Aspect Oriented Programming with AspectJ

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Original AspectJ slides by Gregor Kiczales (UBC) and others

UCSD

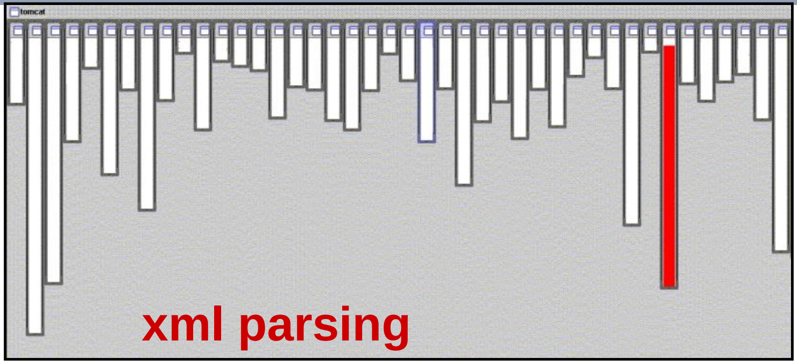
“modularity”

code from org.apache.tomcat

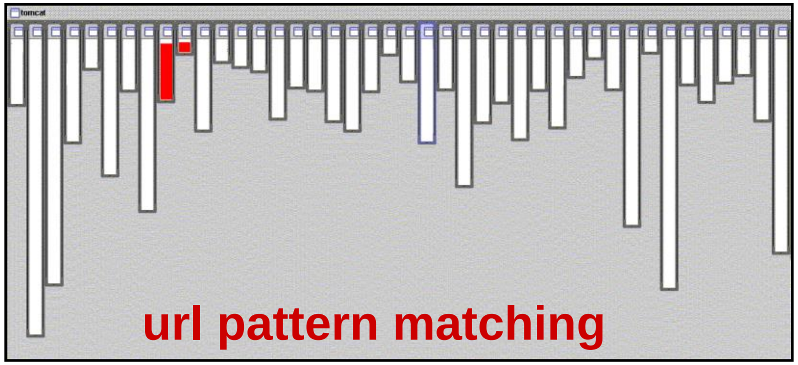
intuitive definition:

a concern is implemented[1] in a modular way if the code for the concern is:

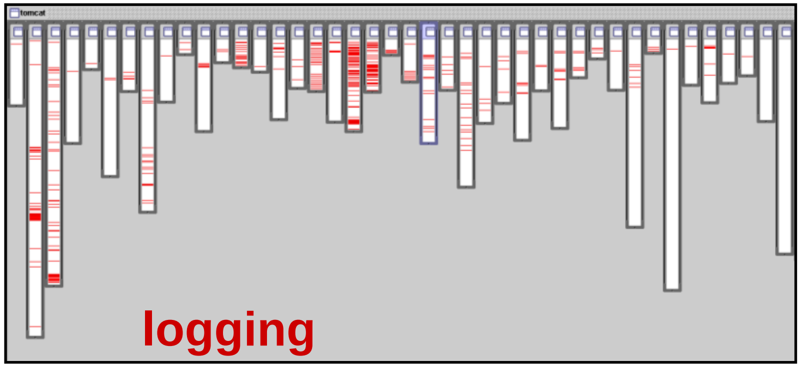
- localized and
- has a clear interface with the rest of the system



xml parsing



url pattern matching



logging

[1] coded, designed, modeled …

Traditional Metrics of PL/Programming

- **Expressiveness**
  - *The conciseness with which a computation can be expressed*
  - Related concepts like *high-level*, *domain-specific*
  - A property of the PL, not the human-PL relationship
- **Understandability**
  - *The relative ease of making sense of a program*
  - Includes human-PL relationship
  - Tends to focus on "quality" of written code, e.g., can be compromised by frequent changes or careless implementation

sources: https://en.wikipedia.org/wiki/The_Design_of_Everyday_Things, https://www.interaction-design.org/literature/book/the-glossary-of-human-computer-interaction/gulf-of-evaluation-and-gulf-of-execution, https://web.media.mit.edu/~lieber/Lieberary/ZStep/Bridging/Bridging.html

HCI of Programming: “Gulfs”

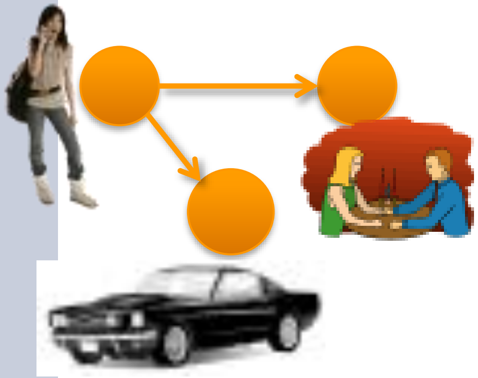
More than “Expressiveness”

- **Gulf of Execution**
  - *The difference between the intentions of the user and what the system allows them to do or how well the system supports those actions*
  - For Programming, e.g.,
    - How difficult is it to introduce this new feature into the program (in a modular way, i.e., so that future changes to it will be easy)?
- **Gulf of Evaluation**
  - *The difficulty of assessing the state of the system and how well the artifact supports the discovery and interpretation of that state*
  - For Programming, e.g.,
    - How hard is it to determine that this new feature code does what I intended?

