

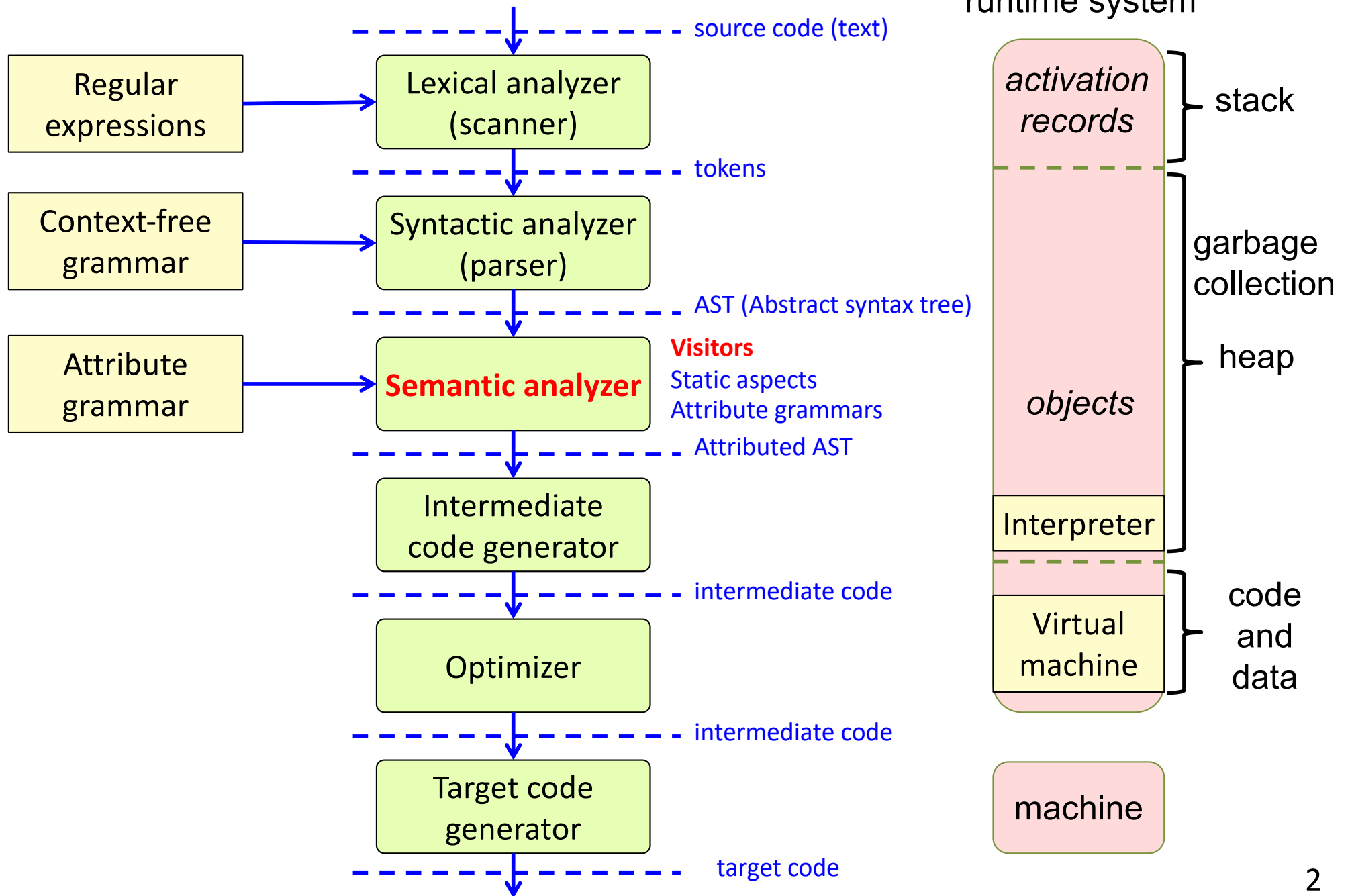
EDAN65: Compilers, Lecture 06 B

# Visitors

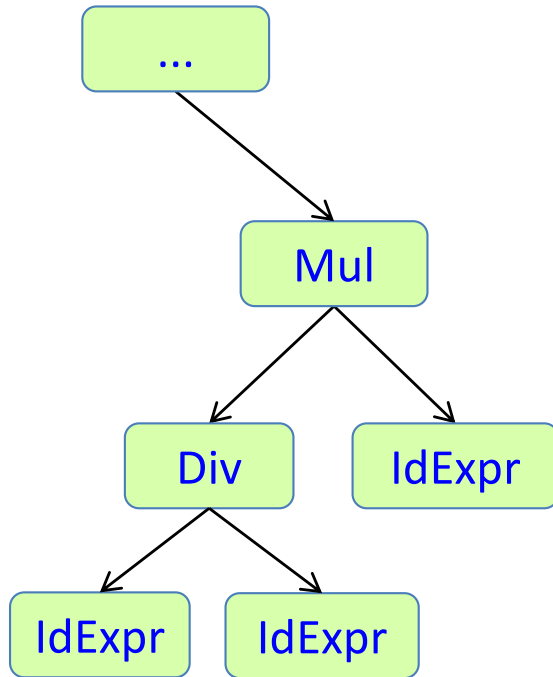
Görel Hedin

Revised: 2023-09-11

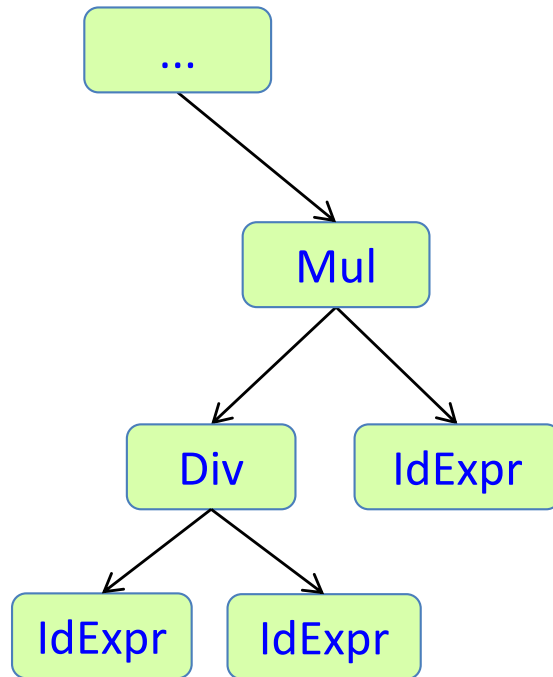
# This lecture



# Example computations on an AST



# 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>;
```

# 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>;
```

