0 \Rightarrow \gamma_1 \Rightarrow \gamma_2 \Rightarrow \dots \Rightarrow \gamma_{n-1} \Rightarrow \gamma_n = W$$

we set i to n and apply the following simple algorithm:

For $i = n$ down to 1

1. Find the handle $A_i \rightarrow \beta_i$ in γ_i
2. Replace β_i with A_i to generate γ_{i-1}

This takes $2n$ steps, where n is the length of the derivation

Stack implementation

- > One scheme to implement a handle-pruning, bottom-up parser is called a *shift-reduce parser*.
- > Shift-reduce parsers use a *stack* and an *input buffer*
 1. initialize stack with \$
 2. Repeat until the top of the stack is the goal symbol and the input token is \$
 - a) *Find the handle.*
If we don't have a handle on top of the stack, shift (push) an input symbol onto the stack
 - b) *Prune the handle.*
If we have a handle $A \rightarrow \beta$ on the stack, reduce
 - I. Pop $|\beta|$ symbols off the stack
 - II. Push A onto the stack

NB: In practice we also lookahead to determine whether to shift or reduce!

Example: back to $x-2*y$

1. $\langle \text{goal} \rangle ::= \langle \text{expr} \rangle$
2. $\langle \text{expr} \rangle ::= \langle \text{expr} \rangle + \langle \text{term} \rangle$
3. $\quad \quad \quad | \quad \langle \text{expr} \rangle - \langle \text{term} \rangle$
4. $\quad \quad \quad | \quad \langle \text{term} \rangle$
5. $\langle \text{term} \rangle ::= \langle \text{term} \rangle * \langle \text{factor} \rangle$
6. $\quad \quad \quad | \quad \langle \text{term} \rangle / \langle \text{factor} \rangle$
7. $\quad \quad \quad | \quad \langle \text{factor} \rangle$
8. $\langle \text{factor} \rangle ::= \text{num}$
9. $\quad \quad \quad | \quad \text{id}$

1. Shift until top of stack is the right end of a handle
2. Find the left end of the handle and reduce

Stack	Input	Action
\$	id - num * id	shift
\$ <u>id</u>	- num * id	reduce 9
\$ <u>$\langle \text{factor} \rangle$</u>	- num * id	reduce 7
\$ <u>$\langle \text{term} \rangle$</u>	- num * id	reduce 4
\$ <u>$\langle \text{expr} \rangle$</u>	- num * id	shift
\$ <u>$\langle \text{expr} \rangle$ -</u>	num * id	shift
\$ <u>$\langle \text{expr} \rangle$ - <u>num</u></u>	* id	reduce 8
\$ <u>$\langle \text{expr} \rangle$ - <u>$\langle \text{factor} \rangle$</u></u>	* id	reduce 7
\$ <u>$\langle \text{expr} \rangle$ - <u>$\langle \text{term} \rangle$</u></u>	* id	shift
\$ <u>$\langle \text{expr} \rangle$ - <u>$\langle \text{term} \rangle$ *</u></u>	id	shift
\$ <u>$\langle \text{expr} \rangle$ - <u>$\langle \text{term} \rangle$ * <u>id</u></u></u>		reduce 9
\$ <u>$\langle \text{expr} \rangle$ - <u>$\langle \text{term} \rangle$ * <u>$\langle \text{factor} \rangle$</u></u></u>		reduce 5
\$ <u>$\langle \text{expr} \rangle$ - <u>$\langle \text{term} \rangle$</u></u>		reduce 3
\$ <u>$\langle \text{expr} \rangle$</u>		reduce 1
\$ <u>$\langle \text{goal} \rangle$</u>		accept

5 shifts + 9 reduces + 1 accept

Shift-reduce parsing

A shift-reduce parser has just four canonical actions:

shift	next input symbol is shifted (pushed) onto the top of the stack
reduce	right end of handle is on top of stack; locate left end of handle within the stack; pop handle off stack and push appropriate non-terminal LHS
accept	terminate parsing and signal success
error	call an error recovery routine

