Design patterns (part 3)

CSE 331
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Outline

- ✓ Introduction to design patterns
- ✓ Creational patterns (constructing objects)
- ✓ Structural patterns (controlling heap layout)
- ⇒ Behavioral patterns (affecting object semantics)

Review: Composite pattern

Composite permits a client to manipulate either an atomic unit or a collection of units in the same way

Good for dealing with part-whole relationships

Example behavior: traversing composites

- Goal: perform operations on all parts of a composite
- Idea: generalize the notion of an iterator

Composite example 1: Bicycle

- Bicycle
  - Frame
  - Drivetrain
  - Wheel
    - Tire
    - Tube
    - Tape
    - Rim
    - Nipples
    - Spokes
    - Hub
    - Skewer
      - Lever
      - Body
      - Cam
      - Rod
      - Acorn nut
  - ...

Methods on components

```
abstract class BicycleComponent {
  int weight();
  float cost();
}
class Wheel
    extends BicycleComponent {
  float assemblyCost;
  Skewer skewer;
  Hub hub;
  ...
  float cost() {
    return assemblyCost
           + skewer.cost()
           + hub.cost()
           + ...;
  }
}
```

```
class Bicycle
    extends BicycleComponent {
  float assemblyCost;
  Frame frame;
  Drivetrain drivetrain;
  Wheel frontWheel;
  ...
  float cost() {
    return assemblyCost
           + frame.cost()
           + drivetrain.cost()
           + frontWheel.cost()
           + ...;
  }
```

Composite example 2: Libraries

Library

Section (for a given genre)

