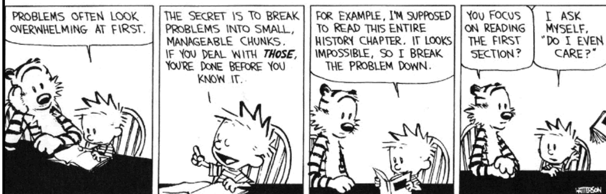
Aspect-Oriented Programming



One-Slide Summary

- Aspect-oriented programming (AOP) is a different way to think about programming. It acknowledges that crosscutting concerns come up in practice.
- AOP provides a way to maintain concerns separately and specify integration rules to weave them together.
- AOP is somewhat similar to event handling, where the "events" are defined outside the code itself.
- AspectJ, a popular AOP system, is not itself a complete programming language, but an adjunct to Java.

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Programming paradigms

- Procedural (or imperative) programming
  - Executing a set of commands in a given sequence
  - `Fortran, C, Cobol`
- Functional programming
  - Evaluating a function defined in terms of other functions
  - `Scheme, Lisp, ML, OCaml`
- Logic programming
  - Proving a theorem by finding values for the free variables
  - `Prolog`
- Object-oriented programming (OOP)
  - Organizing a set of objects, each with its own set of responsibilities
  - `Smalltalk, Java, Ruby, C++`
- Aspect-oriented programming (AOP) =
  - aka Aspect-Oriented Software Design (AOSD)
  - Executing code whenever a program shows certain behaviors
  - `AspectJ` (a Java extension), `Aspect#`, `AspectC++`, …
  - Does not *replace* O-O programming, but rather *complements* it

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Why Learn Aspect-Oriented Design?

- Pragmatics – Google stats 2006 → 2007
  - "object-oriented" 24.0 → 54.6 million
  - functional programming n/a → 30.9 million
  - "aspect-oriented" *OR* "AOP" n/a → 30.4 million
  - extreme programming n/a → 21.2 million
  - "design patterns" 05.0 → 07.7 million
  - "unreal tournament" 04.0 → 02.3 million
  - "COBOL" 01.6 → 09.7 million
- It's growing
  - Just like OOP was years ago
  - Especially in the Java / Eclipse / JBoss world

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Motivation By Allegory

- Imagine that you're the ruler of a fantasy monarchy

Motivation By Allegory (2)

- You announce Wedding 1.0, but must increase security

Motivation By Allegory (3)

- You must make changes everywhere: close the secret door

Motivation By Allegory (4)

- … form a brute squad …

Motivation By Allegory (5)

- … clear the Thieves' Forest …

Motivation By Allegory (6)

- … reduce the number of gate keys to 1 …

Motivation By Allegory (7)

- … kill your rival …

Motivation By Allegory (8)

- … double the guards at the gate …

Motivation By Allegory (9)

- … secure the castle hallways …

Motivation By Allegory (10)

- … even reduce the length of the Wedding itself …

Motivation By Allegory (11)

- … you're swamped – you're not happy!

Motivation By Allegory (12)

- It'd be nice to separately advise: "Increase Security"

Motivation By Allegory (13)

- Then you'd be a happy monarch!

The problem

- Some programming tasks cannot be neatly encapsulated in objects, but must be scattered throughout the code
- Examples:
  - Logging (tracking program behavior to a file)
  - Profiling (determining where a program spends its time)
  - Tracing (determining what methods are called when)
  - Session tracking, session expiration
  - Special security management
  - Error-checking or -handling
- The result is **crosscutting** code -- the necessary code "cuts across" many different classes and methods

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High-Level AOP Goals

- You want to maintain different concerns separately
  - Business logic here
  - Tracing there
  - Security somewhere else
- And yet somehow weave them together to form one unified program that you can run
- Specify rules for integrating them together

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Lecture Goals

- What Is Aspect-Oriented Programming
- When Should You Use It
- What Are Join Points
- What Are Pointcuts
- Where Can You Get More Information

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Example – Adding Tracing

```
class Fraction {
    int numerator;
    int denominator;
    ...
    public Fraction multiply(Fraction that) {
        traceEnter("multiply", new Object[] {that});
        Fraction result = new Fraction(
            this.numerator * that.numerator,
            this.denominator * that.denominator);
        result = result.reduceToLowestTerms();
        traceExit("multiply", result);
        return result;
    }
    ...
}
```