## 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()); }  
}
```

# 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

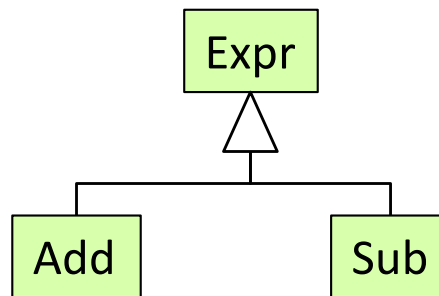
- add language constructs modularly
- add computations on them modularly

and preferably with

- full type checking
- separate compilation

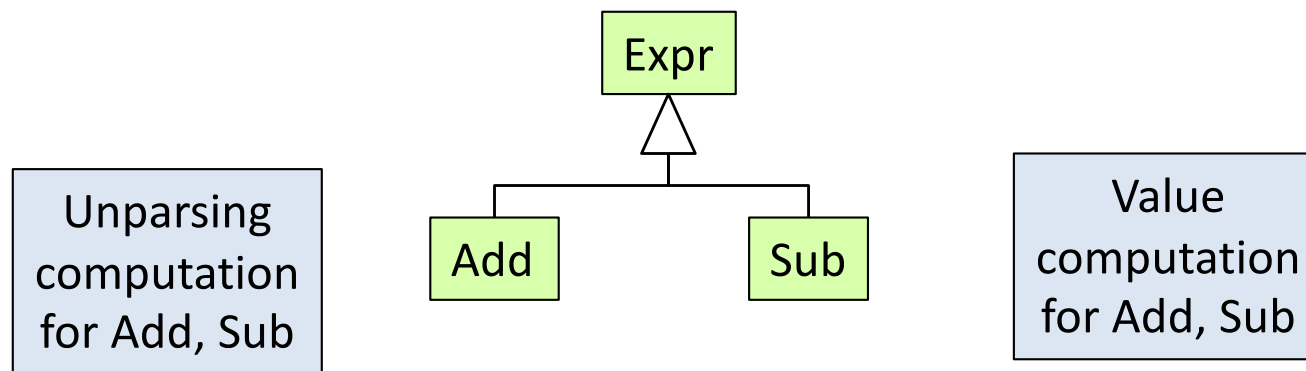
# The Expression Problem

Example initial modules



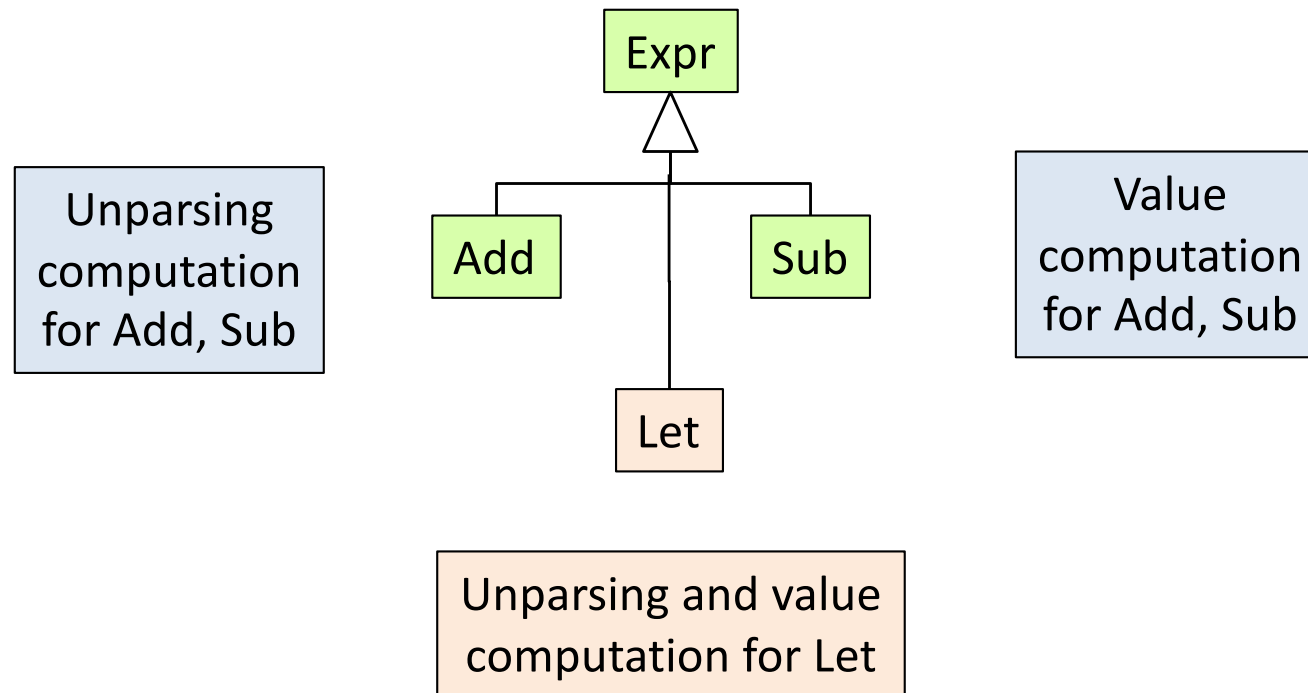
# The Expression Problem

Adding some computations



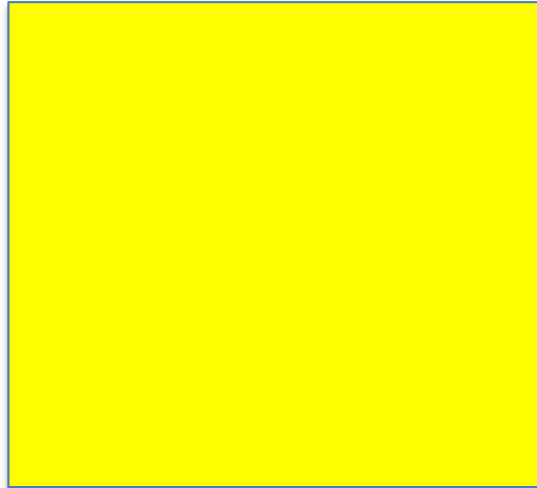
# The Expression Problem

Adding a new construct and some computations

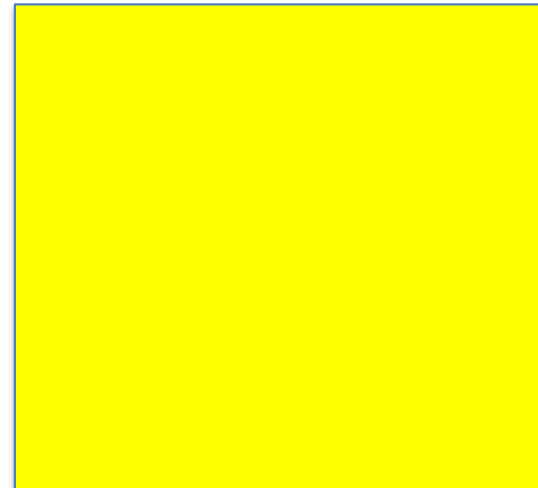


# The Expression Problem

Easy to add  
language  
construct



Hard to add  
language  
construct



Hard to add  
computation

Easy to add  
computation

# The Expression Problem

Easy to add  
language  
construct

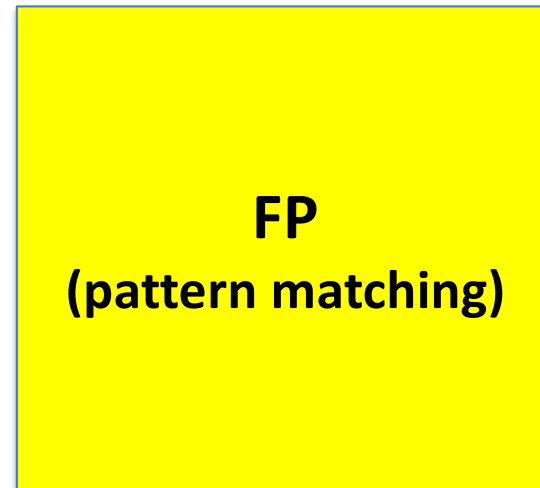
**OOP**  
(subclassing,  