Shelf

Volume

Page

Column

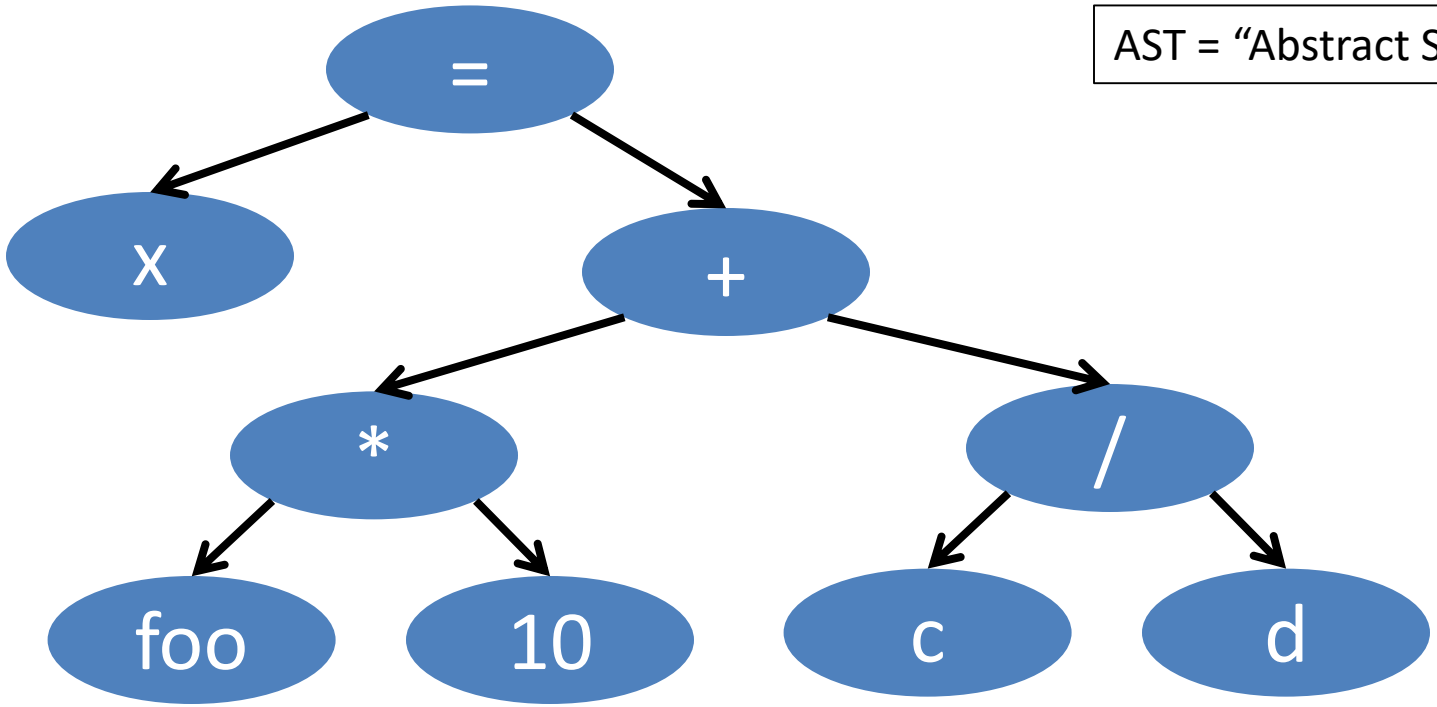
Word

Letter

```
interface Text {
  String getText();
}
class Page implements Text {
  String getText() {
    ... return the concatenation of the column texts ...
  }
}
```

Composite example 3: Representing Java code

```
x = foo * 10 + c / d;
```



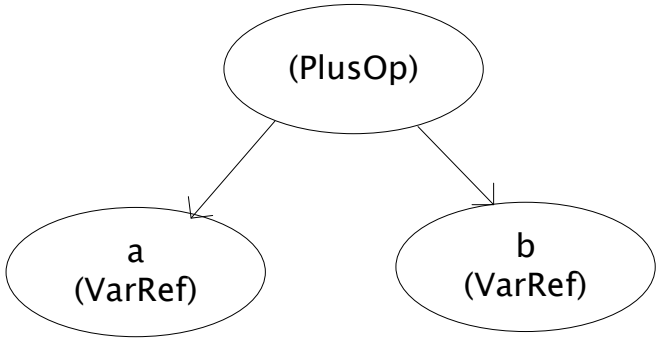
AST = “Abstract Syntax Tree”

Abstract syntax tree (AST) for Java code

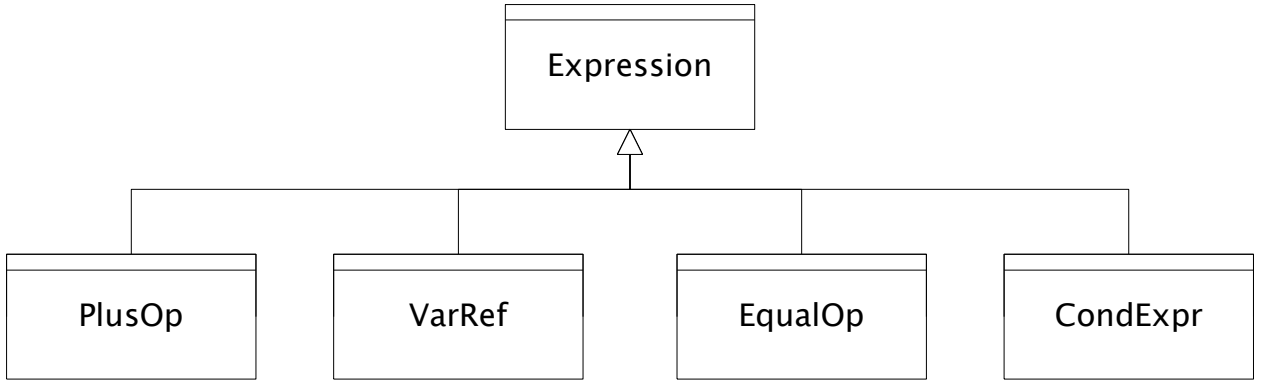
```
class PlusOp extends Expression {    // + operation
  Expression leftExp;
  Expression rightExp;
}
class VarRef extends Expression {    // variable reference
  String varname;
}
class EqualOp extends Expression {  // equality test a==b
  Expression lvalue;     // left-hand side: "a" in "a==b"
  Expression rvalue;     // right-hand side: "b" in "a==b"
}
class CondExpr extends Expression {  // a?b:c
  Expression condition;
  Expression thenExpr;  // value of expression if a is true
  Expression elseExpr;  // value of expression if a is false
}
```

Object model (heap layout) vs. type hierarchy (subtyping)

- AST for "a + b":



- Class hierarchy for **`Expression`**:



Operations on Java expressions

Java expressions

- Plus: `20 + 22`
- Variable reference: `x`
- Method call: `foo(5)`
- Conditional: `b ? 3 : 4`
- Equals: `x == y`
- …