- Now imagine similar code in *every method* you might want to trace

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Consequences of Crosscutting code

- Redundant code
  - Same fragment of code in many places
- Difficult to reason about
  - Non-explicit structure
  - The big picture of the tangling isn't clear
- Difficult to change
  - Have to find all the code involved...
  - ...and be sure to change it consistently
  - ...and be sure not to break it by accident
- Inefficient when crosscutting code is not needed

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Popular AOP System: AspectJ™

- AspectJ is a small, well-integrated extension to Java
  - Based on the 1997 PhD thesis by Christina Lopes, *D: A Language Framework for Distributed Programming*
  - Widely championed by Gregor Kiczales et al.
- AspectJ "modularizes crosscutting concerns"
  - That is, code for one *aspect* of the program (such as tracing) is collected together in one place
- The AspectJ compiler is free and open source
- AspectJ works with JBuilder, Forté, Eclipse, JBoss, probably others
- Good online writeup:
  http://www.eclipse.org/aspectj/

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Terminology

- A join point is a well-defined point in the program flow
  - e.g., "when something calls foo()"
- A pointcut is a group of join points
  - e.g., "every call to foo() in Bar.java"
- Advice is code that is executed at a pointcut
  - e.g., "add in this Tracing code"
- Introduction modifies the members of a class and the relationships between classes
- An aspect is a module for handling crosscutting concerns
  - Aspects are defined in terms of pointcuts, advice, and introduction
  - Aspects are reusable and inheritable
- We'll cover each of these terms in greater detail

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Join points

- A join point is a well-defined point in the program flow
  - Used to specify how to integrate aspects of your program
  - We want to execute some code (“advice”) each time a join point is reached
  - We do *not* want to clutter up the code with explicit indicators saying *“This is a join point”*
  - AspectJ provides a syntax for indicating these join points “from outside” the actual code (but this is somewhat illusory)
- A join point is a point in the program flow “where something happens”
  - When a method is called
  - When an exception is thrown
  - When a variable is accessed (and more)

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Example Join Point Designators

- When a particular method body executes:
  - **execution(void Point.setX(int))**
- When a method is called:
  - **call(void Point.setX(int))**
- When an exception handler executes:
  - **handler(ArrayOutOfBoundsException)**
- When the object currently executing (i.e. this) is of type SomeType:
  - **this(SomeType)**
- When the target object is of type SomeType
  - **target(SomeType)**
- When the executing code belongs to class MyClass
  - **within(MyClass)**

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Example 1: Let’s Add Tracing

- A pointcut named move that chooses various method calls:

```
pointcut move():
    call(void FigureElement.setXY(int,int))    ||
    call(void Point.setX(int))                 ||
    call(void Point.setY(int))                 ||
    call(void Line.setP1(Point))               ||
    call(void Line.setP2(Point));
```

- Advice (code) that runs before (or after) the move pointcut:

```
before(): move() {
    System.out.println("About to move");
}
```

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Pointcut designator wildcards

- It is possible to use wildcards to declare pointcuts:
  - execution(* *(..))
    - Chooses the execution of any method regardless of return or parameter types
  - call(* set(..))
    - Chooses the call to any method named set regardless of return or parameter type
    - In case of overloading there may be more than one such set method; this pointcut picks out calls to all of them

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Pointcut Designators Based on types

- You can select elements based on types. For example,
  - execution(int *())
    - Chooses the execution of any method with no parameters that returns an int
  - call(* setY(long))
    - Chooses the call to any setY method that takes a long as an argument, regardless of return type or declaring type
  - call(* Point.setY(int))
    - Chooses the call to any of Point's setY methods that take an int as an argument, regardless of return type
  - call(*.new(int, int))
    - Chooses the call to any classes' constructor, so long as it takes exactly two ints as arguments

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Pointcut Designator Composition

- Pointcuts compose through the operations **or** ("||"), **and** ("&&") and **not** ("!")
- Examples:
  - target(Point) && call(int *())
    - Chooses any call to an int method with no arguments on an instance of Point, regardless of its name
  - call(* *(..)) && (within(Line) || within(Point))
    - Chooses any call to any method where the call is made from the code in Point's or Line's type declaration
  - within(Line) && execution(*.new(int))
    - Chooses the execution of any constructor taking exactly one int argument, so long as it is inside Line
  - !this(Point) && call(int *(..))
    - Chooses any method call to an int method when the executing object is any type except Point