Due to Don Norman

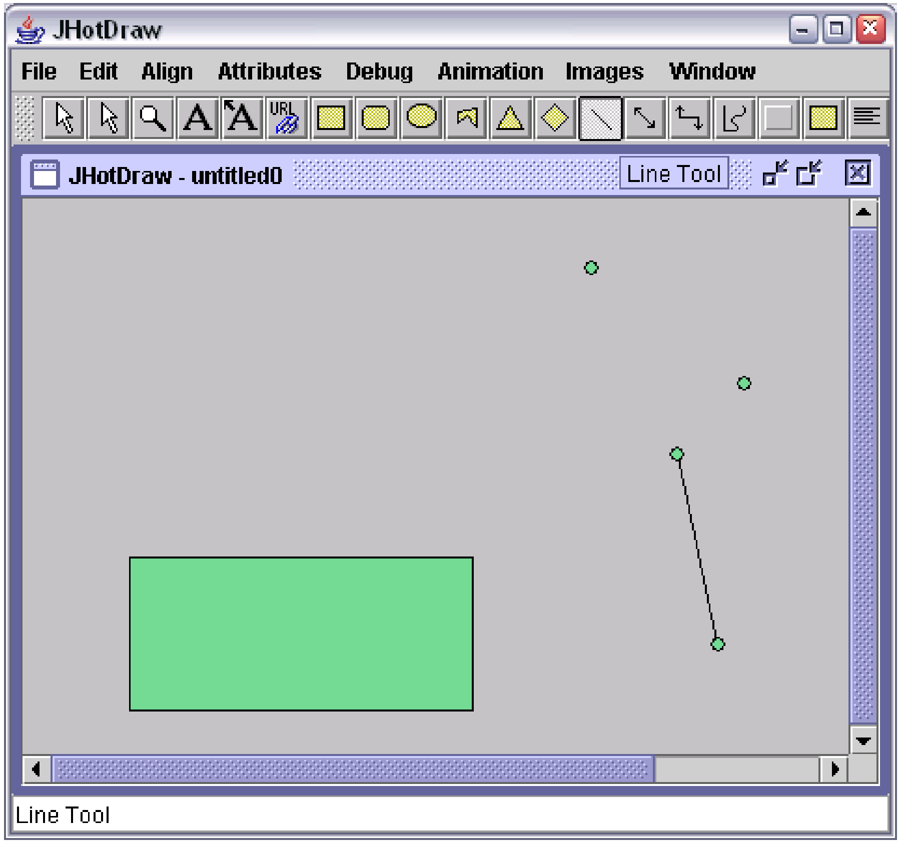
sources: https://www.interaction-design.org/literature/book/the-glossary-of-human-computer-interaction/gulf-of-evaluation-and-gulf-of-execution, https://en.wikipedia.org/wiki/The_Design_of_Everyday_Things, https://web.media.mit.edu/~lieber/Lieberary/ZStep/Bridging/Bridging.html

A Concise Theory of Object-Oriented



- **Object represents a “thing”**
  - *person, car, date*, …
  - (not two things, not ½ thing)
  - Has single purpose of realizing itself
- **Object responds to messages**
  - (method calls)
  - ***Things it does to itself (SRP)***
  - Other objects ask an object to do something to itself via messages
- **Objects are “opaque”**
  - Can’t see each others’ data/vars
  - **Messages (calls) are only way to get things done**

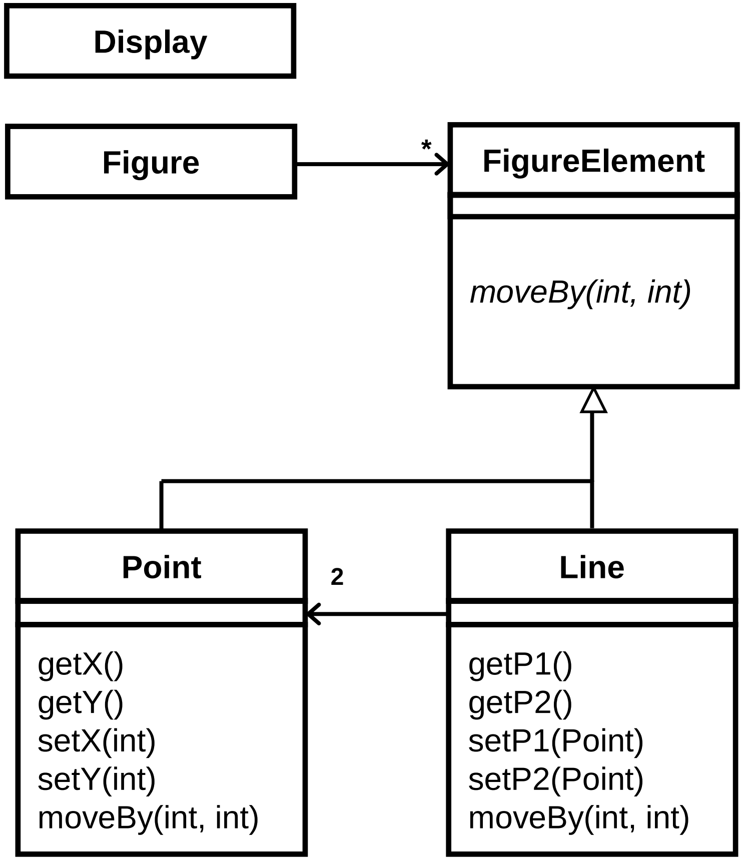
Consider developing…



a simple drawing application (JHotDraw)

Intuitively thinking of objects?

