Compiler Design

Lecture 8: Abstract Syntax Tree Processing

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Compiler Pass

AST pass

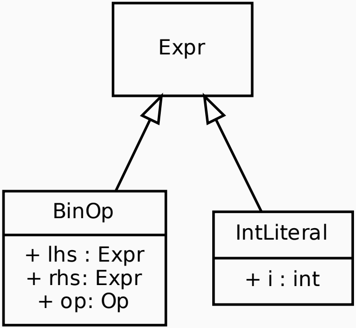
An AST pass is an action that process the AST in a single traversal.

For instance, a pass can:

- interpret the AST
- 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.

Class diagram for arithmetic expressions



Naive approach: instanceof

Example: evaluating integer expressions

```
int evalExpr(Expr exp) {
  if (exp instanceof IntLiteral) {
    IntLiteral it = (IntLiteral) exp;
    return (it.i);
  }
  else if (exp instanceof BinOp) {
    BinOp bo = (BinOp) exp;
    if (bo.op == ADD)
      return(evalExpr(bo.lhs) + evalExpr(bo.rhs));
    ...
} }
```

⚠ What's wrong with this approach?

- a lot of boiler plate code (`instanceof` + `typecast`)
- casting is done dynamically at runtime ⇒ no static guarantee
- no guarantee that all the type of nodes are dealt with
  - If a new type of node is added, might forgot to add a case in a pass

Three Ways to Process an AST

- Object-Oriented Processing
- Pattern Matching
- Visitor Processing

AST Processing Techniques

Object-Oriented 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 arithmetic expressions

- A function to print the AST: `String toStr()`
- A function 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: return (lhs.eval() + rhs.eval());
      case SUB: return (lhs.eval() - rhs.eval());
      case MUL: return (lhs.eval() * rhs.eval());
      case DIV: return (lhs.eval() / rhs.eval());
} } }
```

Main class

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

Object Oriented Processing: Pros & Cons

☺ Pros:

- Type safety

☹ Cons:

- The logic is scattered all over the place in the various classes
- Passes are tightly integrated within the compiler IR, difficult to write standalone passes

❓ Can we do better ❓

What about the following?

Evaluation pass

```
class EvalPass {
  int eval(IntLiteral it) {
    return it.i;
  }
  int eval(BinOp bo) {
    switch(op) {
      case ADD: return (eval(lhs) + eval(rhs));
      case SUB: return (eval(lhs) - eval(rhs));
      case MUL: return (eval(lhs) * eval(rhs));
      case DIV: return (eval(lhs) / eval(rhs));
} } }
```

Main class

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

⚠ Does not work! ⚠

Would require double-dispatch support at language level.

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
A b2 = new B();
b2.print();   // output B
```

The “correct” print method is called based on the instance type.

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
```

⚠ The choice of print method is based on the argument static type.

⇒ Cannot use this approach.

AST Processing Techniques

Pattern Matching

Some Languages Support Pattern Matching

e.g. C#, F#, OCaml, Haskell, ML, Rust, Scala, Swift.

Eval function in Scala using pattern matching

```
def eval(e: Expr): Int =
  e match {
     case IntLiteral(i)      => i
     case BinOp(lhs,rhs,ADD) => eval(lhs) + eval(rhs)
     case BinOp(lhs,rhs,SUB) => eval(lhs) - eval(rhs)
     case BinOp(lhs,rhs,MUL) => eval(lhs) * eval(rhs)
     case BinOp(lhs,rhs,DIV) => eval(lhs) / eval(rhs)
  }
```

Looks a lot like using `instanceof` in Java, without any drawback:

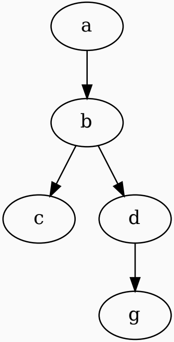
- No boiler plate code
- Static type guarantees
- Scala compiler guarantees no cases are missing

Java Example: AST Visualisation with Pattern Matching

Dot (graph description language)

Simple example dot file

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



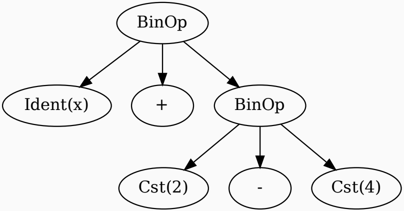
- digraph = directed graph
- prog = name of the graph (can be anything)
- to produce a pdf, simply type on linux
  `dot -Tpdf graph.dot -o graph.pdf`

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;
}
```



Pattern-Matching Implementation

Basic idea:

- Visit method writes out the node and produce edges for each child.
- Visit method returns the id of the node to the parent.

Dot Printer with Pattern Matching

```
DotPrinter {

  PrintWriter writer;
  int nodeCnt=0;

  public DotPrinter(File f) {...}

  String visit(ASTnode node) {
    return switch(node) {
      case IntLiteral i → {
        nodeCnt++;
        writer.println("Node"+nodeCnt+
                       "[label=\"Cst("+il.value+")\"];");
        yield "Node"+nodeCnt;
      }
      ...
```

Dot Printer with Pattern Matchin

```
      ...
      case BinOp bo → {

        // write out node information
        String binOpNodeId = "Node"+nodeCnt++;
        writer.println(binOpNodeId+"[label=\"BinOp\"];");

        // traverse children
        String lhsNodeId = visit(lhs);
        String opNodeId = "Node"+nodeCnt++;
        writer.println(opNodeId+"[label=\"+\"];");
        String rhsNodeId = visit(rhs);

        // write out edges
        writer.println(binOpNodeId + "→" lhsNodeId + ";");
        writer.println(binOpNodeId + "→" opNodeId + ";");
        writer.println(binOpNodeId + "→" rhsNodeId + ";");

        // return node id
        yield binOpNodeId;
      }
      ...
}
```

Problem with Pattern Matching

It is not supported by all programming languages:

- Java only added support in version 17, released 14 sep 2021.
- See `https://blogs.oracle.com/javamagazine/post/java-pattern-matching-switch-preview`
- need to compile with
  `javac --enable-preview --source 17`
  and run with
  `java --enable-preview`

⇒ need other solution if language does not offer pattern matching.

Java Example: AST Visualisation with Pattern Matching

Visitor Processing

Visitor Processing

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

It only relies on single dispatch mechanism:

- 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)

Main idea

- The logic to handle each type of node is split up in separate functions in a single class: the Visitor.
- Each AST node class implements an `accept` method which dispatches the processing of that node to the right function in the visitor.

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);
} } }
```

Examples

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());
  }
}
```

Exercise

Trace all functions called when the `Eval` visitor processes $2 * 3$.

Eval Visitor Class

```
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; } }
```

AST Nodes Class

```
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);  } }
```

Summary

Extensibility

With an AST, there can extensions in two dimensions:

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

Picking the right design

Facilitate extensibility:

- object-oriented design: easy to add new type of AST node
- visitor-based/pattern matching: 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)
- visitor / pattern matching allows for code and data to be shared among the methods of the same pass

Next lecture

- Context-sensitive Analysis