Operations

- Typecheck
- Pretty-print
- Optimize
- …

Type-checking an equality operation

```
// typecheck "a == b" where a and b are arbitrary expressions
Type tcEqualsOp(EqualOp e) {
  Type leftType = tcExpression(e.lvalue); // type of a
  Type rightType = tcExpression(e.rvalue);  // type of b
  if (leftType != ERROR_TYPE
      && rightType != ERROR_TYPE
      && leftType == rightType) {
    return BOOLEAN_TYPE;
  } else {
    return ERROR_TYPE;
  }
}
```

Type-checking a conditional expr

```
// typecheck "a ? b : c"
Type tcCondExpr(CondExpr e) {
  Type condType = tcExpression(e.condition); // type of a
  Type thenType = tcExpression(e.thenExpr);  // type of b
  Type elseType = tcExpression(e.elseExpr);  // type of c
  if (condType != ERROR_TYPE
      && thenType != ERROR_TYPE
      && elseType != ERROR_TYPE
      && condType == BOOLEAN_TYPE
      && thenType == elseType) {
    return thenType;
  } else {
    return ERROR_TYPE;
  }
}
```

Organizing operations on abstract syntax trees

We know how to write code in each cell of this table:

		Objects	
		CondExpr	**EqualOp**
Operations	**typecheck**		
	pretty-print		

Question: Should we group together the code for a particular operation or the code for a particular expression?

(A separate issue: given an operation and an expression, how to select the proper piece of code to execute?)

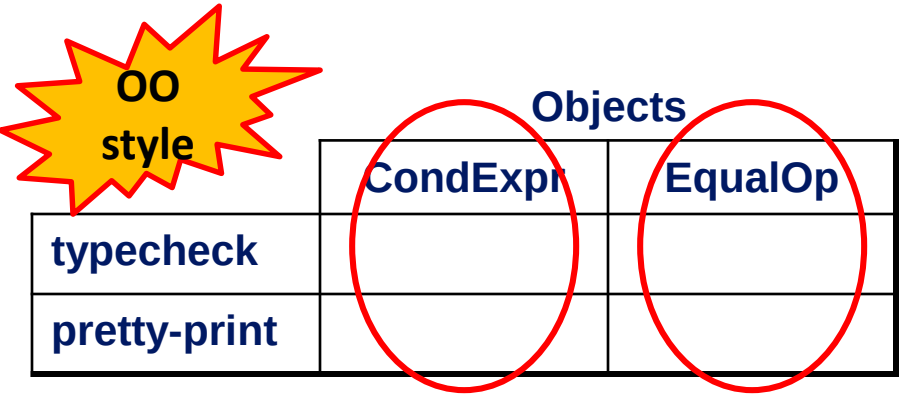
Interpreter and procedural patterns

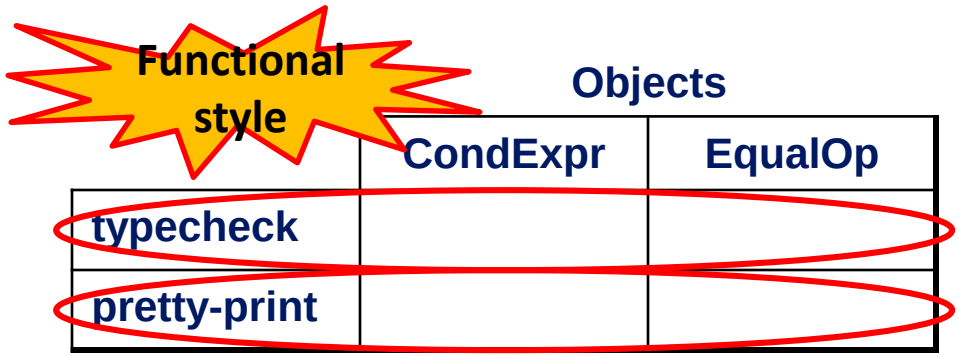
Interpreter: collects code for similar objects, spreads apart code for similar operations

- Easy to add objects
- Hard to add operations
- An instance of the composite pattern

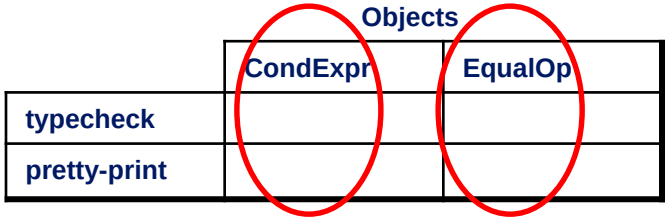
Procedural: collects code for similar operations, spreads apart code for similar objects