Roadmap



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LR(k) grammars

A grammar G is LR(k) iff:

$$1. S \Rightarrow_{rm}^* \alpha Aw \Rightarrow_{rm} \alpha \beta w$$

$$2. S \Rightarrow_{rm}^* \gamma Bx \Rightarrow_{rm} \alpha \beta y$$

$$3. \text{FIRST}_k(w) = \text{FIRST}_k(y) \Rightarrow \alpha Ay = \gamma Bx$$

I.e., if $\alpha \beta w$ and $\alpha \beta y$ have the same k -symbol lookahead, then there is a unique handle to reduce in the rightmost derivation.

Why study LR grammars?

LR(1) grammars are used to construct LR(1) parsers.

- everyone's favorite parser
- virtually all context-free programming language constructs can be expressed in an LR(1) form
- LR grammars are the most general grammars parsable by a deterministic, bottom-up parser
- efficient parsers can be implemented for LR(1) grammars
- LR parsers detect an error as soon as possible in a left-to-right scan of the input
- LR grammars describe a proper superset of the languages recognized by predictive (i.e., LL) parsers

LL(k): recognize use of a production $A \rightarrow \beta$ seeing first k symbols of β

LR(k): recognize occurrence of β (the handle) having seen all of what is derived from β plus k symbols of look-ahead

Left versus right recursion

> ***Right Recursion:***

- needed for termination in predictive parsers
- requires more stack space
- right associative operators

> ***Left Recursion:***

- works fine in bottom-up parsers
- limits required stack space
- left associative operators

> ***Rule of thumb:***

- right recursion for *top-down parsers*
- left recursion for *bottom-up parsers*

Parsing review

> **Recursive descent**

— A hand coded recursive descent parser directly encodes a grammar (typically an LL(1) grammar) into a series of mutually recursive procedures. It has most of the linguistic limitations of LL(1).

> **LL(k):**

— must be able to recognize the use of a production after seeing only the first k symbols of its right hand side.

> **LR(k):**

— must be able to recognize the occurrence of the right hand side of a production after having seen all that is derived from that right hand side with k symbols of look-ahead.

> *The dilemmas:*

— LL dilemma: pick $A \rightarrow b$ or $A \rightarrow c$?

— LR dilemma: pick $A \rightarrow b$ or $B \rightarrow b$?

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The Java Compiler Compiler

- > “Lex and Yacc for Java.”
- > Based on **LL(k)** rather than LR(1) or LALR(1).
- > Grammars are written in EBNF.
- > Transforms an EBNF grammar into an LL(k) parser.
- > Supports embedded action code written in Java (just like Yacc supports embedded C action code)
- > The look-ahead can be changed by writing `LOOKAHEAD (...)`
- > The whole input is given in just one file (not two).

The JavaCC input format

- > Single file:
 - header
 - token specifications for lexical analysis
 - grammar

Examples

Token specification:

```
TOKEN : /* LITERALS */  
{  
  < INTEGER_LITERAL: ( ["1"-"9"] (["0"-"9"])* | "0" ) >  
}
```

Production:

Declarations

*Productions
and actions*

```
void StmtList() :  
{}  
{  
  Stmt() ( ";" Stmt() ) *  
}
```

Generating a parser with JavaCC

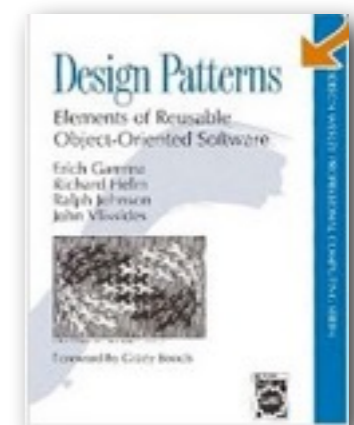
```
javacc fortran.jj           // generates a parser
javac Main.java            // Main.java calls the parser
java Main < prog.f        // parses the program prog.f
```

*NB: JavaCC is just one of many tools available ...
See: <http://catalog.compilertools.net/java.html>*

The Visitor Pattern

> *Intent:*

- Represent an operation to be performed on the elements of an object structure. Visitor lets you define a new operation without changing the classes of the elements on which it operates.