virtual methods)



Hard to add  
language  
construct



**FP**  
(pattern matching)



Hard to add  
computation

Easy to add  
computation

# The Expression Problem

Easy to add  
language  
construct

**OOP**



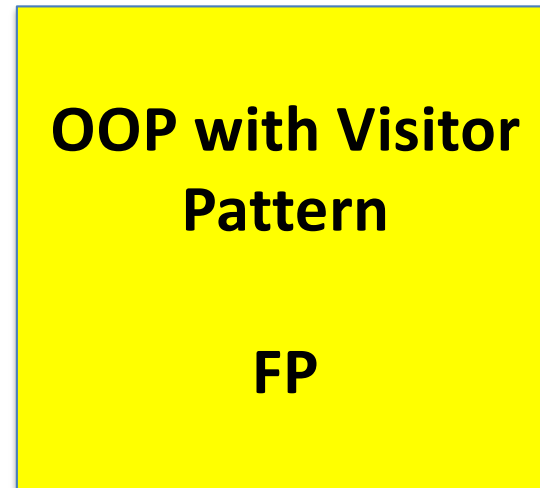
Hard to add  
language  
construct



Hard to add  
computation

**OOP with Visitor  
Pattern**

**FP**



Easy to add  
computation

# The Expression Problem

Easy to add  
language  
construct

**OOP**

**OOP  
with Static Aspects\***

\* Not Java,  
no separate  
compilation.

Hard to add  
language  
construct

**OOP  
with Visitor Pattern**

**FP**

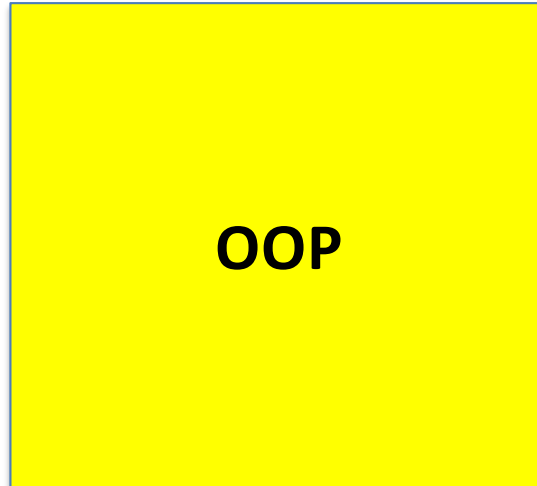
Hard to add  
computation

Easy to add  
computation



# The Expression Problem

Easy to add  
language  
construct



\* Not Java,  
no separate  
compilation.

Hard to add  
language  
construct



Hard to add  
computation

Easy to add  
computation

# The simplest solution: Static aspects

