EDAN65: Compilers, Lecture 06 B

# Visitors

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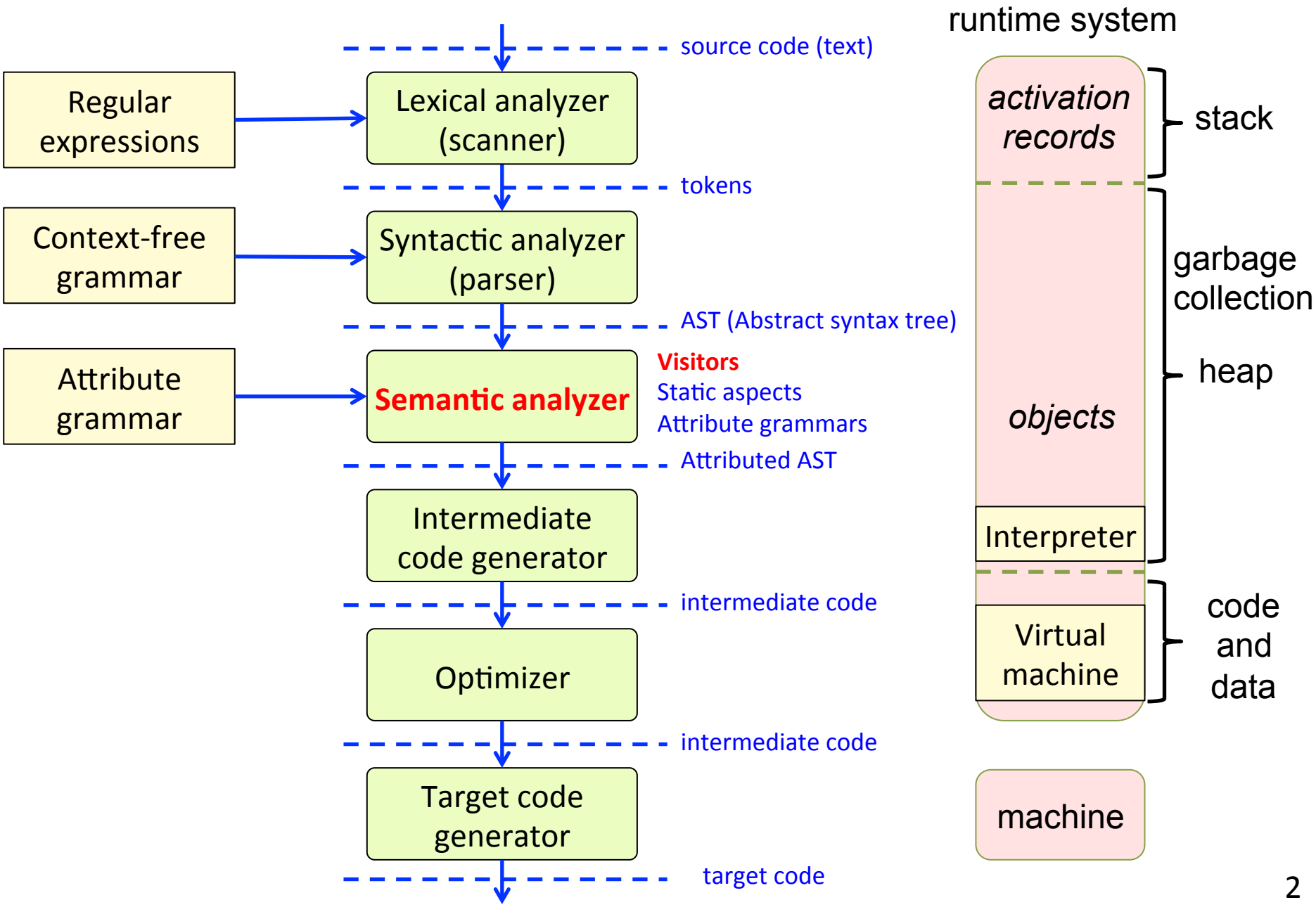
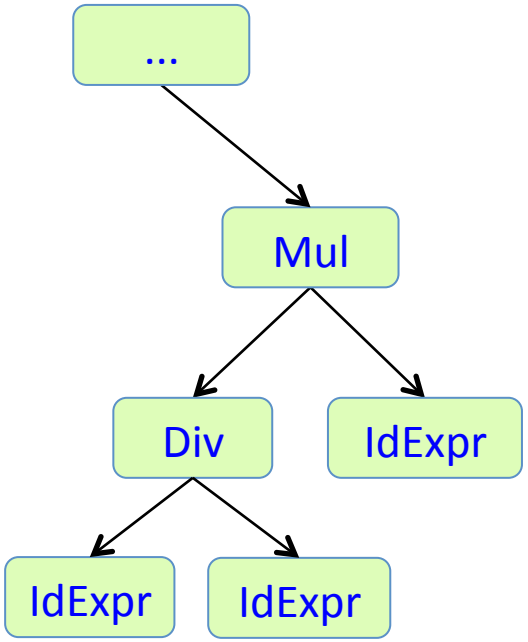
Revised: 2015-09-14