Sneak Preview

- > When using the Visitor pattern,
 - the set of classes must be fixed in advance, and
 - each class must have an `accept` method.

First Approach: instanceof and downcasts

The running Java example: summing an integer list.

```
public interface List {}  
public class Nil implements List {}  
public class Cons implements List {  
    int head;  
    List tail;  
    Cons(int head, List tail) {  
        this.head = head;  
        this.tail = tail;  
    }  
}
```

```
public class SumList {  
    public static void main(String[] args) {  
        List l = new Cons(5, new Cons(4,  
            new Cons(3, new Nil())));  
        int sum = 0;  
        boolean proceed = true;  
        while (proceed) {  
            if (l instanceof Nil) {  
                proceed = false;  
            } else if (l instanceof Cons) {  
                sum = sum + ((Cons) l).head;  
                l = ((Cons) l).tail;  
            }  
        }  
        System.out.println("Sum = " + sum);  
    }  
}
```

Advantage: The code does not touch the classes Nil and Cons.
Drawback: The code must use downcasts and instanceof to check what kind of List object it has.

Second Approach: Dedicated Methods

```
public interface List {
    public int sum();
}

public class Nil implements List {
    public int sum() {
        return 0;
    }
}

public class Cons implements List {
    int head;
    List tail;
    Cons(int head, List tail) {
        this.head = head;
        this.tail = tail;
    }
    public int sum() {
        return head + tail.sum();
    }
}
```

The classical OO approach is to offer dedicated methods through a common interface.

```
public class SumList {
    public static void main(String[] args) {
        List l = new Cons(5, new Cons(4,
            new Cons(3, new Nil())));
        System.out.println("Sum = "
            + l.sum());
    }
}
```

Advantage: Downcasts and instanceof calls are gone, and the code can be written in a systematic way.

Disadvantage: For each new operation on List-objects, new dedicated methods have to be written, and all classes must be recompiled.

Third Approach: The Visitor Pattern

> The Idea:

- Divide the code into an object structure and a Visitor
- Insert an `accept` method in each class. Each `accept` method takes a Visitor as argument.
- A Visitor contains a `visit` method for each class (overloading!). A method for a class `C` takes an argument of type `C`.

Third Approach: The Visitor Pattern

```
public interface List {
    public void accept(Visitor v);
}
public class Nil implements List {
    public void accept(Visitor v) {
        v.visit(this);
    }
}
public class Cons implements List {
    int head;
    List tail;
    Cons(int head, List tail) {... }
    public void accept(Visitor v) {
        v.visit(this);
    }
}
public interface Visitor {
    void visit(Nil l);
    void visit(Cons l);
}
```

```
public class SumVisitor implements Visitor
{
    int sum = 0;
    public void visit(Nil l) { }

    public void visit(Cons l) {
        sum = sum + l.head;
        l.tail.accept(this);
    }

    public static void main(String[] args) {
        List l = new Cons(5, new Cons(4,
            new Cons(3, new Nil())));
        SumVisitor sv = new SumVisitor();
        l.accept(sv);
        System.out.println("Sum = " + sv.sum);
    }
}
```

NB: The visit methods capture both (1) actions, and (2) access of subobjects.

Comparison

The Visitor pattern combines the advantages of the two other approaches.

	Frequent downcasts?	Frequent recompilation?
<code>instanceof</code> + downcasting	Yes	No
dedicated methods	No	Yes
Visitor pattern	No	No

JJTree (Sun) and Java Tree Builder (Purdue/UCLA) are front-ends for JavaCC that are based on Visitors

Visitors: Summary

- > A visitor gathers related operations.
 - It also separates unrelated ones.
 - Visitors can accumulate state.
- > Visitor makes adding new operations easy.
 - Simply write a new visitor.
- > Adding new classes to the object structure is hard.
 - Key consideration: are you most likely to change the algorithm applied over an object structure, or are you most like to change the classes of objects that make up the structure?
- > Visitor can break encapsulation.
 - Visitor's approach assumes that the interface of the data structure classes is powerful enough to let visitors do their job. As a result, the pattern often forces you to provide public operations that access internal state, which may compromise its encapsulation.

