CSE 331
Software Design & Implementation

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Design Patterns, Part 2

(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins, Zach Tatlock)

Announcements

- Course evaluation: https://uw.iasystem.org/survey/179905
- Email cse331-staff (or me directly) if you want to demo on Wed
- Web site has details on final
  - important concepts
  - prior exams
    - 16su will be most informative

Review: Factories

Goal: want more flexible abstractions for what class to instantiate

Factory method

- call a method to create the object
- method can do computation, return subtype, reuse objects

Factory object (also Builder)

- Factory has factory methods for some type(s)
- Builder has methods to describe object and then create it

Prototype

- every object is a factory, can create more objects like itself
- call **`clone`** to get a new object of same subtype as receiver

Dependency Injection

- put choice of subclass in a file to avoid source-code changes when decision changes (meh)

Review: Factory Method

Factory method: call a method to create the object

- can return any subtype or an existing object
- can give it a better name

```
new Matrix(double[] vals) { ... }
new Matrix(double[] vals, int rowSize) { ... }
```

versus `Matrix.fromX`

```
Matrix fromVector(double[] vals)
Matrix fromRowMajorEntries(double[] vals, int rowSize)
Matrix fromColMajorEntries(double[] vals, int colSize)
```

- Has two methods with same signature — impossible w/ constructors
- This approach can be used for *any* Java class.

Review: Builder

Builder: object with methods to describe object and then create it

- fits especially well with immutable classes when clients want to add data one bit at a time

Example: **`StringBuilder`**

```
StringBuilder buf = new StringBuilder();
buf.append("Total distance: ");
buf.append(dist);
buf.append(" meters");
return buf.toString();
```

Example: **`Graph.Builder`**

- `addNode`, `addEdge`, and `createGraph` methods
- (static inner class `Builder` can use **private** constructors)

Sharing

Second weakness of constructors: they always return a *new object*

Singleton: only one object exists at runtime

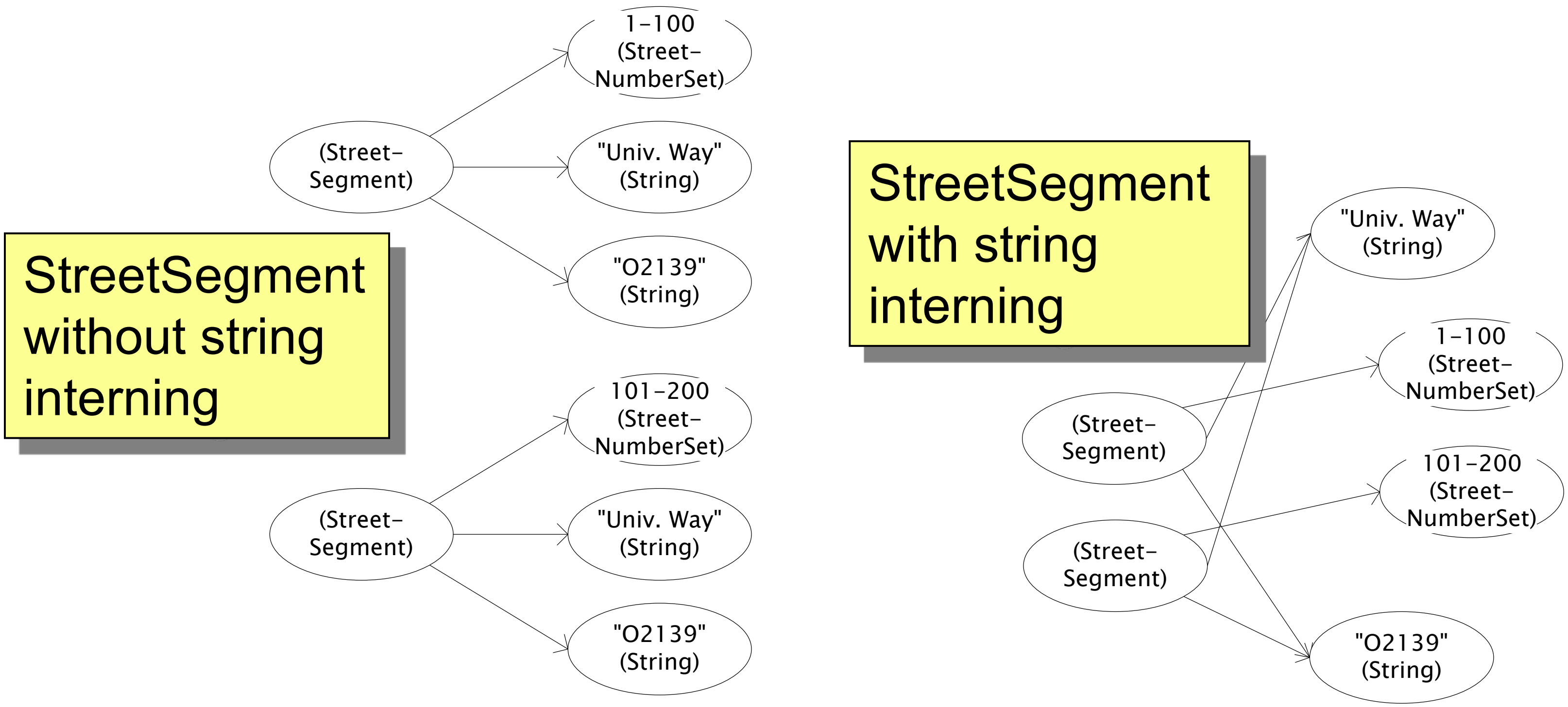
- factory method returns the same object every time
- (we've seen this already)

