Compiling Techniques

Lecture 7: Abstract Syntax

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Table of contents

A parser does more than simply recognising syntax. It can:

- evaluate code (interpreter)
- emit code (simple compiler)
- build an internal representation of the program (multi-pass compiler)

In general, a parser performs semantic actions:

- recursive descent parser: integrate the actions with the parsing functions
- bottom-up parser (automatically generated): add actions to the grammar

Syntax Tree

In a multi-pass compiler, the parser builds a syntax tree which is used by the subsequent passes

A syntax tree can be:

- a concrete syntax tree (or parse tree) if it directly corresponds to the context-free grammar
- an abstract syntax tree if it corresponds to a simplified (or abstract) grammar

The abstract syntax tree (AST) is usually used in compilers.

Example: Concrete Syntax Tree (Parse Tree)

Example: CFG for arithmetic expressions (EBNF form)

```
Expr   ::= Term  ( ('+'| '-') Term  )*
Term   ::= Factor ( ('*' | '/') Factor)*
Factor ::= number | '(' Expr ')'
```

After removal of EBNF syntax

```
Expr    ::= Term Terms
Terms   ::= ('+' | '-') Term Terms | ϵ
Term    ::= Factor Factors
Factors ::= ('*' | '/') Factor Factors | ϵ
Factor  ::= number | '(' Expr ')'
```

After further simplification

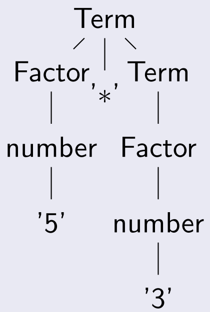
```
Expr    ::= Term (('+' | '-') Expr | ϵ)
Term    ::= Factor (('*'|'/') Term | ϵ)
Factor  ::= number | '(' Expr ')'
```

Example: Concrete Syntax Tree (Parse Tree)

CFG for arithmetic expressions

```
Expr    ::= Term (('+' | '−') Expr | ε)
Term    ::= Factor (('*'|'/') Term | ε)
Factor  ::= number | '(' Expr ')'
```

Concrete Syntax Tree for $5 * 3$



The concrete syntax tree contains a lot of unnecessary information.

It is possible to simplify the concrete syntax tree to remove the redundant information.

For instance parenthesis are not necessary.

Exercise

1. Write the concrete syntax tree for $3 * (4 + 5)$
2. Simplify the tree.

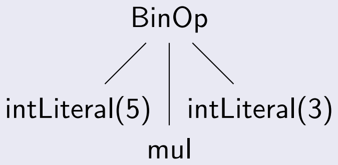
Abstract Grammar

These simplifications leads to a new simpler context-free grammar caller Abstract Grammar.

Example: abstract grammar for arithmetic expressions

```
Expr   ::= BinOp | intLiteral
BinOp  ::= Expr Op Expr
Op     ::= add | sub | mul | div
```

$5 * 3$



This is called an Abstract Syntax Tree

Example: abstract grammar for arithmetic expressions

```
Expr   ::= BinOp | intLiteral
BinOp  ::= Expr Op Expr
Op     ::= add | sub | mul | div
```

Note that for given concrete grammar, there exist numerous abstract grammar:

```
Expr   ::= AddOp | SubOp | MulOp | DivOp | intLiteral
AddOp  ::= Expr add Expr
SubOp  ::= Expr sub Expr
MulOp  ::= Expr mul Expr
DivOp  ::= Expr div Expr
```

We pick the most suitable grammar for the compiler.

Abstract Syntax Tree

The Abstract Syntax Tree (AST) forms the main intermediate representation of the compiler's front-end.

For each non-terminal or terminal in the abstract grammar, we define a class.

- If a non-terminal has any alternative on the rhs (right hand side), then the class is abstract (cannot instantiate it). The terminal or non-terminal appearing on the rhs are subclasses of the non-terminal on the lhs.
- The sub-trees are represented as instance variable in the class.
- Each non-abstract class has a unique constructor.
- If a terminal does not store any information, then we can use an Enum type in Java instead of a class.

Example: abstract grammar for arithmetic expressions

```
Expr  ::= BinOp | intLiteral
BinOp ::= Expr Op Expr
Op    ::= add | sub | mul | div
```

Corresponding Java Classes

```java
abstract class Expr { }

class IntLiteral extends Expr {
  int i;
  IntLiteral(int i){...}
}

class BinOp extends Expr {
  Op op;
  Expr lhs;
  Expr rhs;
  BinOp(Op op, Expr lhs, Expr rhs) {...}
}

enum Op {ADD, SUB, MUL, DIV}
```

CFG for arithmetic expressions

```
Expr    ::= Term (('+' | '-') Expr | ε)
Term    ::= Factor (('*'|'/') Term | ε)
Factor  ::= number | '(' Expr ')'
```