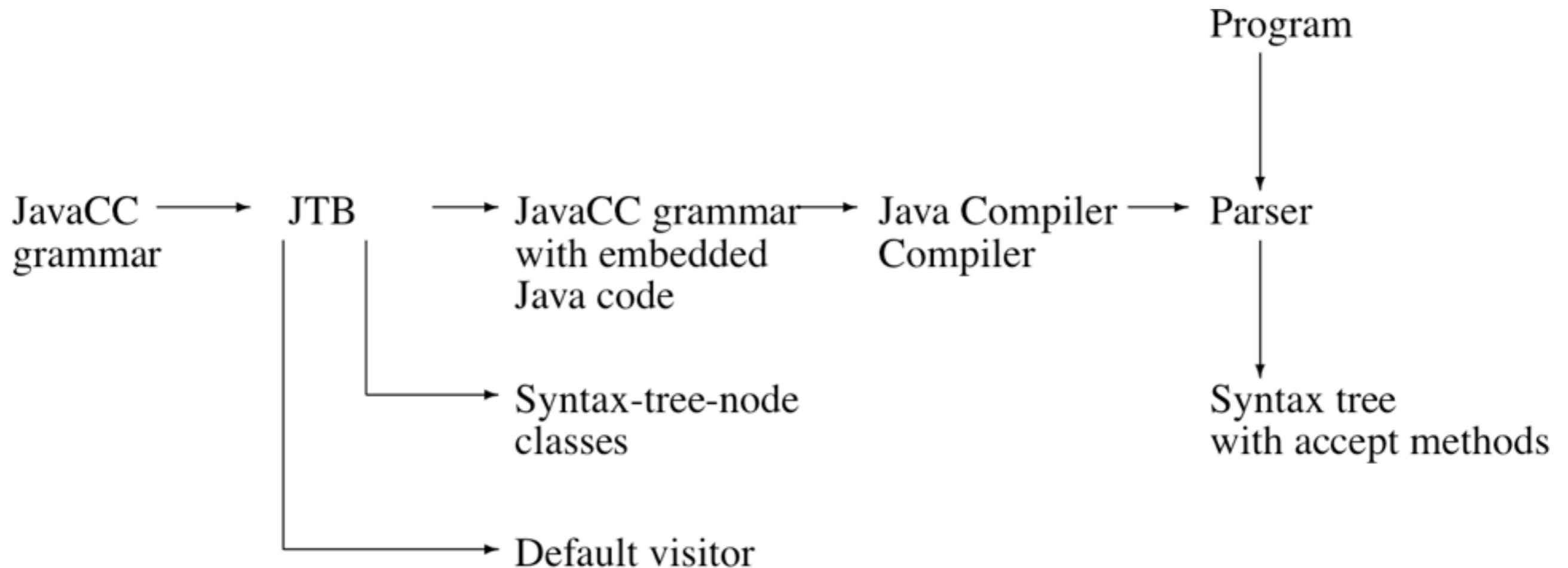
The Java Tree Builder (JTB)

- > front-end for The Java Compiler Compiler.
- > supports the building of syntax trees which can be traversed using visitors.
- > transforms a bare JavaCC grammar into three components:
 - a JavaCC grammar with embedded Java code for building a syntax tree;
 - one class for every form of syntax tree node; and
 - a default visitor which can do a depth-first traversal of a syntax tree.

<http://compilers.cs.ucla.edu/jtb/>

The Java Tree Builder

The produced JavaCC grammar can then be processed by the Java Compiler Compiler to give a parser which produces syntax trees. The produced syntax trees can now be traversed by a Java program by writing subclasses of the default visitor.