- Points, Lines…
- Drawing surfaces
- GUI Widgets
- …



What is OOP?

- **a learned *intuitive way of thinking***
- **design concepts**
  - objects, classification hierarchies
- **supporting language mechanisms**
  - classes, encapsulation, polymorphism…
- **allows us to**
  - make code look like the design
  - improves design and code modularity

many other benefits build on these

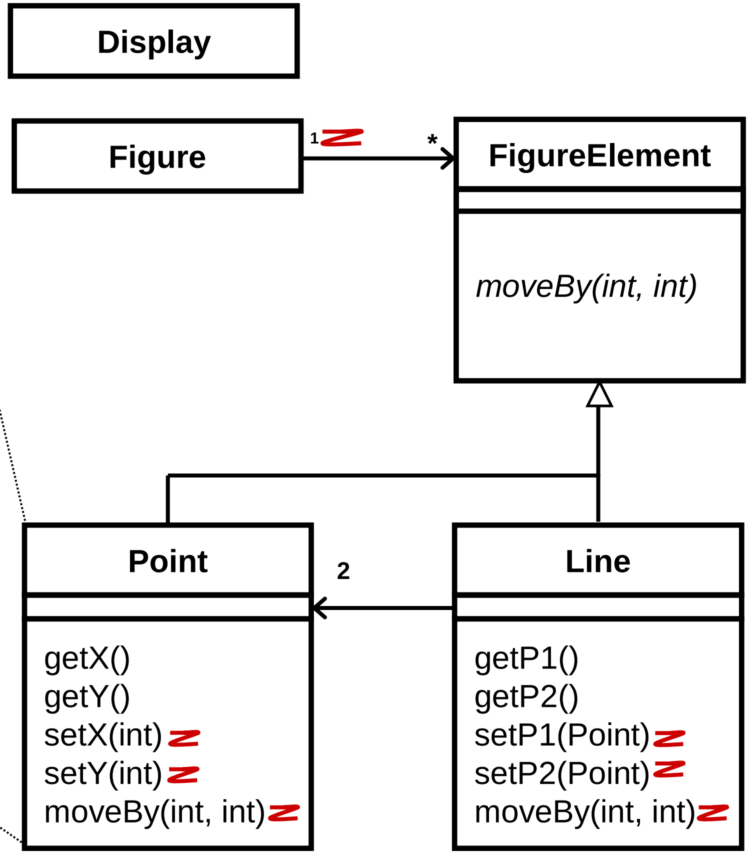
- **captures concerns a *function* can't hold**
  - concern = design decision

But some concerns “don’t fit”

i.e., a simple Observer pattern

```
class Point extends … {
  private int x = 0, y = 0;

  int getX() { return x; }
  int getY() { return y; }

  void setX(int x) {
    this.x = x;
    display.update(this);
  }
  void setY(int y) {
    this.y = y;
    display.update(this);
  }
}
```

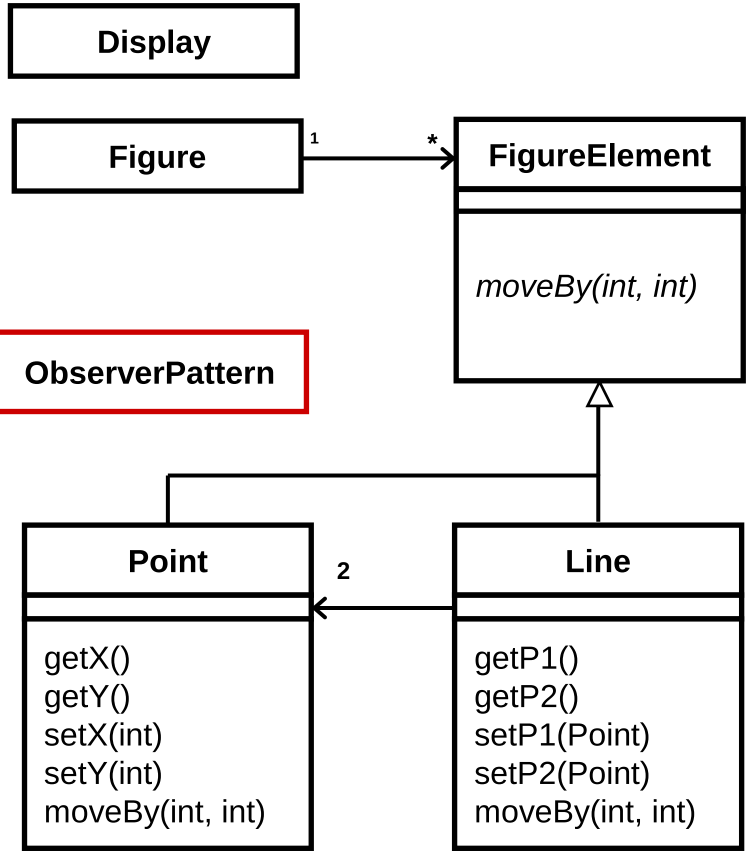
fair design modularity
but poor code modularity