# This lecture



# Example computations on an AST




Name analysis: find the declaration of an identifier

Type analysis: compute the type of an expression

Expression evaluation: compute the value of a constant expression

Code generation: compute an intermediate code representation of the program

Unparsing: compute a text representation of the program

# Exercise: expression evaluation

Abstract grammar

```
abstract Expr;
BinExpr : Expr ::= Left:Expr Right:Expr;
Add : BinExpr;
Sub : BinExpr;
IntExpr : Expr ::= <INT:String>;
```

Generated AST classes

```
abstract class Expr extends ASTNode {

}
class BinExpr extends Expr { Expr getLeft() {…} Expr getRight {…} }
class Add extends BinExpr {

}
class Sub extends BinExpr {

}
class IntExpr extends Expr {
  String getINT() {…}

}
```

# Solution: expression evaluation

Abstract grammar

```
abstract Expr;
BinExpr : Expr ::= Left:Expr Right:Expr;
Add : BinExpr;
Sub : BinExpr;
IntExpr : Expr ::= <INT:String>;
```

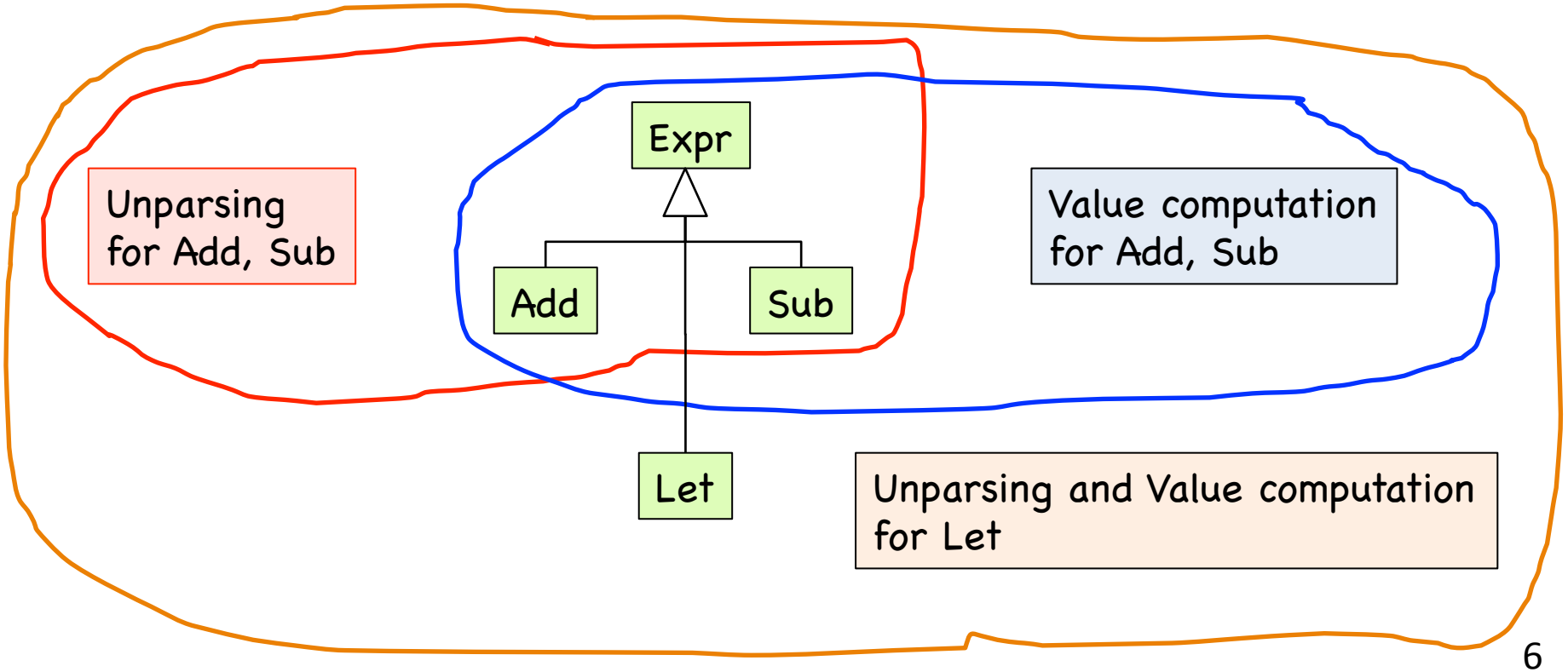
Problem 1: NEVER EDIT GENERATED CODE!!
Problem 2: The code is not modular!
We have to edit every AST class!
The computation of value() is a cross-cutting concern, leading to tangled code.