```
abstract class Exp extends ASTNode {
    abstract int value();
}
class Add extends Exp {
    int value() {
        return getLeft().value() +
            getRight().value();
    }
}
class IntExp extends Exp{
    String getINT() {...}
    int value() {
        return String.parseInt(getINT());
    }
}
```

Factor out the tangled code into an aspect.

Requires the language to support static aspects.

Not supported in Java. Requires another language like AspectJ, or JastAdd.

# The simplest solution: Static aspects

```
abstract class Exp extends ASTNode {  
  
}  
class Add extends Exp {  
  
  
}  
class IntExp extends Exp {  
    String getINT() {...}  
  
}
```

```
aspect ValueComputation {  
    abstract int Exp.value();  
  
    int Add.value() {  
        return getLeft().value() +  
            getRight().value();  
    }  
  
    int IntExp.value() {  
        return String.parseInt(getINT());  
    }  
}
```

Factor out the tangled code into an aspect.

Requires the language to support static aspects.

Not supported in Java. Requires another language like AspectJ, or JastAdd.

# Dealing with the expression problem

# 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 (without visitors)

Original code

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

# A simple example (without visitors)

Original code

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

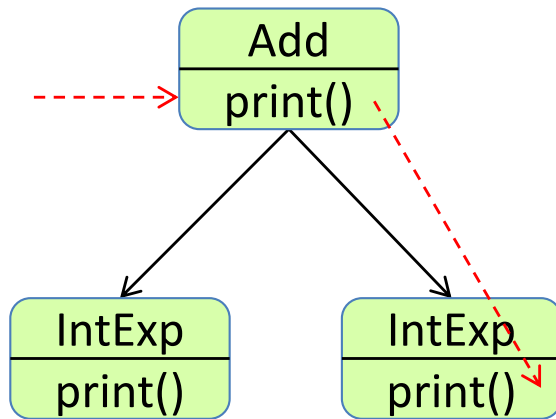
After adding the **print** method

```
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?



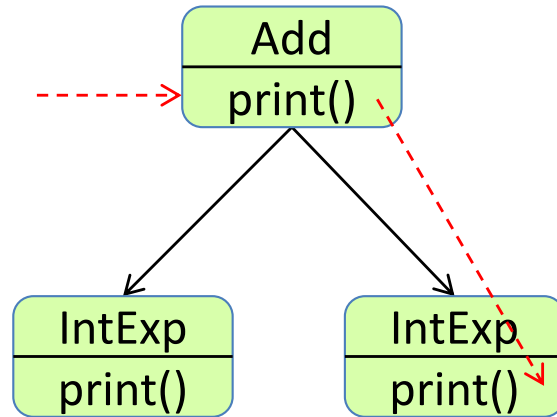
# Without Visitors



Straight-forward  
implementation,  
but not modular.

method call  
----->

# Without Visitors

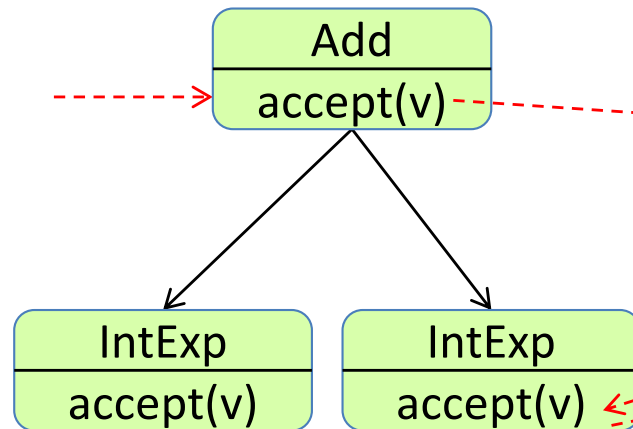


Straight-forward implementation, but not modular.

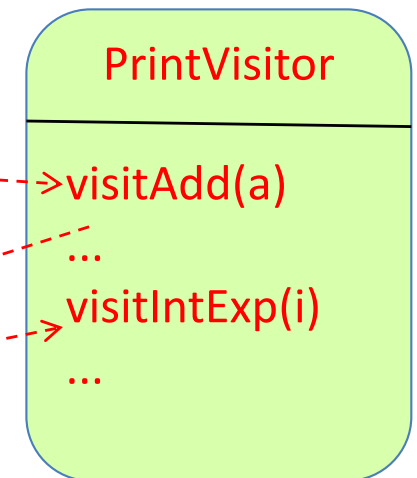
method call →

# With Visitors

Nodes prepared with "accept" methods



Print code in Visitor module



# Example implementation

AST classes

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

# Example implementation

## AST classes

```
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);  
}
```

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

# Example implementation

## AST classes

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

## General visitor

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

## Modular addition of **print**

```
class PrintVisitor 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);
  }
}
```

# Many implementations use Java overloading for the visit methods

## AST classes

```
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 PrintVisitor 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! Can it be factored out to a superclass?

# Many implementations use Java overloading for the visit methods

## AST classes

```
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);
    }
}
```

Tricky question: The accept methods all look the same! Can it be factored out to a superclass?

## General visitor

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

## Modular addition of **print**

```
class PrintVisitor 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);
    }
}
```

Answer: No! 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

Without visitors:

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

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

```
class Sub extends Exp{  
  int value() { ... }  
}
```

```
class IntExp extends Exp{  
  int value() { ... }  
}
```

# Example visitor: expression evaluation

Without visitors:

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

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

```
class Sub extends Exp{  
  int value() { ... }  
}
```

```
class IntExp extends Exp{  
  int value() { ... }  
}
```

Corresponding Visitor

```
class EvaluatorVisitor implements Visitor {  
  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(IntExp node, Object data) { ... }  
}
```

quite a lot of boilerplate  
extra type casts

# Example visitor: expression evaluation

Without visitors:

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

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

```
class Sub extends Exp{  
  int value() { ... }  
}
```

```
class IntExp extends Exp{  
  int value() { ... }  
}
```

Corresponding Visitor

```
class EvaluatorVisitor implements Visitor {  
  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(IntExp 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.)