With AOP they do fit

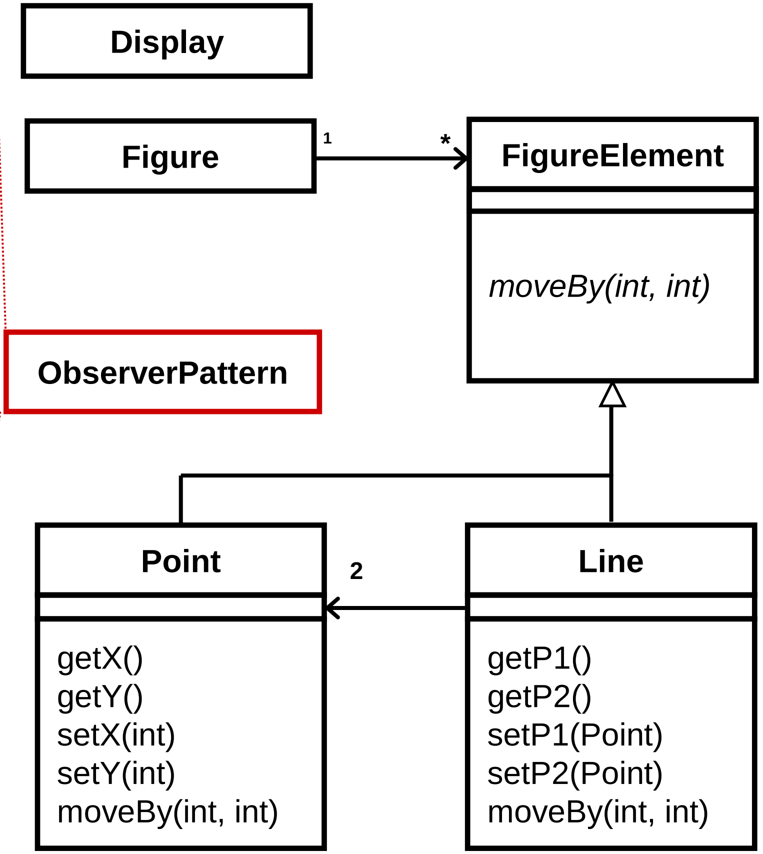
good design modularity
good code modularity

```
aspect ObserverPattern {

  private Display FigureElement.display;

  pointcut change():
    call(void figures.Point.setX(int))
     || call(void Point.setY(int))
     || call(void Line.setP1(Point))
     || call(void Line.setP2(Point))
     || call(void Shape.moveBy(int, int));

 after(FigureElement s) returning:
                 change() && target(s) {
   s.display.update();
  }
}
```



Code looks like the design

```
aspect ObserverPattern {

  private Display FigureElement.display;

  pointcut change():
    call(void FigureElement.moveBy(int,int))
    || call(void FigureElement+.set*(..));

  after(FigureElement s) returning:
                  change() && target(s) {
   s.display.update();
  }
}
```



Display

Figure

1

*

FigureElement

moveBy(int, int)

ObserverPattern

Point

getX()
getY()
setX(int)
setY(int)
moveBy(int, int)

2

Line

getP1()
getP2()
setP1(Point)
setP2(Point)
moveBy(int, int)

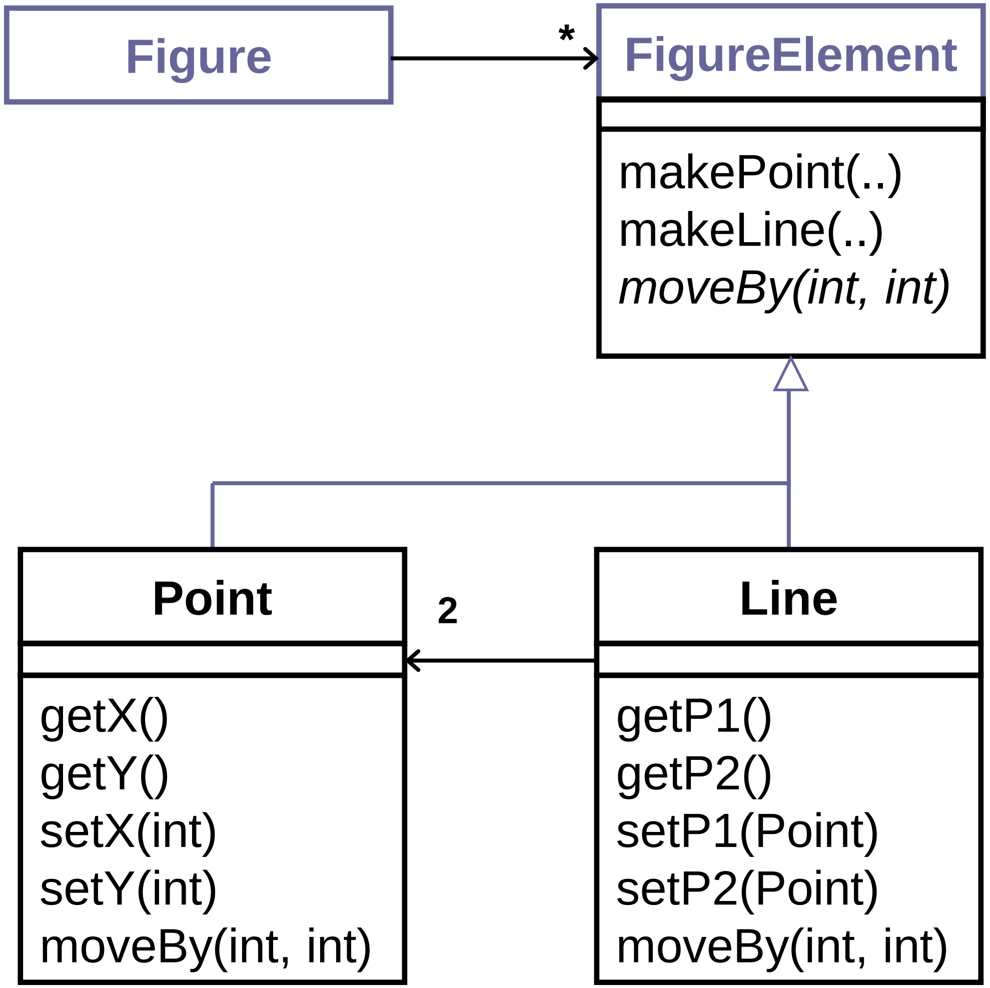
Ask yourself: could you name a <u>single</u> class “ObserverPattern” in Java?