Interning: only one object with a particular value exists at runtime

- (with a particular *abstract* value)
- factory method can return an existing object (not a new one)
- interning can be used without factory methods
    - see `String.intern`

Interning pattern

Reuse existing objects instead of creating new ones:



Interning mechanism

- Maintain a collection of all objects in use
- If an object already appears, return that instead
  - (be careful in multi-threaded contexts)

```
HashMap<String, String> segNames;
String canonicalName(String n) {
  if (segNames.containsKey(n)) {
    return segNames.get(n);
  } else {
    segNames.put(n, n);
    return n;
  }
}
```

Why not `Set<String>` ?

`Set` supports `contains` but not `get`

- Java builds this in for strings: `String.intern()`

Interning pattern

- Benefits of interning:

  1. May compare with `==` instead of `equals()`
     - eliminates a source of common bugs!!

  2. May save space by creating fewer objects
     - (space is less and less likely to be a problem nowadays)
     - also, interning can actually waste space if objects are not cleaned up when *no longer needed*
       - there are additional techniques to fix that ("weak references")

- Sensible only for immutable objects

`java.lang.Boolean` does not use the Interning pattern

```
public class Boolean {
  private final boolean value;

  // construct a new Boolean value
  public Boolean(boolean value) {
    this.value = value;
  }

  public static Boolean FALSE = new Boolean(false);
  public static Boolean TRUE = new Boolean(true);

  // factory method that uses interning
  public static Boolean valueOf(boolean value) {
    if (value) {
      return TRUE;
    } else {
      return FALSE;
    }
  }
}
```

Recognition of the problem

Javadoc for **`Boolean`** constructor:

Allocates a **`Boolean`** object representing the value argument.

Note: It is rarely appropriate to use this constructor. Unless a new instance is required, the static factory `valueOf(boolean)` is generally a better choice. It is likely to yield significantly better space and time performance.

Josh Bloch (JavaWorld, January 4, 2004):

The **`Boolean`** type should not have had public constructors. There's really no great advantage to allow multiple **`true`**s or multiple **`false`**s, and I've seen programs that produce millions of **`true`**s and millions of **`false`**s, creating needless work for the garbage collector.

So, in the case of immutables, I think factory methods are great.

GoF patterns: three categories

Creational Patterns are about the object-creation process

Factory Method, Abstract Factory, Singleton, Builder, Prototype, …

Structural Patterns are about how objects/classes can be combined

Adapter, Bridge, Composite, Decorator, Façade, Proxy, …

Behavioral Patterns are about communication among objects

Command, Interpreter, Iterator, Mediator, Observer, State, Strategy, Chain of Responsibility, Visitor, Template Method, …

Green = ones we've seen already

Structural patterns: Wrappers

Wrappers are a thin veneer over an encapsulated class

- modify the interface
- extend behavior
- restrict access

The encapsulated class does most of the work

Pattern	Functionality	Interface
Adapter	same	different
Decorator	different	same
Proxy	same	same