Edited AST classes

```
abstract class Expr extends ASTNode {
  abstract int value();
}
class BinExpr extends Expr { Expr getLeft() {...} Expr getRight {...} }
class Add extends BinExpr {
  int value() { return getLeft().value() + getRight().value(); }
}
class Sub extends BinExpr {
  int value() { return getLeft().value() - getRight().value(); }
}
class IntExpr extends Expr {
  String getINT() {...}
  int value() { return String.parseInt(getINT()); }
}
```

# The Expression Problem

- We would like to
  - define language constructs in a modular way.
  - define computations in a modular way
  - compose these modules as we like
  - preferrably, with separate compilation of the modules
  - and with full type safety (without need for casts)



# Dealing with the expression problem

- Edit the AST classes (i.e., actually not solving the problem)
  - Non-modular, non-compositional.
  - **It is always a VERY BAD IDEA to edit generated code!**
  - Sometimes used anyway in industry.
- Visitors: an OO design pattern.
  - Modularize through clever indirect calls.
  - Not full modularization, not composition.
  - Supported by many parser generators.
  - Reasonably useful, commonly used in industry.
- Static Aspect-Oriented Programming (AOP)
  - Also known as *inter-type declarations* (ITDs)
  - Use new language constructs (aspects) to factor out code.
  - Solves the expression problem in a nice simple way.
  - The drawback: you need a new language: AspectJ, JastAdd, ...
- Advanced language constructs
  - Use more advanced language constructs: virtual classes in gbeta, traits in Scala, typeclasses in Haskell, ...
  - Drawbacks: More complex than static AOP. You need an advanced language. Not much practical experience (so far).

This lecture: Visitors

# Visitors

How to modularize compilers in Java
(or any other OO language without AOP mechanisms).

*The Visitor design pattern lets you define a new operation without changing the elements on which it operates.*
[Gamma, Helm, Johnson, Vlissides, 1994]

# A simple example

Original code

```
class Add extends Exp {
  Exp e1, e2;
}
class IntExp extends Exp {
  int value;
}
```

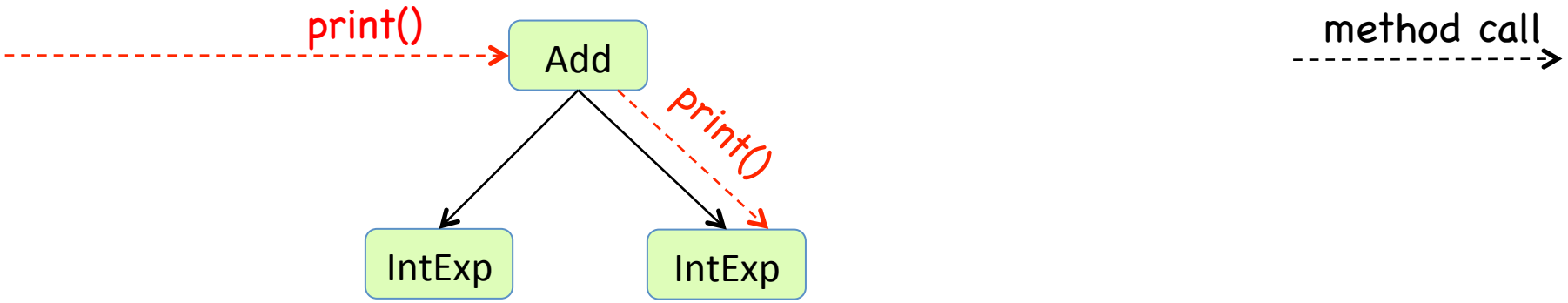
After adding the print method

```
class Add extends Exp {
  Exp e1, e2;
  void print() {
    e1.print();
    System.out.print("+");
    e2.print();
  }
}
class IntExp extends Exp {
  int value;
  void print() {
     System.out.print(value);
  }
}
```