What is AOP?

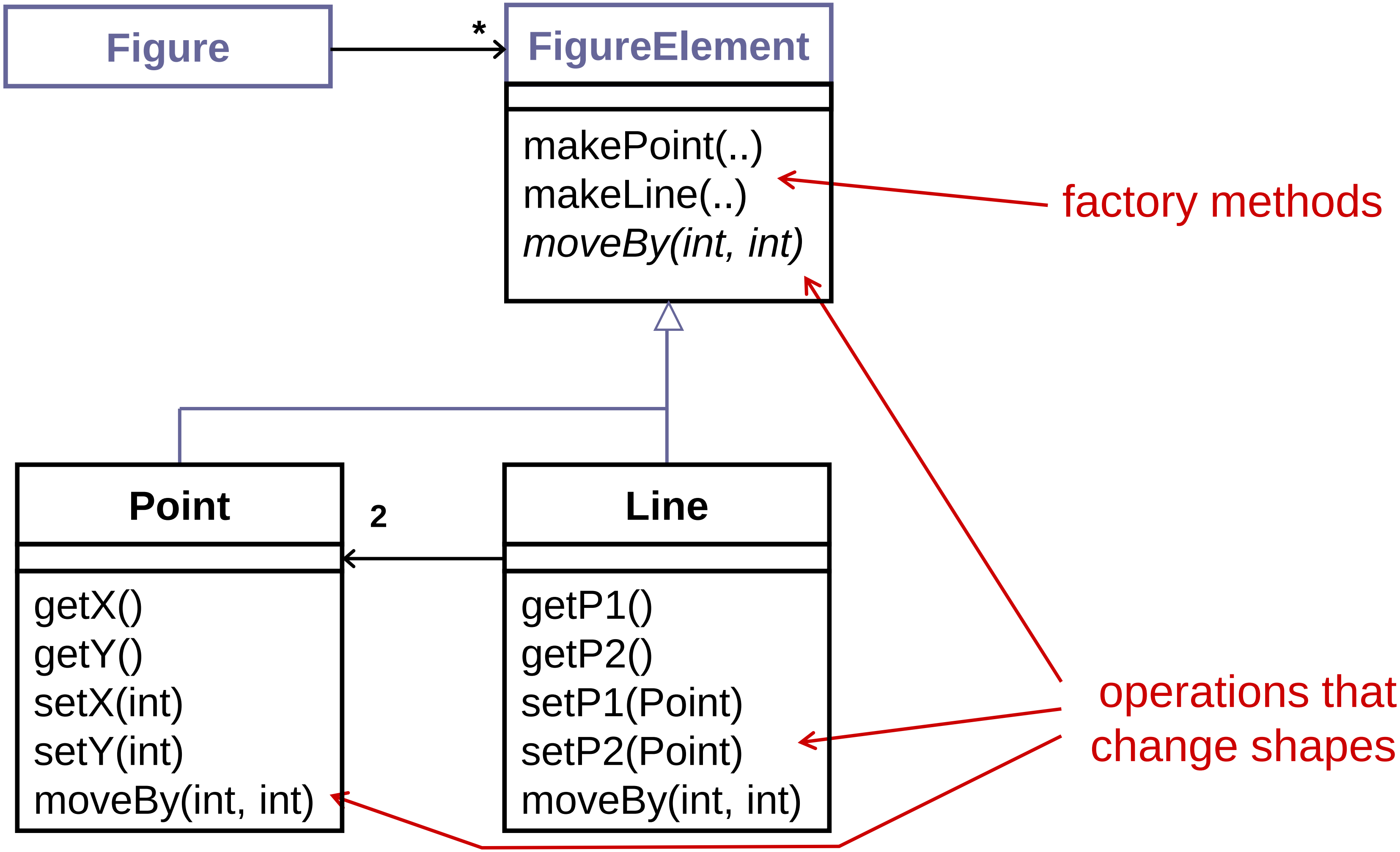
- **a learned *intuitive way of thinking***
- **design concepts**
  - aspects, crosscutting structure
- **supporting language mechanisms**
  - join points, pointcuts, advice…
- **allows us to**
  - make code look like the design
  - improve design and code modularity