Current Parser (class)

```
Expr parseExpr() {
  parseTerm();
  if (accept(PLUS|MINUS))
    nextToken();
    parseExpr();
}

Expr parseTerm() {
  parseFactor();
  if (accept(TIMES|DIV))
    nextToken();
    parseTerm();
}
```

```
Expr parseFactor() {
  if (accept(LPAR))
    parseExpr();
    expect(RPAR);
  else
    expect(NUMBER);
}
```

Current Parser

```
void parseExpr() {
  parseTerm();
  if (accept(PLUS|MINUS))
    nextToken();
    parseExpr();
}
```

AST building (modified Parser)

```
Expr parseExpr() {
  Expr lhs = parseTerm();
  if (accept(PLUS|MINUS))
    Op op;
    if (token == PLUS)
      op = ADD;
    else // token == MINUS
      op = SUB;
    nextToken();
    Expr rhs = parseExpr();
    return new BinOp(op, lhs, rhs);
  return lhs;
}
```

Current Parser

```
void parseTerm() {
  parseFactor();
  if (accept(TIMES|DIV))
    nextToken();
    parseTerm();
}
```

AST building (modified Parser)

```
Expr parseTerm() {
  Expr lhs = parseFactor();
  if (accept(TIMES|DIV))
    Op op;
    if (token == TIMES)
      op = MUL;
    else // token == DIV
      op = DIV;
    nextToken();
    Expr rhs = parseTerm();
    return new BinOp(op, lhs, rhs);
  return lhs;
}
```

Current Parser

```
void parseFactor() {
  if (accept(LPAR))
    parseExpr();
    expect(RPAR);
  else
    expect(NUMBER);
}
```

AST building (modified Parser)

```
Expr parseFactor() {
  if (accept(LPAR))
    Expr e = parseExpr();
    expect(RPAR);
    return e;
  else
    IntLiteral il = parseNumber();
    return il;
}

IntLiteral parseNumber() {
  Token n = expect(NUMBER);
  int i = Integer.parseInt(n.data);
  return new IntLiteral(i);
}
```

Compiler Pass

AST pass

An AST pass is an action that process the AST in a single traversal.

A pass can for instance:

- assign a type to each node of the AST
- perform an optimisation
- generate code

It is important to ensure that the different passes can access the AST in a flexible way. An inefficient solution would be to use instanceof to find the type of syntax node

Example

```
if (tree instanceof IntLiteral)
  ((IntLiteral)tree).i;
```

Two Ways to Process an AST

- Object-Oriented Processing
- Visitor Processing

Object-Oriented Processing

Using this technique, a compiler pass is represented by a function `f()` in each of the AST classes.

- The method is abstract if the class is abstract
- To process an instance of an AST class `e`, we simply call `e.f()`.
- The exact behaviour will depends on the concrete class implementations

Example for the arithmetic expression

- A pass to print the AST: `String toStr()`
- A pass to evaluate the AST: `int eval()`

```
abstract class Expr {
  abstract String toStr();
  abstract int eval();
}
class IntLiteral extends Expr {
  int i;
  String toStr() { return ""+i; }
  int eval() { return i; }
}
class BinOp extends Expr {
  Op op;
  Expr lhs;
  Expr rhs;
  String toStr() { return lhs.toStr() + op.name() + rhs.toStr();}
  int eval() {
    switch(op) {
      case ADD: lhs.eval() + rhs.eval(); break;
      case SUB: lhs.eval() - rhs.eval(); break;
      case MUL: lhs.eval() * rhs.eval(); break;
      case DIV: lhs.eval() / rhs.eval(); break;
} } }
```

Main class

```
class Main {
  void main(String[] args) {
    Expr expr = ExprParser.parse(some_input_file);
    String str = expr.toStr();
    int result = expr.eval();
  }
}
```

Visitor Processing

With this technique, all the methods from a pass are grouped in a visitor.

For this, need a language that implements single dispatch:

- the method is chosen based on the dynamic type of the object (the AST node)

The visitor design pattern allows us to implement double dispatch, the method is chosen based on:

- the dynamic type of the object (the AST node)
- the dynamic type of the argument (the visitor)

Note that if the language supports pattern matching, it is not needed to use a visitor since double-dispatch can be implemented more effectively.