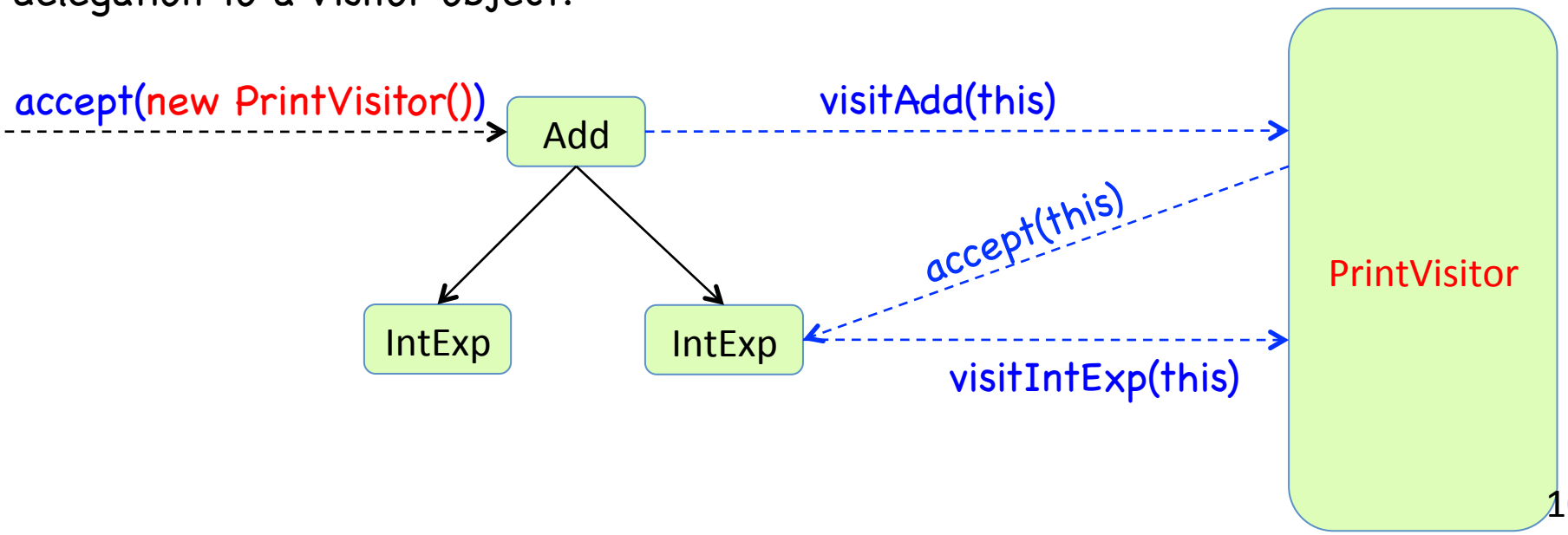
Could we add the print methods, without changing the original code?

# Main idea of visitors

Instead of:




Add some boilerplate code that allows delegation to a Visitor object:



# Example implementation

Original code

```
class Add extends Exp {
  Exp e1, e2;
  void accept(Visitor v) {
    v.visitAdd(this);
  }
}
class IntExp extends Exp {
  int value;
  void accept(Visitor v) {
    v.visitIntExp(this);
  }
}
```

General visitor

```
interface Visitor {
  void visitAdd(Add n);
  void visitIntExp(IntExp n);
}
```

Modular addition of print

```
class Print implements Visitor {
  void visitAdd(Add n) {
    n.e1.accept(this);
    System.out.print("+");
    n.e2.accept(this);
  }
  void visitIntExp(IntExp n) {
    System.out.print(n.value);
  }
}
```

General boilerplate code for visitors, can be generated from the grammar.