# Calling the visitor

Method 1: Create the visitor and call the accept method

```
Exp e = ...;  
int result = (Integer) e.accept(new EvaluatorVisitor(), null);
```

# Calling the visitor

Method 1: Create the visitor and call the accept method

```
Exp e = ...;  
int result = (Integer) e.accept(new EvaluatorVisitor(), null);
```

Method 2: Much simpler client code. Provide a static convenience method

```
Exp e = ...;  
int result = EvaluatorVisitor.result(e);
```

# Calling the visitor

Method 1: Create the visitor and call the accept method

```
Exp e = ...;  
int result = (Integer) e.accept(new EvaluatorVisitor(), null);
```

Method 2: Much simpler client code. Provide a static convenience method

```
Exp e = ...;  
int result = EvaluatorVisitor.result(e);
```

Implementation of convenience method

```
class EvaluatorVisitor implements Visitor {  
    static int result(Exp node) {  
        return (Integer) node.accept(new EvaluatorVisitor(), null);  
    }  
    Object visit(Add node, Object data) {...}  
    Object visit(Sub node, Object data) { ... }  
    Object visit(IntExp node, Object data { ...}  
}
```

# Example: Visitor with local field

Without visitors:

```
class Exp{  
  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 IntExp ... {  
  ...  
}
```

# Example: Visitor with local field

Without visitors:

```
class Exp{  
  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 IntExp ... {  
  ...  
}
```

Corresponding Visitor

```
class UnparserVisitor implements Visitor {  
  UnparserVisitor(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

# Adding a convenience method for clients

Client code

```
Exp e = ...;  
Stream s = ...;  
UnparserVisitor.doit(e, s);
```

# Adding a convenience method for clients

Client code

```
Exp e = ...;  
Stream s = ...;  
UnparserVisitor.doit(e, s);
```

Visitor

```
class UnparserVisitor implements Visitor {  
    static void doit(Exp e, Stream s) {  
        e.accept(new UnparserVisitor(s), null);  
    }  
    UnparserVisitor(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

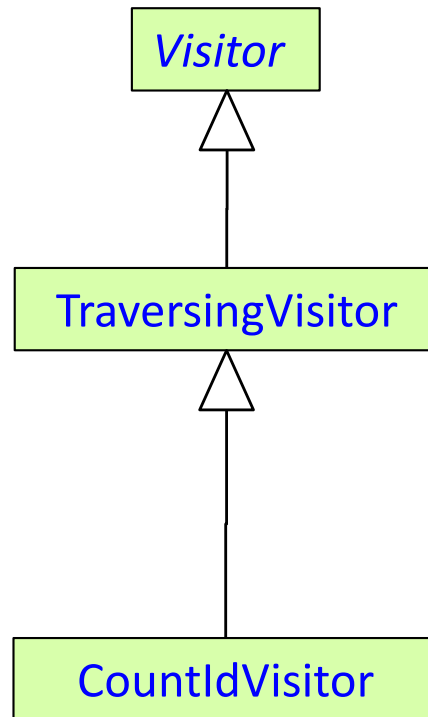
```
abstract Stmt;  
IfStmt : Stmt ::= Cond:Exp Then:Stmt [Else:Stmt]  
...  
abstract Expr;  
BinExpr : Expr ::= Left:Expr Right:Expr;  
Add : BinExpr;  
Sub : BinExpr;  
IntExpr : Expr ::= <INT:String>;  
IdExpr : Expr ::= <ID:String>  
...
```

How can we implement the visitor?