Using JTB

```
jtb fortran.jj // generates jtb.out.jj
javacc jtb.out.jj // generates a parser
javac Main.java // Main.java calls the parser and visitors
java Main < prog.f // builds a syntax tree and executes visitors
```

Roadmap

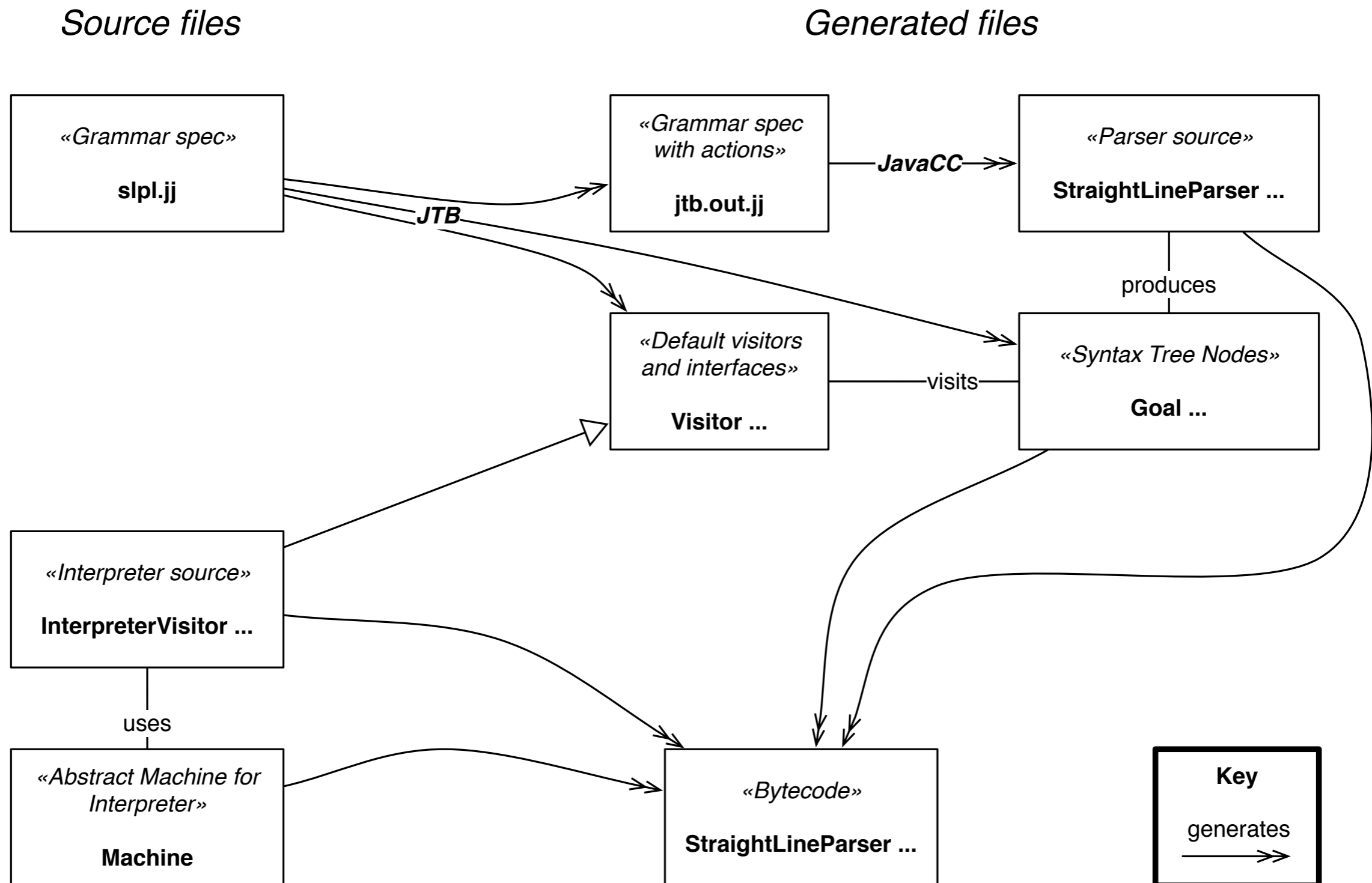


- > Bottom-up parsing
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- > **Example: a straightline interpreter**