Single vs. double dispatch

In Java:

Single dispatch

```
class A {
  void print() { System.out.print("A") };
}
class B extends A {
  void print() { System.out.print("B") };
}
A a = new A();
B b = new B();
a.print(); // outputs A
b.print(); // outputs B
```

Single vs. double dispatch

In Java:

Double dispatch (Java does not support double dispatch)

```
class A { }
class B extends A { }
class Print() {
  void print(A a) { System.out.print("A") };
  void print(B b) { System.out.print("B") };
}
A a  = new A();
B b  = new B();
A b2 = new B();
Print p = new Print();
p.print(a);  // outputs A
p.print(b);  // outputs B
p.print(b2); // outputs A
```

Visitor Interface

```
interface Visitor<T> {
  T visitIntLiteral(IntLiteral il);
  T visitBinOp(BinOp bo);
}
```

Modified AST classes

```
abstract class Expr {
  abstract <T> T accept(Visitor<T> v);
}
class IntLiteral extends Expr {
  ...
  <T> T accept(Visitor<T> v) {
    return v.visitIntLiteral(this);
} }
class BinOp extends Expr {
  ...
  <T> T accept(Visitor<T> v) {
    return v.visitBinOp(this);
} } }
```

ToStr Visitor

```
ToStr implements Visitor<String> {
  String visitIntLiteral(IntLiteral il) {
    return ""+il.i;
  }
  String visitBinOp(BinOp bo) {
    return bo.lhs.accept(this) + bo.op.name() + bo.rhs.accept(this
} }
```

Eval Visitor

```
Eval implements Visitor<Integer> {
  Integer visitIntLiteral(IntLiteral il) {
    return il.i;
  }
  Integer visitBinOp(BinOp bo) {
    switch(bo.op) {
      case ADD: lhs.accept(this) + rhs.accept(this); break;
      case SUB: lhs.accept(this) - rhs.accept(this); break;
      case MUL: lhs.accept(this) * rhs.accept(this); break;
      case DIV: lhs.accept(this) / rhs.accept(this); break;
} }
```

Main class

```
class Main {
  void main(String[] args) {
    Expr expr = ExprParser.parse(some_input_file);
    String str = expr.accept(new ToStr());
    int result = expr.accept(new Eval());
  }
}
```

Extensibility

With an AST, there can extensions in two dimensions:

1. Adding a new AST node
   - For the object-oriented processing this means add a new sub-class
   - In the case of the visitor, need to add a new method in every visitor
2. Adding a new pass
   - For the object-oriented processing, this means adding a function in every single AST node classes
   - For the visitor case, simply create a new visitor

Picking the right design

Facilitate extensibility:

- the object-oriented design makes it easy to add new type of AST node
- the visitor-based scheme makes it easy to write new passes

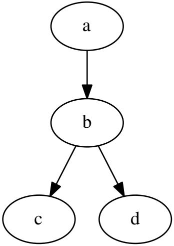
Facilitate modularity:

- the object-oriented design allows for code and data to be stored in the AST node and be shared between phases (*e.g.* types)
- the visitor design allows for code and data to be shared among the methods of the same pass

Dot (graph description language)

Simple example dot file

```
digraph prog {
      a → b → c;
      b → d;
}
```



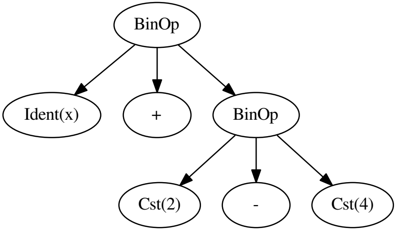
- digraph = directed graph
- prog = name of the graph (can be anything)
- to produce a pdf, simply type on linux
  `dot -Tpdf graph.dot -o graph.pdf`

Representing an AST in Dot

x + 2 - 4

```
digraph ast {
  binOpNode1 [label="BinOp"];
  idNode1 [label="Ident(x)"];
  OpNode1 [label="+"];
  binOpNode2 [label="BinOp"];
  cstNode1 [label="Cst(2)"];
  OpNode2 [label="-"];
  cstNode2 [label="Cst(4)"];

  binOpNode1 -> OpNode1;
  binOpNode1 -> idNode1;
  binOpNode1 -> binOpNode2;
  binOpNode2 -> OpNode2;
  binOpNode2 -> cstNode1;
  binOpNode2 -> cstNode2;
}
```



Dot Printer Visitor

```
DotPrinter implements Visitor<String> {
  PrintWriter writer;
  int nodeCnt=0;

  public DotPrinter(File f) {...}

  String visitIntLiteral(IntLiteral il) {
    nodeCnt++;
    writer.println("Node"+nodeCnt+
                   "[label=\"Cst("+il.value+")\"];");
    return "Node"+nodeCnt;
  }

  ...
```

Dot Printer Visitor

```
  ...

  Integer visitBinOp(BinOp bo) {
    String binOpNodeId = "Node"+nodeCnt++;
    writer.println(binOpNodeId+"[label=\"BinOp\"];");

    String lhsNodeId = lhs.accept(this);
    String opNodeId = "Node"+nodeCnt++;
    writer.println(opNodeId+"[label=\"+\"];");
    String rhsNodeId = rhs.accept(this);

    writer.println(binOpNodeId + "->" lhsNodeId + ";");
    writer.println(binOpNodeId + "->" opNodeId + ";");
    writer.println(binOpNodeId + "->" rhsNodeId + ";");
  }

  ...
}
```

Next lecture

- Context-sensitive Analysis