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

# Solution:

Introduce a general traversing Visitor



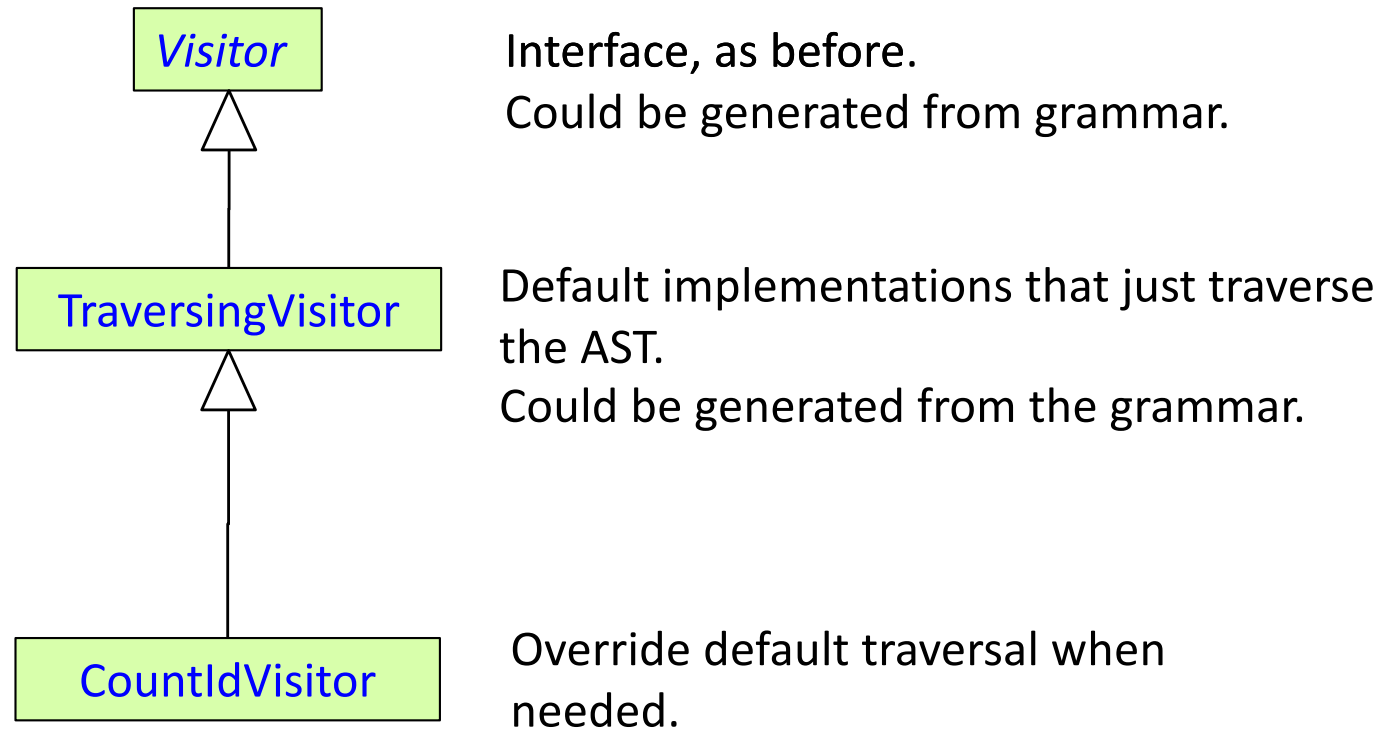
Interface, as before.  
Could be generated from grammar.

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

Override default traversal when  
needed.

# Solution:

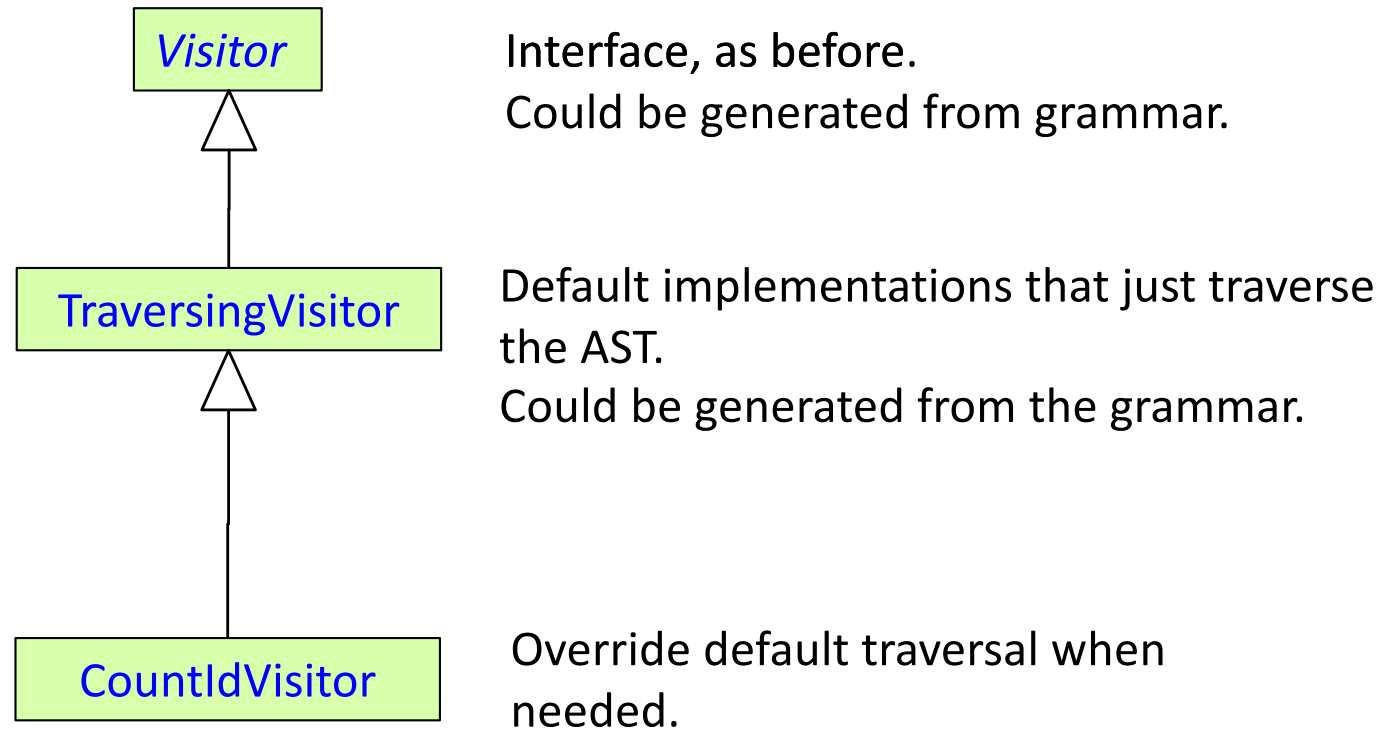
Introduce a general traversing Visitor



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

# Solution:

Introduce a general traversing Visitor



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

In assignment 3, you will write the Visitor interface by hand – to understand how it works.