Some wrappers have qualities of more than one of adapter, decorator, and proxy

Adapter

Real life example: adapter to go from US to UK power plugs

- both do the same thing
- but they have slightly interface expectations

Change an interface without changing functionality

- rename a method
- convert units
- implement a method in terms of another

Example: angles passed in radians vs. degrees

Example: use “old” method names for legacy code

Adapter example: rectangles

Our code is using this **`Rectangle`** interface:

```
interface Rectangle {
  // grow or shrink this by the given factor
  void scale(float factor);
  // move to the left or right
  void translate(float x, float y);
}
```

But we want to use a library that has this class:

```
class JRectangle {
  void scaleWidth(float factor) { ... }
  void scaleHeight(float factor) { ... }
  void shift(float x, float y) { ... }
}
```

Adapter example: rectangles

Create an adapter that delegates to `Rectangle`:

```
class RectangleAdapter implements Rectangle {
  JRectangle rect;
  RectangleAdapter(JRectangle rect) {
    this.rect = rect;
  }
  void scale(float factor) {
    rect.scaleWidth(factor);
    rect.scaleHeight(factor);
  }

  void translate(float x, float y) {
    rect.shift(x, y);
  }
  ...
}
```

Adapters

- This sort of thing happens **a lot**
  – unless two libraries were designed to work together, they probably won't fit together without an adapter

- The example code uses **delegation**:
  – special case of composition where the outer object just forwards calls on to one other object

- Adapters can also **remove** methods

- Adapters can also be written by subclassing
  – but then all the usual warnings about subclassing apply ***if*** you override any methods of the superclass
  – your subclass could easily break when superclass changes

Decorator

- Add functionality without breaking the interface:
    1. Add to existing methods to do something extra
        - satisfying a stronger specification
    2. Provide extra methods

- Subclasses are often decorators
    - but not always: Java subtypes are not always true subtypes

Decorator example: Bordered windows

```
interface Window {
  // rectangle bounding the window
  Rectangle bounds();
  // draw this on the specified screen
  void draw(Screen s);
  ...
}

class WindowImpl implements Window {
  ...
}
```

Bordered window implementations

Via subclasssing:

```
class BorderedWindow1 extends WindowImpl {
  void draw(Screen s) {
    super.draw(s);
    bounds().draw(s);
  }
}
```

Delegation permits multiple borders on a window, or a window that is both bordered and shaded

Via delegation:

```
class BorderedWindow2 implements Window {
  Window innerWindow;
  BorderedWindow2(Window innerWindow) {
    this.innerWindow = innerWindow;
  }
  void draw(Screen s) {
    innerWindow.draw(s);
    innerWindow.bounds().draw(s);
  }
}
```

A decorator can remove functionality

Remove functionality without changing the Java interface

- no longer a true subtype, but *sometimes* that is necessary

Example: **`UnmodifiableList`**

- What does it do about methods like **`add`** and **`put`**?
  - throws an exception
  - moves error checking from the compiler to runtime
    - like Java array subtypes are another example of this

Problem: **`UnmodifiableList`** is not a true subtype of **`List`**

Decoration via delegation can create a class with no Java subtyping relationship, which is often desirable

- Java subtypes that are not true subtypes are **confusing**
- maybe necessary for **`UnmodifiableList`** though

Proxy

- Same interface *and* functionality as the wrapped class
  - so... uh... wait, what?

- Control access to other objects
  - communication: manage network details when using a remote object
  - locking: serialize access by multiple clients
  - security: permit access only if proper credentials
  - creation: object might not yet exist (creation is expensive)
    - hide latency when creating object
    - avoid work if object is never used

Composite pattern

- Composite permits a client to manipulate either an *atomic* unit or a *collection* of units in the same way
  - no need to "always know" if an object is a collection of smaller objects or not
- Good for dealing with "part-whole" relationships
- Used by jQuery in JavaScript
- An extended example…

Composite example: Bicycle

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

Methods on components

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

Composite example: Libraries

Library
- Section (for a given genre)
  - Shelf
    - Volume
      - Page
        - Column
          - Word
            - Letter