- Easy to add operations
- Hard to add objects
- The visitor pattern is a variety of the procedural pattern





Interpreter pattern



Add a method to each class for each supported operation

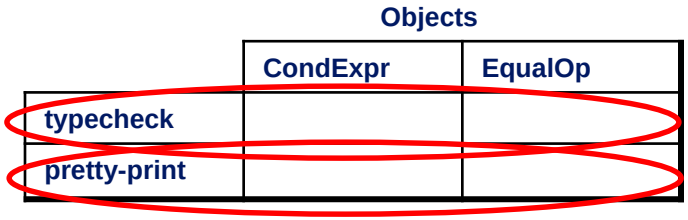
```
class Expression {
  ...
  Type typecheck();
  String prettyPrint();
}

class EqualOp extends Expression {  // "a == b"
  ...
  Type typecheck() { ... }
  String prettyPrint() { ... }
}

class CondExpr extends Expression {  // "a?b:c"
  ...
  Type typecheck() { ... }
  String prettyPrint() { ... }
}
```

Dynamic dispatch chooses the right implementation, for a call like **`myExpr.typeCheck()`**

Procedural pattern



Create a class per operation, with a method per operand type

```
class Typecheck {
  // typecheck "a?b:c"
  Type tcCondExpr(CondExpr e) {
    Type condType = tcExpression(e.condition); // type of "a"
    Type thenType = tcExpression(e.thenExpr);  // type of "b"
    Type elseType = tcExpression(e.elseExpr);  // type of "c"
    if ((condType == BoolType) && (thenType == elseType)) {
      return thenType;
    } else {
      return ErrorType; }
  }

  // typecheck "a==b"
  Type tcEqualOp(EqualOp e) {
    ...
  }
}
```

Given an expression, how to invoke the right implementation?

Definition of tcExpression (in procedural pattern)

```
class Typecheck {
  ...
  Type tcExpression(Expression e) {
    if (e instanceof PlusOp) {
      return tcPlusOp((PlusOp)e);
    } else if (e instanceof VarRef) {
      return tcVarRef((VarRef)e);
    } else if (e instanceof EqualOp) {
      return tcEqualOp((EqualOp)e);
    } else if (e instanceof CondExpr) {
      return tcCondExpr((CondExpr)e);
    } else ...
    ...
  }

}
```

Maintaining this code is tedious and error-prone.

The cascaded if tests may to run slowly.

Code duplication: this code is repeated in PrettyPrint and every other operation class.

(Languages with pattern matching mitigate these problems.)

Visitor pattern: a variant of the procedural pattern

Visitor encodes a traversal of a hierarchical data structure

Nodes (objects in the hierarchy) accept visitors

Visitors visit nodes (objects)

```
class SomeExpression extends Expression {
  void accept(Visitor v) {
    for each child of this node {
      child.accept(v);
    }
    v.visit(this);
  }
}
class SomeVisitor {
  void visit(SomeExpression n) {
    perform work on n
  }
  void visit(OtherExpression n) {
    perform work on n
  }
}
```

`n.accept(v)` traverses the structure rooted at **`n`**, invoking **`v`**'s operation

`visit` does the work on one element

What happened to all the **`instanceof`** operations?

Visitor pattern: example

Objects

```
class VarOp extends Expression {
  void accept(Visitor v) {
    v.visit(this);
  }
}

class EqualsOp extends Expression {
  void accept(Visitor v) {
    leftExp.accept(v);
    leftExp.accept(v);
    v.visit(this);
  }
}

class CondOp extends Expression {
  void accept(Visitor v) {
    testExp.accept(v);
    thenExp.accept(v)`
    elseExp.accept(v);
    v.visit(this);
  }
}
```

Operations

```
class TypeCheckVisitor implements
   Visitor {
  void visit(EqualsOp e) {
    assert e.leftExp and e.rightExp
   have the same type
  }
  void visit(PlusOp e) {
    assert e.leftExp and e.rightExp
   are numeric
  }
}
```