# Implementation of TraversingVisitor

```
class TraversingVisitor implements Visitor {  
  
    private Object visitChildren(ASTNode node, Object data) {  
        for (ASTNode child: astChildren()) {  
            child.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(CountIdVisitor.result(p));
```

Visitor

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

# CountIdentifiers as a traversing visitor

Example use:

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

Visitor

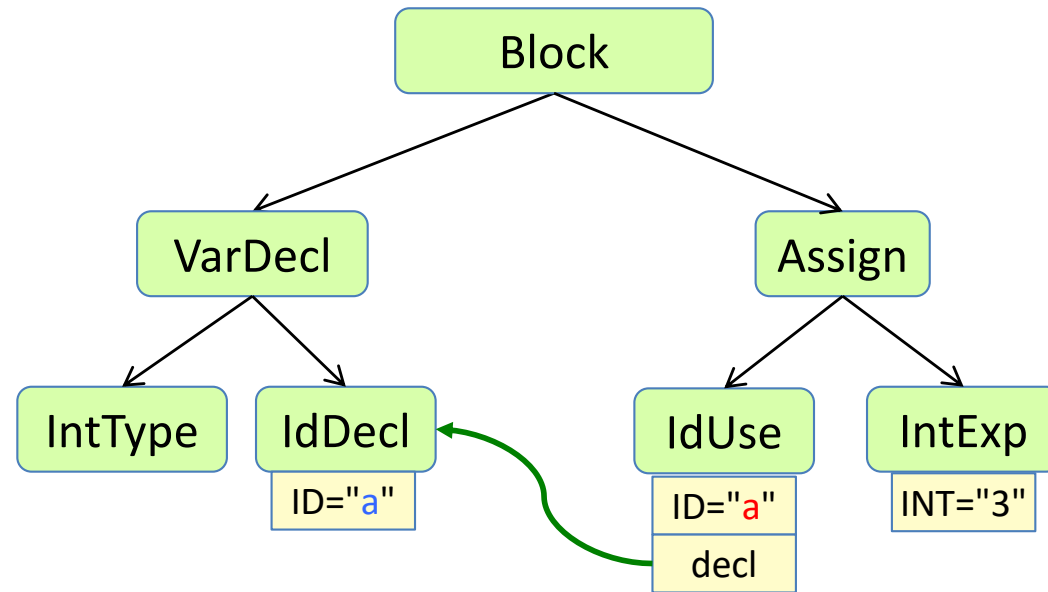
```
class CountIdVisitor extends TraversingVisitor {  
    int count = 0;  
    static int result(Program root) {  
        CountIdVisitor v = new CountIdVisitor();  
        root.accept(v);  
        return v.count;  
    }  
    Object visit(IdExpr node, Object data) {  
        count++;  
       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

Only one visit  
method needed.

Nice!