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

Composite example: jQuery

- jQuery provides a function **`$`** that returns one or many objects
  - **`$("#foo")`** would return the object with ID "foo"
    - (or returns an empty collection if none exists)
  - **`$("p")`** wound return a collection of all P nodes

- Calling a method on a jQuery object calls that method on all objects in the collection:
  - if **`foo`** is a node with id "foo", then **`foo.hide()`** has the same effect as **`$("foo").hide()`**
  - **`$("p").hide()`** would hide *all* the P nodes

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Traversing composites

- Goal: perform operations on all parts of a composite

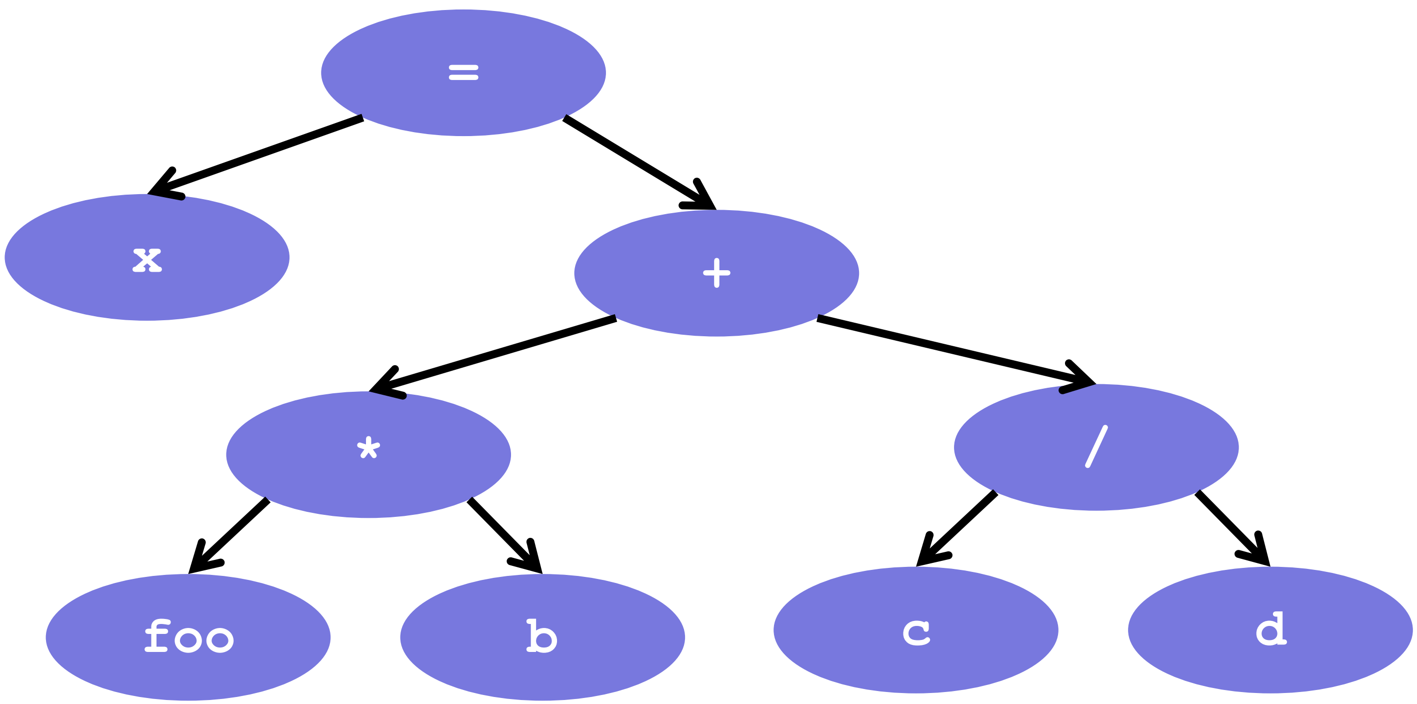
- Idea is to generalize the notion of an iterator: process the components in an order appropriate for the application

- This is really important when writing a compilers
  - (doesn't come up nearly as much elsewhere though)

- Example: arithmetic expressions in Java
  - how do we represent, say, `x = foo*b + c/d;`
  - how do we traverse/process these expressions?

