Structuring Analysis

- Analysis is a traversal of AST
- Technique used in lecture: recursion using methods of AST node objects—object-oriented style

```java
class Add extends Expr {
    Type typeCheck(SymTab s) {
        Type t1 = e1.typeCheck(s),
        t2 = e2.typeCheck(s);
        if (t1 == Int && t2 == Int) return Int;
        else throw new TypeCheckError("+");
    }
}
```

Separating Syntax, Impl.

- Can write each traversal in a single method
- Constant folding
- Translation to intermediate code
- Optimization
- Final code generation

```java
abstract class Expr {
    Expr foldConstants();
}
class Add extends Expr {
    Expr e1, e2;
    Expr foldConstants() {
        e1 = e1.foldConstants(); e2 = e2.foldConstants();
        if (e1 instanceof IntConst && e2 instanceof IntConst)
            return new IntConst(e1.value + e2.value);
        else return new Add(e1, e2);
    }
}
```

Constant Folding

- AST optimization: replaces constant expressions with constants they would compute
- Traverses (and modifies) AST

```java
constant Folding

Redundancy

- There will be several more compiler phases like typeCheck and foldConstants
- Constant folding
- Translation to intermediate code
- Optimization
- Final code generation
- Object-oriented style: each phase is a method in AST node objects
- Weakness 1: code for each phase spread
- Weakness 2: traversal logic replicated
Modularity Conflict

- No good answer!
- Two orthogonal organizing principles: node types and phases (rows or columns)

<table>
<thead>
<tr>
<th>typeCheck</th>
<th>foldConst</th>
<th>codeGen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add</td>
<td>Num</td>
<td>Id</td>
</tr>
<tr>
<td></td>
<td>node types</td>
<td>Stmt</td>
</tr>
</tbody>
</table>

Which is better?

- Neither completely satisfactory
- Both involve repetitive code
  - modularity by data (rows): different traversals share basic traversal code—boilerplate code
  - modularity by operations (columns): lots of boilerplate:
    ```java
    if (n instanceof Add) { Add a = (Add) n; ...}
    else if (n instanceof Id) { Id x = (Id) n; ... } else ...
    ```

Visitors

- Idea: avoid repetition by providing one set of standard traversal code.
- Knowledge of particular phase embedded in visitor object.
- Standard traversal code is done by object methods, reused by every phase.
- Visitor invoked at every step of traversal to allow it to do phase-specific work.

Polyglot Visitors

- Allow rewriting AST lazily in functional style
- Class `Node` is superclass for all AST nodes
- `NodeVisitor` is superclass for all visitor classes (one visitor class per phase)

Folding constants with visitors

```java
public class ConstantFolder extends NodeVisitor {
    public Node leave (Node old, Node n, NodeVisitor v) {
        return n.foldConstants(); // note: all children of n already folded
    }
}
```

```java
class Node {
    Node foldConstants() {
        return this;
    }
}
class BinaryExpression {
    Node foldConstants() {
        switch(op) {
            ... } }
}
class UnaryExpression {
    Node foldConstants() {
        switch(op) {
            ... }
    }
}
```
Summary

- Semantic analysis: traversal of AST
- Symbol tables needed to provide context during traversal
- Traversals can be modularized differently
- Visitor pattern avoids repetitive code
- Read Appel, Ch. 4 & 5
- See also: Design Patterns (The “Gang of Four book”)