Recall our straight-line grammar

Stm	→	Stm ; Stm	<i>CompoundStm</i>
Stm	→	id := Exp	<i>AssignStm</i>
Stm	→	print (ExpList)	<i>PrintStm</i>
Exp	→	id	<i>IdExp</i>
Exp	→	num	<i>NumExp</i>
Exp	→	Exp Binop Exp	<i>OpExp</i>
Exp	→	(Stm , Exp)	<i>EseqExp</i>
ExpList	→	Exp , ExpList	<i>PairExpList</i>
ExpList	→	Exp	<i>LastExpList</i>
Binop	→	+	<i>Plus</i>
Binop	→	−	<i>Minus</i>
Binop	→	×	<i>Times</i>
Binop	→	/	<i>Div</i>

Straightline Interpreter Files



Tokens

slpl.jj starts with the scanner declarations

```
options {
  JAVA_UNICODE_ESCAPE = true;
}

PARSER_BEGIN(StraightLineParser)
  package parser;
  public class StraightLineParser {}
PARSER_END(StraightLineParser)

SKIP : /* WHITE SPACE */
{ " " | "\t" | "\n" | "\r" | "\f" }

TOKEN :
{ < SEMICOLON: ";" >
| < ASSIGN: "==" >
...
}
more tokens here!

TOKEN : /* LITERALS */
{ < INTEGER_LITERAL: ( ["1"-"9"] (["0"-"9"])*
| "0" ) >
}

TOKEN : /* IDENTIFIERS */
{ < IDENTIFIER: <LETTER> (<LETTER>|<DIGIT>)* >
| < #LETTER: [ "a"-"z", "A"-"Z" ] >
| < #DIGIT: ["0"-"9" ] >
}
```

Rewriting our grammar

Goal \rightarrow StmtList
StmtList \rightarrow **Stmt (; Stmt) ***
Stmt \rightarrow id := Exp
| print "(" ExpList "
Exp \rightarrow **MulExp ((+ | -) MulExp) ***
MulExp \rightarrow **PrimExp ((* | /) PrimExp) ***
PrimExp \rightarrow id
| num
| "(" StmtList , Exp "
ExpList \rightarrow Exp (, Exp) *

We introduce a start rule, eliminate all left-recursion, and establish precedence.

Grammar rules

The grammar rules directly reflect our BNF!

NB: We add some non-terminals to help our visitors.

```
void Goal() : {} { StmList() <EOF> }
void StmList() : {}{ Stm() ( ";" Stm() ) * }

void Stm() : {} { Assignment() | PrintStm() }

/* distinguish reading and writing Id */
void Assignment() : {} { WriteId() ":@" Exp() }
void WriteId() : {} { <IDENTIFIER> }

void PrintStm() : {} { "print" "(" ExpList() ")" }

void ExpList() : {} { Exp() ( AppendExp() ) * }
void AppendExp() : {} { "," Exp() }

void Exp() : {} { MulExp() ( PlusOp() | MinOp() ) * }
void PlusOp() : {} { "+" MulExp() }
void MinOp() : {} { "-" MulExp() }

void MulExp() : {} { PrimExp() ( MulOp() | DivOp() ) * }
void MulOp() : {} { "*" PrimExp() }
void DivOp() : {} { "/" PrimExp() }

void PrimExp() : {}{ ReadId() | Num() | StmExp() }
void ReadId() : {}{ <IDENTIFIER> }
void Num() : {} { <INTEGER_LITERAL> }
void StmExp() : {}{ "(" StmList() "," Exp() ")" }
```

Java Tree Builder

JTB automatically generates actions to build the syntax tree, and visitors to visit it.