- **captures concerns a *class* can’t hold**

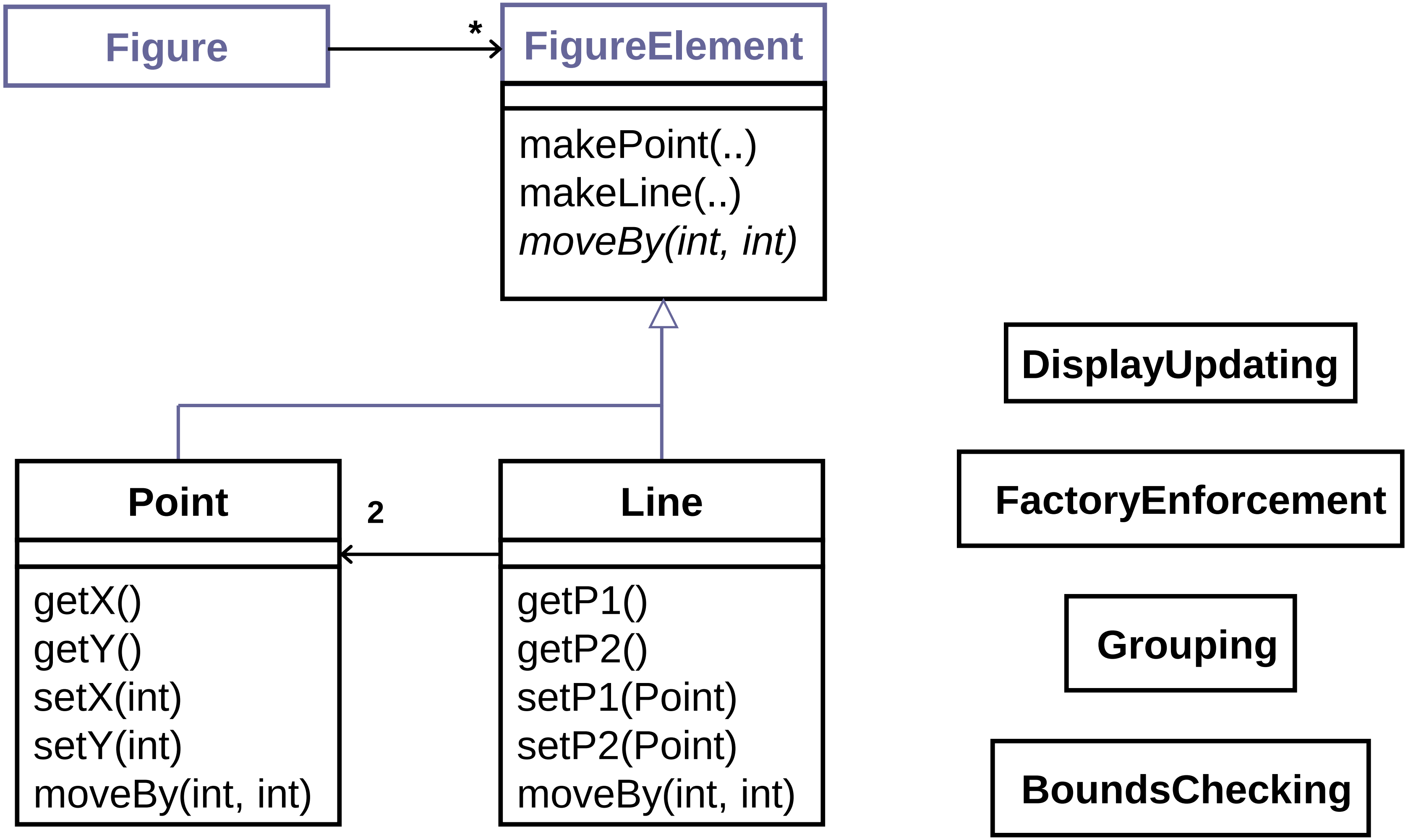
Thinking OO, We *Intuitively* See



Thinking OO, We *Intuitively* See



AOP Developers Intuitively See…



The AspectJ AOP Model

Dynamic (*runtime* crosscutting)