Representing Java code

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

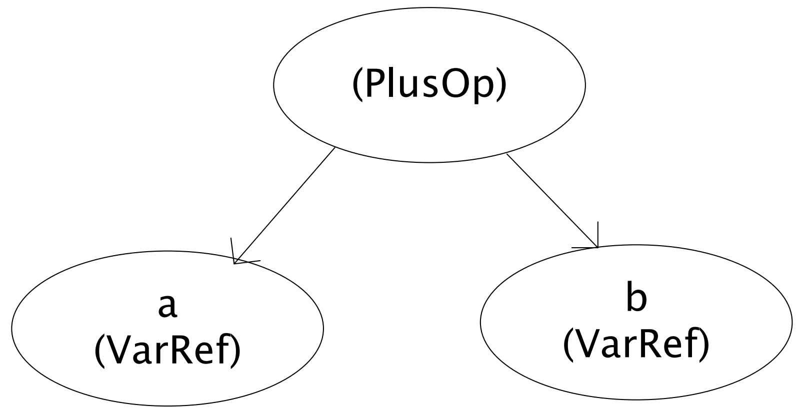


Abstract syntax tree (AST) for Java code

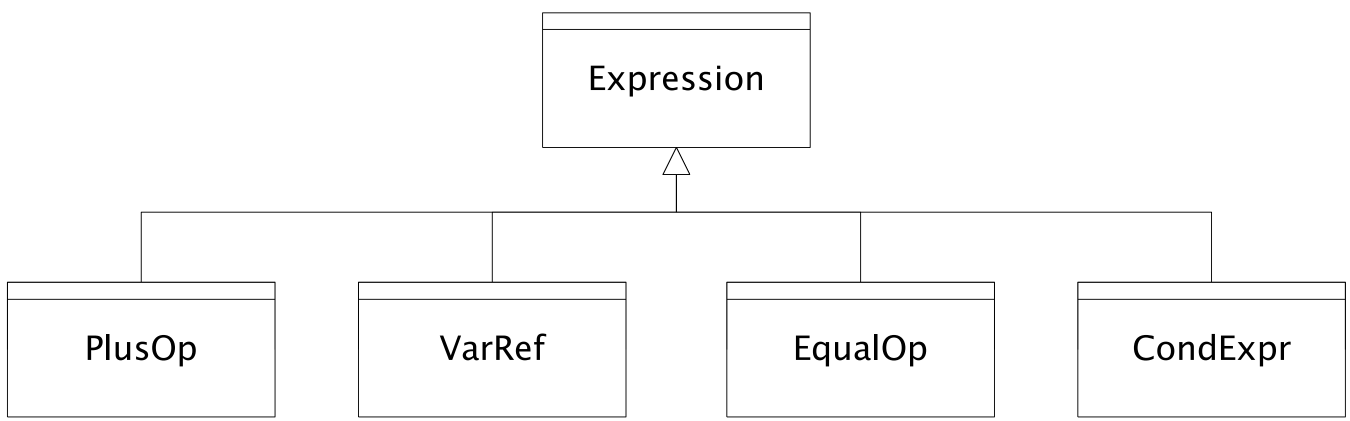
```
class PlusOp extends Expression { // + operation
  Expression leftExp;
  Expression rightExp;
}
class VarRef extends Expression { // variable use
  String varname;
}
class EqualOp extends Expression {  // test a==b;
  Expression leftExp; // left-hand side: a in a==b
  Expression rightExp; // right-hand side: b in a==b
}
class CondExpr extends Expression {  // a?b:c
  Expression testExp;
  Expression thenExp;
  Expression elseExp;
}
```

Object model vs. type hierarchy

- AST for **`a + b`**:



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



Operations on abstract syntax trees

Need to write code for each entry in this table

Types of Objects

		CondExpr	EqualOp
Operations	typecheck		
	print		

- Question: Should we group together the code for a particular operation or the code for a particular expression?
  - That is, do we group the code into rows or columns?
- Given an operation and an expression, how do we "find" the proper piece of code?