# Representing name bindings in an AST

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



Differ between **declarations** and **uses**!

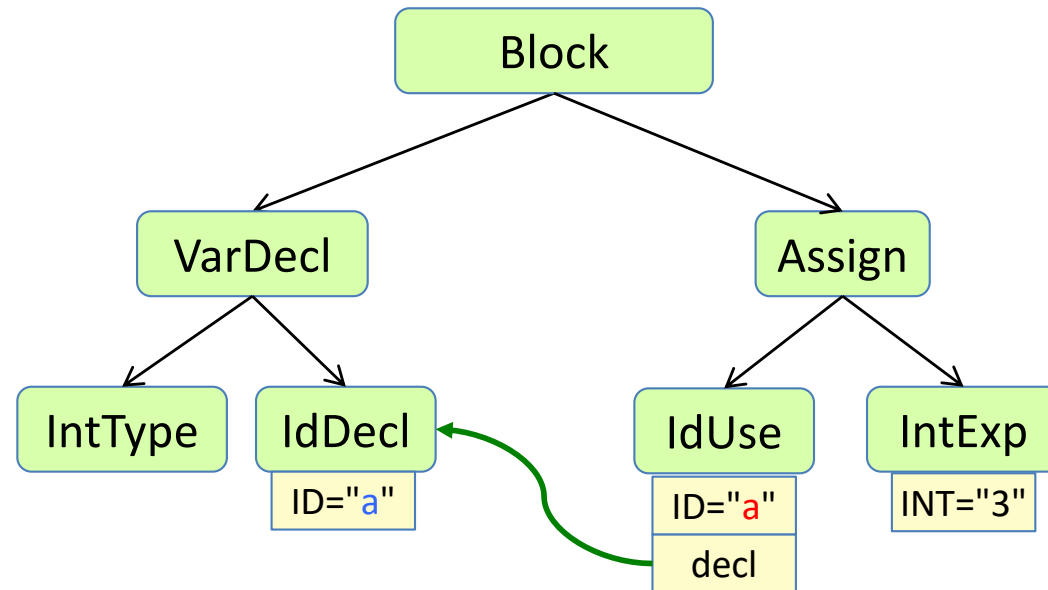
**IdDecl** for declared names

**IdUse** for used names

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

# Representing name bindings in an AST

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



Differ between **declarations** and **uses**!

**IdDecl** for declared names

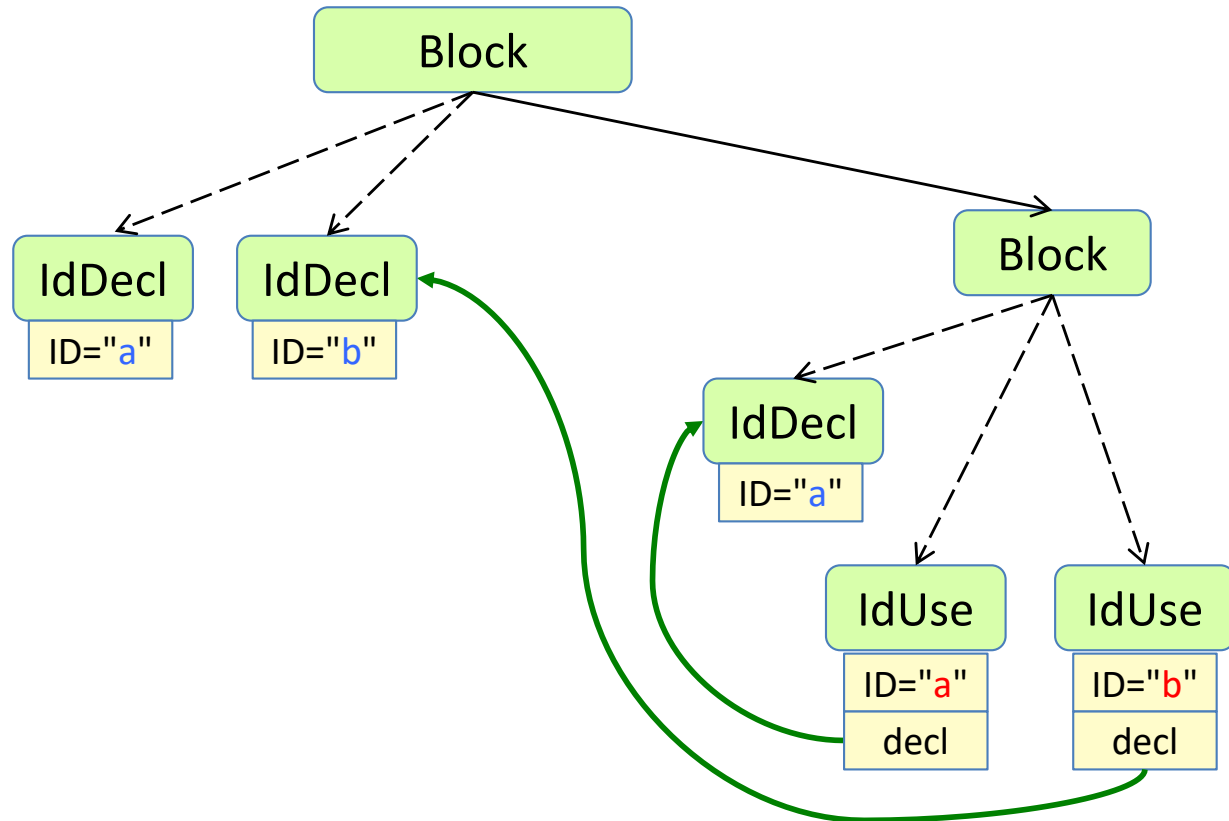
**IdUse** for used names

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

Make sure to use both **IdDecl** and **IdUse** for your AST in assignment 2!

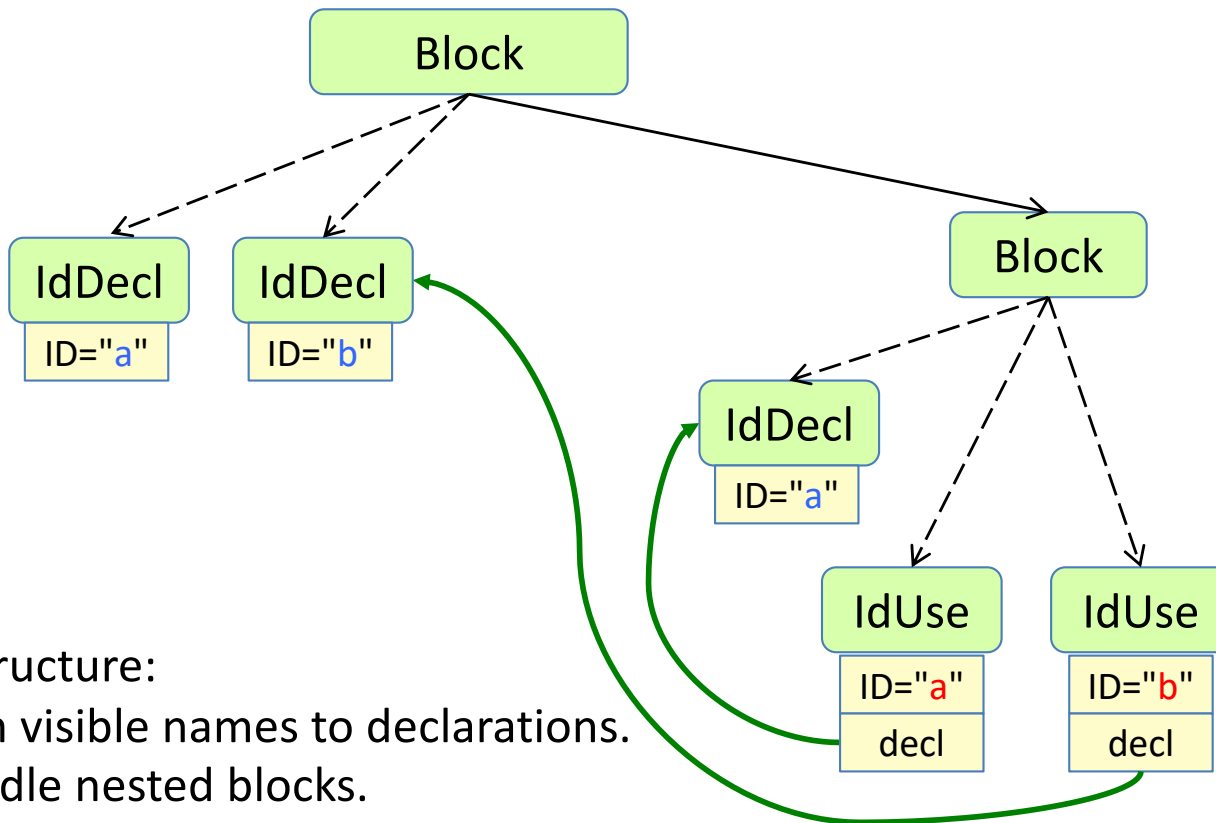
# Computing name bindings imperatively

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



# 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  
}
```

# 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 NameAnalysisVisitor 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?