“join points” – natural events in an OO execution

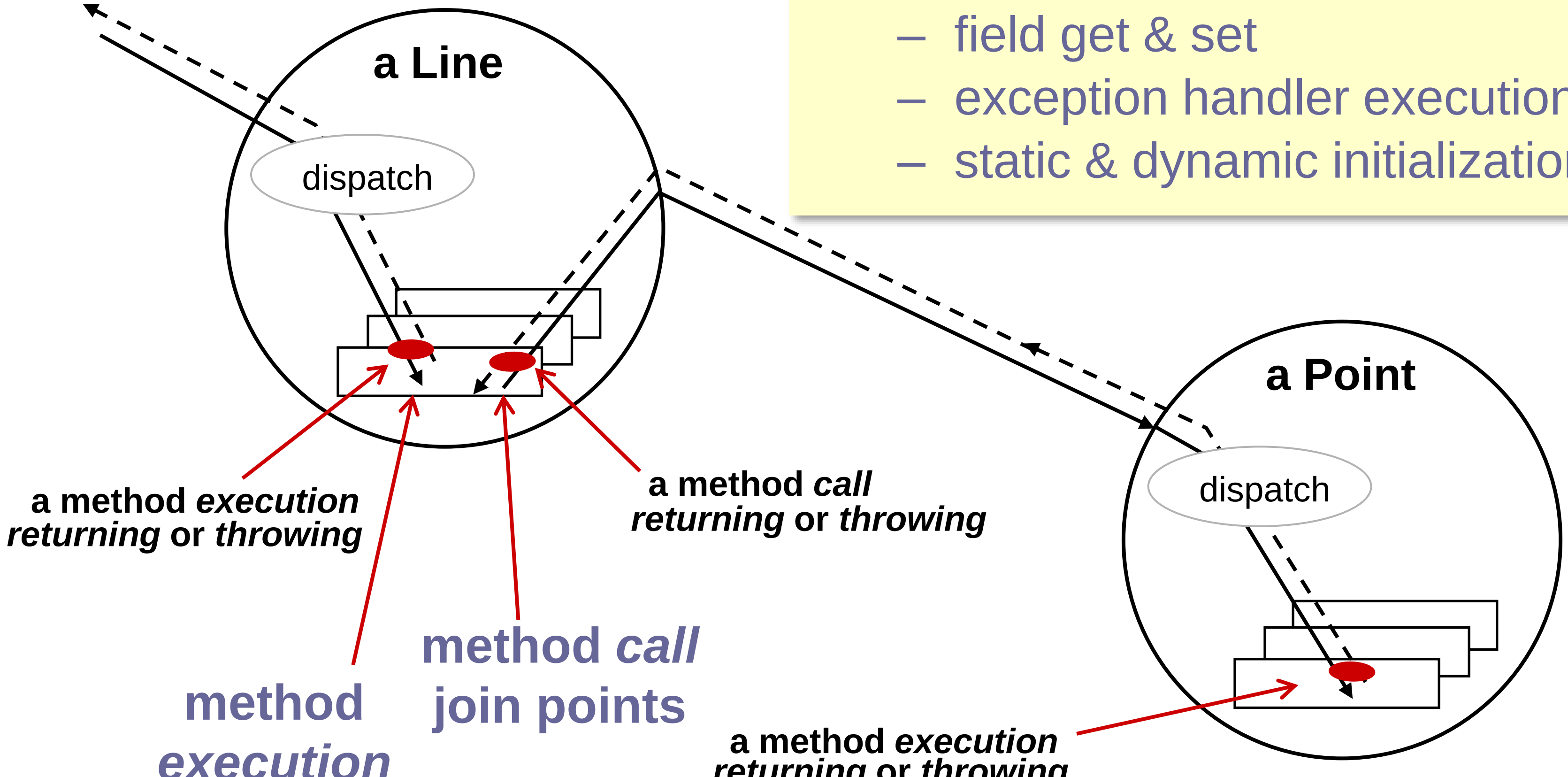
join points

key points in dynamic call graph

several kinds of join points

- method & constructor call
- method & constructor execution
- field get & set
- exception handler execution
- static & dynamic initialization