# Many implementations use Java overloading

## for the visit methods

Original code

```
class Add extends Exp {
  Exp e1, e2;
  void accept(Visitor v) {
    v.visit(this);
  }
}
class IntExp extends Exp {
  int value;
  void accept(Visitor v) {
    v.visit(this);
  }
}
```

General visitor

```
interface Visitor {
  void visit(Add n);
  void visit(IntExp n);
}
```

Modular addition of print

```
class Print implements Visitor {
  void visit(Add n) {
    n.e1.accept(this);
    System.out.print("+");
    n.e2.accept(this);
  }
  void visit(IntExp n) {
    System.out.print(n.value);
  }
}
```

Tricky question: The accept methods all look the same! Why can't we define just one accept method in the superclass, and let all classes inherit it???

Answer: Because the calls go to *different* visit methods: "this" has different types for the different calls. The visit methods are *overloaded* (same name but different argument types).

# Typical Visitor interface

## has return value and data parameter

The Visitor interface

```
interface Visitor {
  Object visit(Add node, Object data);
  Object visit(IntExp node, Object data);
}
```

The AST classes

```
class Add extends Exp {
  …
  Object accept(Visitor v, Object data) {
    return v.visit(this, data);
  }
}
class IntExp extends Exp {
  …
  Object accept(Visitor v, Object data) {
    return v.visit(this, data);
  }
}
```

# Example visitor: expression evaluation

Tangled crosscutting code

```
class Expr{
  abstract int value();
}
```

```
class Add{
  int value() {
    return getLeft().value() +
      getRight().value(); }
}
```

```
class Sub{
  int value() { … }
}
```

```
class IntExpr{
  int value() { … }
}
```

Corresponding Visitor

```
class Evaluator implements Visitor {
  Object visit(Add node, Object data) {
    return
      (Integer) node.getLeft().accept(this, data) +
      (Integer) node.getRight().accept(this, data);
  }
  Object visit(Sub node, Object data) { … }
  Object visit(IntExpr node, Object data { …}
}
```

quite a lot of boilerplate

extra type casts

Casts needed to access return and data values.
(Could be solved by type parameters on the visitor interface.)

# Making the client code simple

## add a static convenience method to the Visitor

The client code we want to write:

```
Expr e = …;
int result = Evaluator.result(e);
```

Visitor

```
class Evaluator implements Visitor {
  static int result(Expr node) {
    return (Integer) node.accept(new Evaluator(), null);
  }
  Object visit(Add node, Object data) {
    int n1 = (Integer) node.getLeft().accept(this, data);
    int n2 = (Integer) node.getRight().accept(this, data);
    return new Integer(n1+n2);
  }
  Object visit(Sub node, Object data) { … }
  Object visit(IntExpr node, Object data { …}
}
```

# Example: unparser

Tangled crosscutting code

```
class Expr{
  abstract void unparse(Stream s);
}
```

Pass the stream as a parameter

```
class Add{
  void unparse(Stream s) {
    getLeft().unparse(s);
    s.print("+");
    getRight().unparse(s);
  }
}
```

```
class Sub{
  …
}
```

```
class IntExpr{
  …
}
```

Corresponding Visitor

```
class Unparser implements Visitor {
  Unparser(Stream s) { this.s = s; }
  Stream s;
  Object visit(Add node, Object data) {
    node.getLeft().accept(this, data);
    s.print("+");
    node.getRight().accept(this, data);
    return null;
  }
  …
}
```

No need for stream parameter.
Keep it in the visitor.
Nice!

# Adding a convenience method for clients

Client code

```
Expr e = …;
Stream s = …;
Unparser.doit(e, s);
```

Visitor

```
class Unparser implements Visitor {
  static void doit(Expr e, Stream s) {
    e.accept(new Unparser(s), null);
  }
  Unparser(Stream s) { this.s = s; }
  Stream s;
  Object visit(Add node, Object data) {
    node.getLeft().accept(this, data);
    s.print("+");
    node.getRight().accept(this, data);
    return null;
  }
  …
}
```