Interpreter and procedural patterns

Interpreter: collects code for similar objects, spreads apart code for similar operations
- easy to add new types
- hard to add operations
- Composite pattern

Procedural: collects code for similar operations, spreads apart code for similar objects
- easy to add operations
- hard to add new types
- Visitor pattern

(See CSE341 for an extended take on this question:
- statically typed functional languages help with procedural whereas statically typed OO languages help with interpreter)

Interpreter pattern

	Objects	
	CondExpr	EqualOp
typecheck		
print		

Add a method to each class for each supported operation

```
abstract class Expression {
  ...
  Type typecheck();
  String print();
}
class EqualOp extends Expression {
  ...
  Type typecheck() { ... }
  String print() { ... }
}
class CondExpr extends Expression {
  ...
  Type typecheck() { ... }
  String print() { ... }
}
```

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

Overall type-checker spread across classes

Procedural pattern

		Objects
	CondExpr	EqualOp
typecheck		
print		

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

```
class Typecheck {
  Type typeCheckCondExpr(CondExpr e) {
    Type condType = typeCheckExpr(e.condition);
    Type thenType = typeCheckExpr(e.thenExpr);
    Type elseType = typeCheckExpr(e.elseExpr);
    if (condType.equals(BoolType) &&
            thenType.equals(elseType))
      return thenType;
    else
      return ErrorType;
  }
  Type typeCheckEqualOp(EqualOp e) {
    ...
  }
}
```

How to invoke the right method for an expression **e**?

Definition of `typeCheckExpr` (using procedural pattern)

```
class Typecheck {
  ...
  Type typeCheckExpr(Expression e) {
    if (e instanceof PlusOp) {
      return typeCheckPlusOp((PlusOp)e);
    } else if (e instanceof VarRef) {
      return typeCheckVarRef((VarRef)e);
    } else if (e instanceof EqualOp) {
      return typeCheckEqualOp((EqualOp)e);
    } els
      ret
    } els
    ...
  }
}
```

Maintaining this code is tedious and error-prone

- No help from type-checker to get all the cases (unlike in functional languages)

Cascaded if tests are likely to run slowly (in Java)

Need similar code for each operation

Visitor pattern: A variant of the procedural pattern

- Nodes (objects in the hierarchy) accept visitors for traversal
- 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 extends Visitor {
  void visit(SomeExpression n) {
    perform work on n
  }
}
```

n.accept(v) traverses the structure rooted at **n**, performing **v**'s operation on each element of the structure

Example: accepting visitors

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

First visit all children

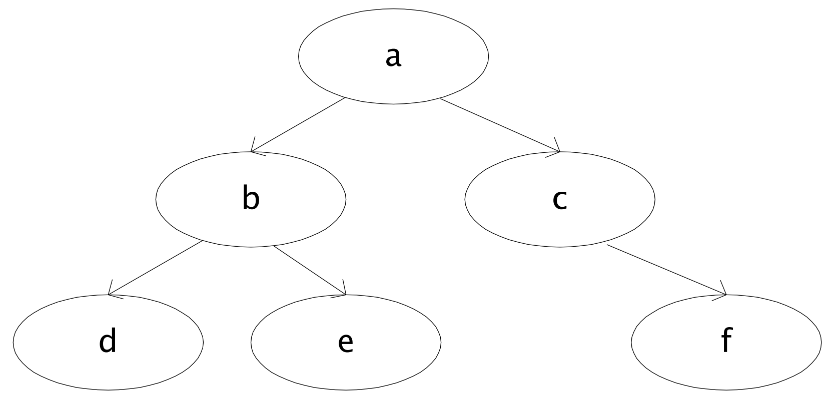
Then pass “self” back to visitor

The visitor has a **`visit`** method for each kind of expression, thus picking the right code for this kind of expression

- Overloading makes this look more magical than it is…

Lets clients provide unexpected visitors

Sequence of calls to accept and visit



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

Sequence of calls to visit: d, e, b, f, c, a

Example: Implementing visitors

```
class TypeCheckVisitor
   implements Visitor {
  void visit(VarOp e) { … }
  void visit(EqualsOp e) { …
  void visit(CondOp e) { … }
}

class PrintVisitor implement
   Visitor {
  void visit(VarOp e) { … }
  void visit(EqualsOp e) { …
  void visit(CondOp e) { … }
}
```

Now each operation has its cases back together

And type-checker should tell us if we fail to implement an abstract method in Visitor

Again: overloading just a nicety

Again: An OOP workaround for procedural pattern

- Because language/type-checker is not instance-of-test friendly