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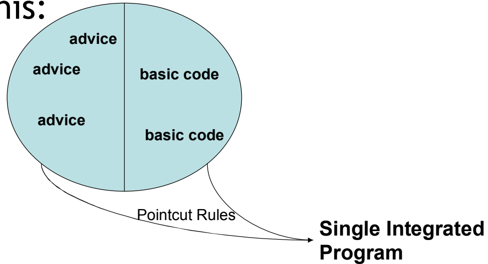
A Faulty Mental Model

- Many imagine that AOP works like this:



Single Integrated Program

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A Problem

- Consider this Logger:

```
aspect Logger {
   before(): call (* *.*(..)) {
        System.out.println("call to " + thisJoinPoint);
   }
}
```

- What might go wrong?

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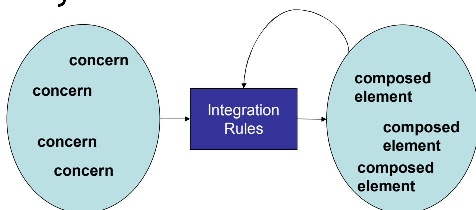
A Better Mental Model

- This idea won't lead you as far astray:



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Kinds of advice

- AspectJ has several kinds of advice; here are some of them:
  - Advice is just like your normal code
    - (cf. AspectWerkz, AspectJ 5)
  - Before advice runs as a join point is reached, before the join point executes
  - After advice on a join point runs after that join point executes:
    - after returning advice is executed after a method returns normally
    - after throwing advice is executed after a method returns by throwing an exception
    - after advice is executed after a method returns, regardless of whether it returns normally or by throwing an exception
  - Around advice on a join point runs as the join point is reached, and has explicit control over whether the program proceeds with the join point

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Example 2: With Parameters

- You can access the context of the join point:
- ```
  pointcut setXY(FigureElement fe, int x, int y):
      call(void FigureElement.setXY(int, int))
      && target(fe)
      && args(x, y);
  ```
- ```
  after(FigureElt fe, int x, int y)
  returning: setXY(fe, x, y) {
      println(fe + " moved to (" + x + ", " + y + ").");
  }
  ```

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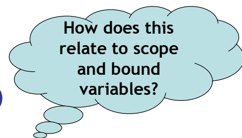
  ```



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Introductions

- An **introduction** is a member of an aspect, but it defines or modifies a member of another type (class). With introduction we can
  - add methods to an existing class
  - add fields to an existing class
  - extend an existing class with another
  - implement an interface in an existing class
  - convert checked exceptions into unchecked exceptions

Why would we want to?

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Example introduction

```
aspect CloneablePoint {

  declare parents:
   Point implements Cloneable;

  declare soft:
   CloneNotSupportedException:
     execution(Object clone());

  Object Point.clone()
   { return super.clone(); }
}
```

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AOP Challenges

- It’s not all wine and roses
- Debugging is a problem
  - You debug the integrated (“weaved”) program - but that doesn’t correspond to any particular piece of source
  - Like debugging C++ with macros and templates
- Aspects may depend on each other or themselves
  - This is difficult to reason about
  - What integrated code is really being produced?

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Concluding remarks

- Aspect-oriented programming (AOP) is a new paradigm -- a new way to think about programming
- It acknowledges that crosscutting concerns come up in practice
- It provides a way to maintain concerns separately and specify integration rules to weave them together
- AOP is somewhat similar to event handling, where the "events" are defined outside the code itself
- AspectJ is not itself a complete programming language, but an adjunct to Java
- AspectJ does not add new capabilities to what Java can do, but adds new ways of modularizing the code
- Like all new technologies, AOP may--or may not--catch on in a big way

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And They Lived Happily Ever After

- You may be skeptical. Any questions?

Homework

- WA5 due this Thursday at 1pm
- PA4 due Friday March 30th (10 days)
- For Thursday:
  - Read CRM Opsem
  - Read Grant & Smith 2 - 2.2.2
  - Optional Grant & Smith 2.3 - 2.4.4

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