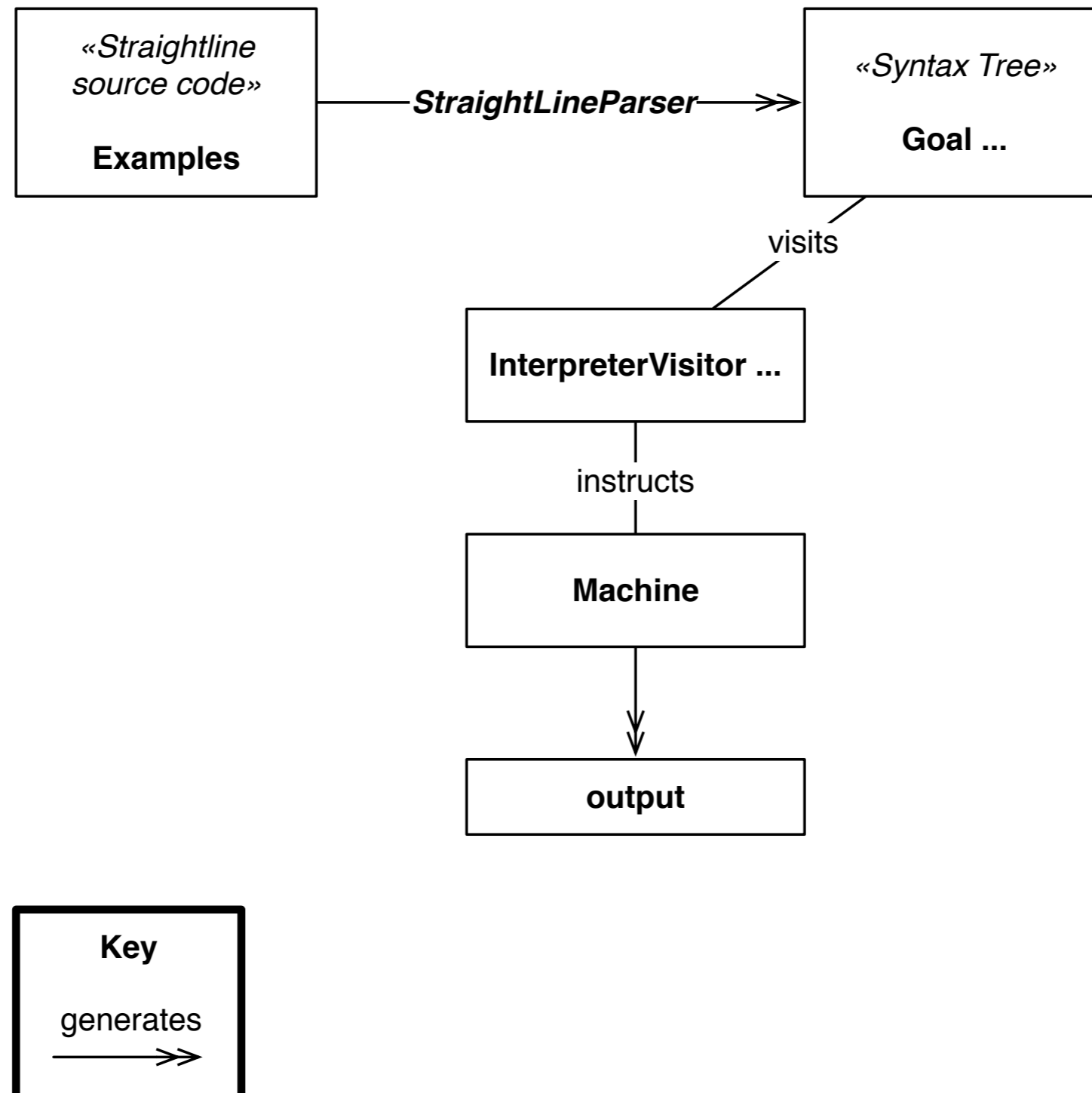
original source LOC	441
generated source LOC	4912

```
// Generated by JTB 1.3.2
options {
    JAVA_UNICODE_ESCAPE = true;
}
PARSER_BEGIN(StraightLineParser)
package parser;
import syntaxtree.*;
import java.util.Vector;

public class StraightLineParser
{
}
...
Goal Goal() :
{
    StmList n0;
    NodeToken n1;
    Token n2;
}
{
    n0=StmList()
    n2=<EOF> {
        n2.beginColumn++; n2.endColumn++;
        n1 = JTBTToolkit.makeNodeToken(n2);
    }

    { return new Goal(n0,n1); }
}
...
```