# One more example

## Count the number of identifiers in a program

Abstract grammar

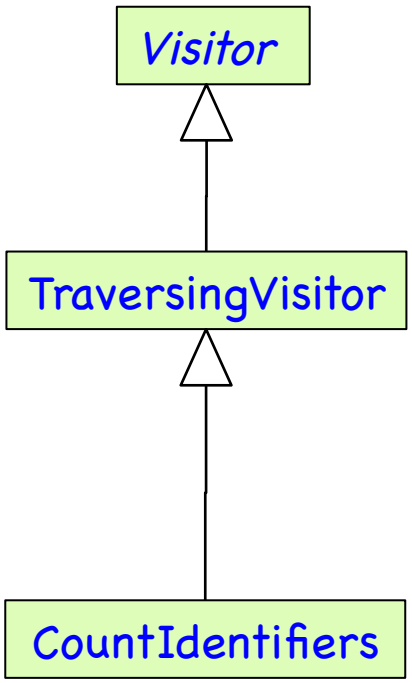
```
abstract Stmt;
IfStmt : Stmt ::= Cond:Exp Then:Stmt [Else:Stmt]
…
abstract Expr;
BinExpr : Expr ::= Left:Expr Right:Expr;
Add : BinExpr;
Sub : BinExpr;
IntExpr : Expr ::= <INT:String>;
IdExpr : Expr ::= <ID:String>
…
```

How can we implement the visitor?

Problem: We need to write lots of boring traversal code…

# Solution:

## Introduce a general traversing Visitor




Interface, as before

Default implementations that just traverse the AST.
Could be generated from the grammar.

Override default traversal when needed.

Some parser generators generate several different kinds of visitors, for different kinds of traversals.

# Implementation of TraversingVisitor

```
class TraversingVisitor implements Visitor {

 private Object visitChildren(ASTNode node, Object data) {
    for (int i = 0; i < node.getNumChild(); ++i) {
      node.getChild(i).accept(this, data);
    }
    return data;
  }

  Object visit(IfStmt node, Object data) {
    return visitChildren(node, data);
  }
  Object visit(Add node, Object data) {
    return visitChildren(node, data);
  }
  Object visit(Sub node, Object data) {
    return visitChildren(node, data);
  }
  …
}
```

# CountIdentifiers as a traversing visitor

Example use:

```
Program p = …
System.out.print("The number of identifiers is: ");
System.out.println(CountIdentifiers.result(p));
```

Visitor

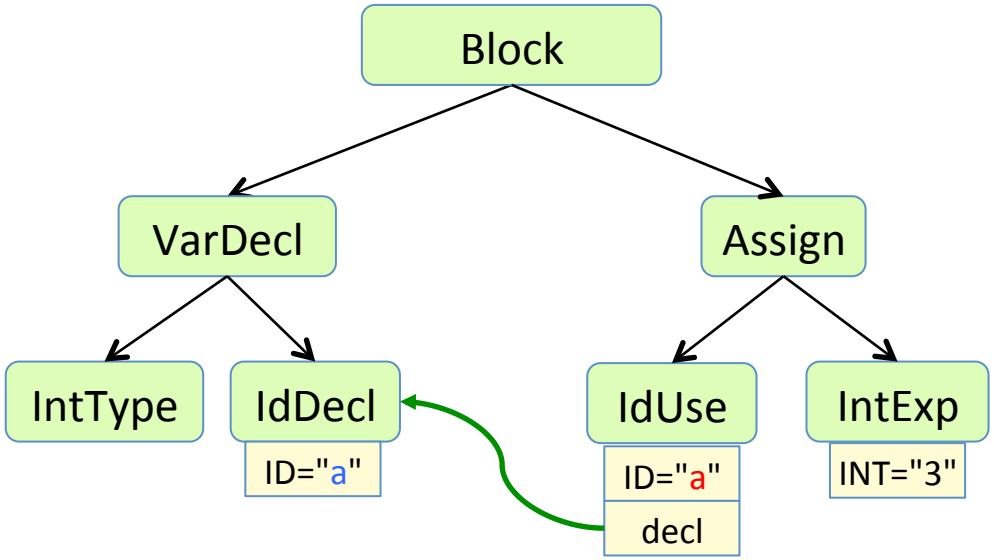
```
class CountIdentifiers extends TraversingVisitor {
  int count = 0;
  static int result(Program root) {
    root.accept(new CountIdentifiers());
    return count;
  }
  Object visit(IdExpr node, Object data) {
    count++;
    return null;
  }
}
```

Only one visit method needed.

Nice!