Each operation has its cases together.
Compiler error if a case is missing.

```
class PrettyPrintVisitor implements
   Visitor {
  void visit(EqualsOp e) {
    print e
  }
  void visit(PlusOp e) {
    print e
  }
}
```

Visitor pattern: example

Objects

```
class VarOp extends Expression {
  void accept(Visitor v) {
    v.visit(this);
  }
}

class EqualsOp extends Expression {
  void accept(Visitor v) {
    leftExp.accept(v);
    leftExp.accept(v);
    v.visit(this);
  }
}

class CondOp extends Expression {
  void accept(Visitor v) {
    testExp.accept(v);
    thenExp.accept(v)`
    elseExp.accept(v);
    v.visit(this);
  }
}
```

Overloading

Operations

```
class TypeCheckVisitor implements
   Visitor {
  void visit(EqualsOp e) {
    assert e.leftExp and e.rightExp
   have the same type
  }
  void visit(PlusOp e) {
    assert e.leftExp and e.rightExp
   are numeric
  }
}

class PrettyPrintVisitor implements
   Visitor {
  void visit(EqualsOp e) {
    print e
  }
  void visit(PlusOp e) {
    print e
  }
}
```

Visitor pattern: example

Objects

```
class VarOp extends Expression {
  void accept(Visitor v) {
    v.visitVar(this);
  }
}

class EqualsOp extends Expression {
  void accept(Visitor v) {
    leftExp.accept(v);
    leftExp.accept(v);
    v.visitEquals(this);
  }
}

class CondOp extends Expression {
  void accept(Visitor v) {
    testExp.accept(v);
    thenExp.accept(v)`
    elseExp.accept(v);
    v.visitCond(this);
  }
}
```

Same behavior

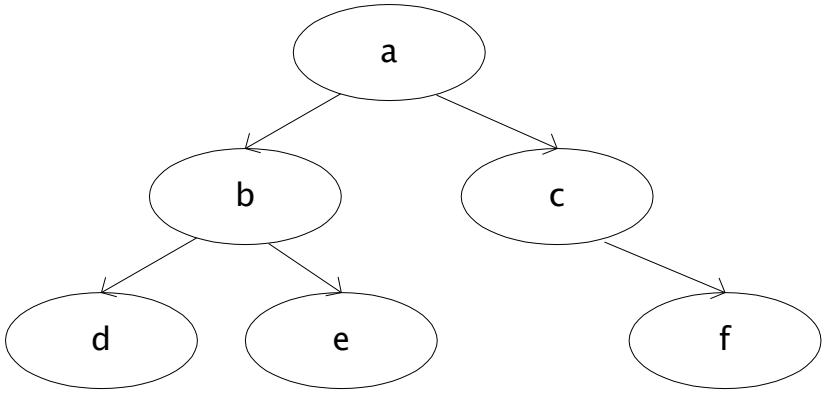
Operations

```
class TypeCheckVisitor implements
   Visitor {
  void visitEquals(EqualsOp e) {
    assert e.leftExp and e.rightExp
   have the same type
  }
  void visitPlus(PlusOp e) {
    assert e.leftExp and e.rightExp
   are numeric
  }
}

class PrettyPrintVisitor implements
   Visitor {
  void visitEquals(EqualsOp e) {
    print e
  }
  void visitPlus(PlusOp e) {
    print e
  }
}
```

Sequence of calls to accept and visit

```
a.accept(v)
   b.accept(v)
      d.accept(v)
         v.visit(d)          d
      e.accept(v)
         v.visit(e)          e
      v.visit(b)             b
   c.accept(v)
      f.accept(v)
         v.visit(f)          f
      v.visit(c)             c
   v.visit(a)                a
```



Sequence of calls to visit = depth-first (children before parents)

How could we make it breadth-first (parents before children)?

Requires a different visitor

Visitors are like iterators

- Each element of the data structure is presented in turn to the **`visit`** method
- Visitors have knowledge of the structure, not just the sequence

Calls to `visit` cannot communicate with one another

1. Use an auxiliary data structure
2. **`visit`** returns a value
3. Move more work into the visitor itself

```
class Node {
  void accept(Visitor v) {
    v.visit(this);
  }
}
class Visitor {
  void visit(Node n) {
    for each child of this node {
      child.accept(v);
     }
    perform work on n
  }
}
```

Information flow is clearer (if visitor depends on children)

Traversal code repeated in all visitors (acceptor is extraneous)