Straightline Interpreter Runtime



The interpreter

```
package interpreter;
import ...;
public class StraightLineInterpreter {
    Goal parse;
    StraightLineParser parser;

    public static void main(String [] args) {
        System.out.println(new StraightLineInterpreter(System.in).interpret());
    }

    public StraightLineInterpreter(InputStream in) {
        parser = new StraightLineParser(in);
        this.initParse();
    }

    private void initParse() {
        try { parse = parser.Goal(); }
        catch (ParseException e) { ... }
    }

    public String interpret() {
        assert(parse != null);
        Visitor visitor = new Visitor();
        visitor.visit(parse);
        return visitor.result();
    }
}
```

The interpreter simply runs the parser and visits the parse tree.

An abstract machine for straight line code

```
package interpreter;
import java.util.*;
public class Machine {
    private Hashtable<String,Integer> store; // current values of variables
    private StringBuffer output;           // print stream so far
    private int value;                     // result of current expression
    private Vector<Integer> vlist;         // list of expressions computed

    public Machine() {
        store = new Hashtable<String,Integer>();
        output = new StringBuffer();
        setValue(0);
        vlist = new Vector<Integer>();
    }
    void assignValue(String id) { store.put(id, getValue()); }
    void appendExp() { vlist.add(getValue()); }
    void printValues() {...}
    void setValue(int value) {...}
    int getValue() { return value; }
    void readValueFromId(String id) {
        assert isDefined(id); // precondition
        this.setValue(store.get(id));
    }
    private boolean isDefined(String id) { return store.containsKey(id); }
    String result() { return this.output.toString(); }
}
```

The Visitor interacts with this machine as it visits nodes of the program.

The visitor

```
package interpreter;
import visitor.DepthFirstVisitor;
import syntaxtree.*;

public class Visitor extends DepthFirstVisitor {
    Machine machine;
    public Visitor() { machine = new Machine(); }
    public String result() { return machine.result(); }

    public void visit(Assignment n) {
        n.f0.accept(this);
        n.f1.accept(this);
        n.f2.accept(this);
        String id = n.f0.f0.tokenImage;
        machine.assignValue(id);
    }
    public void visit(PrintStm n) { ... }
    public void visit(AppendExp n) { ... }
    public void visit(PlusOp n) { ... }
    public void visit(MinOp n) { ... }
    public void visit(MulOp n) { ... }
    public void visit(DivOp n) { ... }
    public void visit(ReadId n) { ... }
    public void visit(Num n) { ... }
}
```

f0 → *WriteId()*
f1 → " :=" "
f2 → *Exp()*

The Visitor interprets interesting nodes by directly interacting with the abstract machine.

What you should know!

- ✎ Why do bottom-up parsers yield rightmost derivations?*
- ✎ What is a “handle”? How is it used?*
- ✎ What is “handle-pruning”? How does a shift-reduce parser work?*
- ✎ When is a grammar LR(k)?*
- ✎ Which is better for hand-coded parsers, LL(1) or LR(1)?*
- ✎ What kind of parsers does JavaCC generate?*
- ✎ How does the Visitor pattern help you to implement parsers?*

Can you answer these questions?

- ✎ What are “shift-reduce” errors?*
- ✎ How do you eliminate them?*
- ✎ Which is more expressive? $LL(k)$ or $LR(k)$?*
- ✎ How would you implement the Visitor pattern in a dynamic language (without overloading)?*
- ✎ How can you manipulate your grammar to simplify your JTB-based visitors?*



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