# Representing name bindings in an AST

```
{
  int a;
  a = 3;
}
```



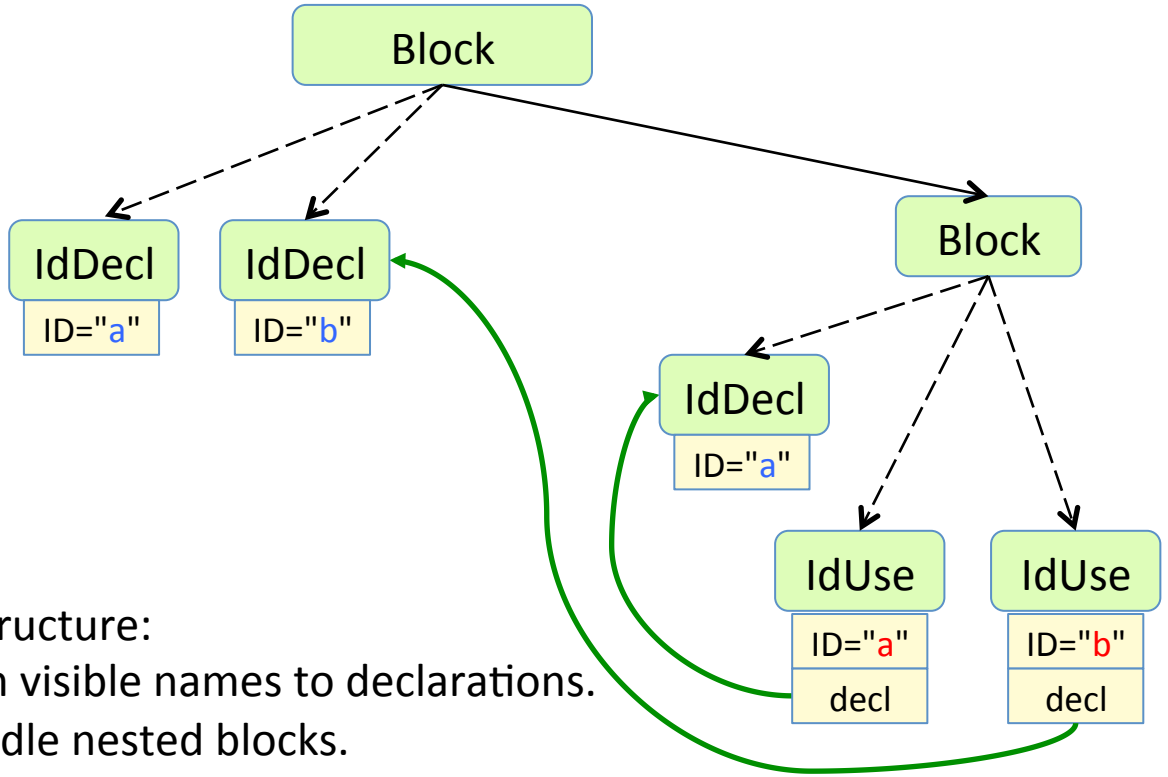

Differ between declarations and uses!

**IdDecl** for declared names
**IdUse** for used names

An attribute **decl** represents the name binding.

# Computing name bindings imperatively

```
{
  int a = 3;
  int b = 4;
  {
    int a;
    a = b;
  }
}
```




Use a **symbol table** data structure:
For each block, a **map** from visible names to declarations.
Use a **stack** of maps to handle nested blocks.

**Algorithm:**
Traverse the AST
push/pop symbol table when entering/leaving a block
add/lookup identifiers when encountering IdDecls/IdUses

# Example API for block structured symbol table

```
class SymbolTable<M> {
    void add(String symbol, M meaning); // add to top table
    void enterBlock(); // push new table
    void exitBlock();  // pops top table
    M lookup(String symbol); // returns the meaning of the symbol
}
```

Could be used, for example, in a visitor:

```
class NameAnalysis extends TraversingVisitor {
  SymbolTable<IdDecl> st = new SymbolTable<IdDecl>();
  void visit(Block node) {
    st.enterBlock();
    visitChildren(node);
    st.exitBlock();
  }
  void visit(IdDecl node) {
    st.add(node.getID(), node);
  }
  void visit(IdUse node) {
    node.decl = st.lookup(node.getID());
  }
}
```

# Summary questions

- What is the Expression Problem?
- Why is solving the Expression Problem desirable for implementing compilers?
- Why is it a bad idea to edit generated code?
- Explain how the Visitor pattern can be implemented.
- Implement a computation over the AST using visitors.
- Add a convenience method to the visitor to make it easier to call from client code.
- Why can traversing visitors be useful?
- What is a symbol table?
- Why use both IdDecl and IdUse instead of just one AST type?