suppose `l.moveBy(2, 2)`



a method *execution* returning or throwing

a method *call* returning or throwing

method *call* join points

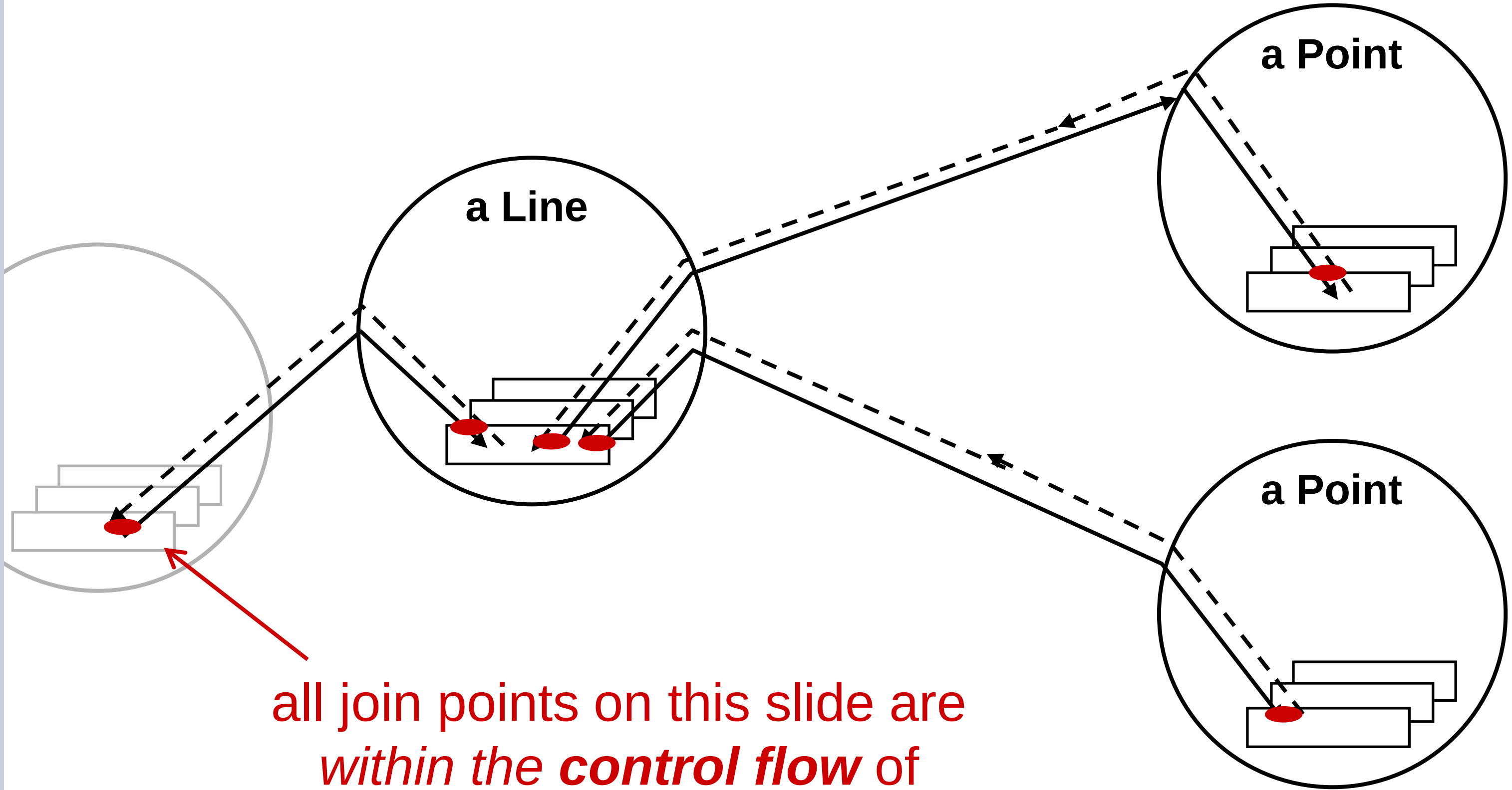
method *execution* join points

a method *execution* returning or throwing

note that the scope of call vs. execution joinpoints is different (caller vs. callee)

join point terminology

key points in dynamic call graph



all join points on this slide are *within the **control flow*** of this join point

pointcuts

“a means of identifying join points”

a *pointcut* is a set membership predicate on join points that:

- can match or *not* match any given join point and
- optionally, can pull out some of the values at that join point

```
call(void Line.setP1(Point))
```

matches method *call* join points that have this *type signature*

pointcut composition

pointcuts compose as set predicates, using &&, || and !

a “void Line.setP1(Point)” call

or

```
call(void Line.setP1(Point)) ||
call(void Line.setP2(Point));
```

a “void Line.setP2(Point)” call

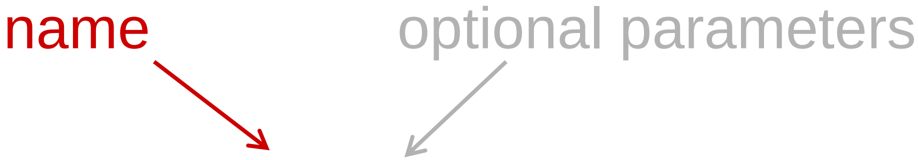
whenever a Line receives a
“void setP1(Point)” or “void setP2(Point)” method call

user-defined pointcuts

defined using the pointcut construct

user-defined (*aka* named) pointcuts

- can be used in the same way as primitive pointcuts



name

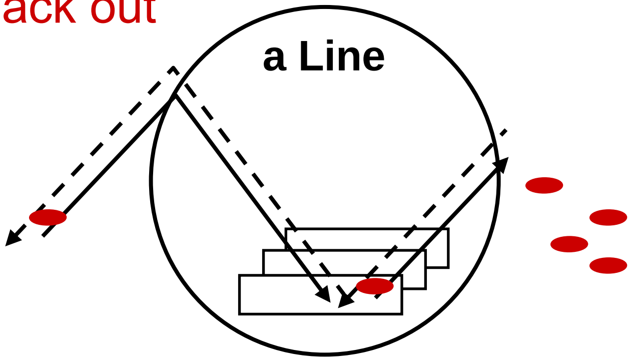
optional parameters

```
pointcut move():
  call(void Line.setP1(Point)) ||
  call(void Line.setP2(Point));
```

after “advice”

action to take after computation under join points

after advice runs “on the way back out”



```
pointcut move():
  call(void Line.setP1(Point)) ||
  call(void Line.setP2(Point));

after() returning: move() {
  Display.update();
}
```

a simple aspect

DisplayUpdating v1

an aspect defines a special class that can crosscut other classes

```
aspect DisplayUpdating {

  pointcut move():
    call(void Line.setP1(Point)) ||
    call(void Line.setP2(Point));

  after() returning: move() {
    Display.update();
  }
}
```

box means complete, running code

a multi-class aspect

DisplayUpdating v2

can cut across multiple classes, and use interface signatures

```
aspect DisplayUpdating {

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

  after() returning: move() {
    Display.update();
  }
}
```

without AspectJ

DisplayUpdating v2

```
class Line {
  private Point p1, p2;

  Point getP1() { return p1; }
  Point getP2() { return p2; }

  void setP1(Point p1) {
    this.p1 = p1;
    Display.update();
  }
  void setP2(Point p2) {
    this.p2 = p2;
    Display.update();
  }
}
```

```
class Point {
   private int x = 0, y = 0;

  int getX() { return x; }
  int getY() { return y; }

  void setX(int x) {
    this.x = x;
    Display.update();
  }
  void setY(int y) {
    this.y = y;
    Display.update();
  }
}
```

- **no locus of “display updating”**
  - evolution is cumbersome
  - changes in all classes
  - have to track & change all callers
  - we say the concerns are “tangled”

with AspectJ

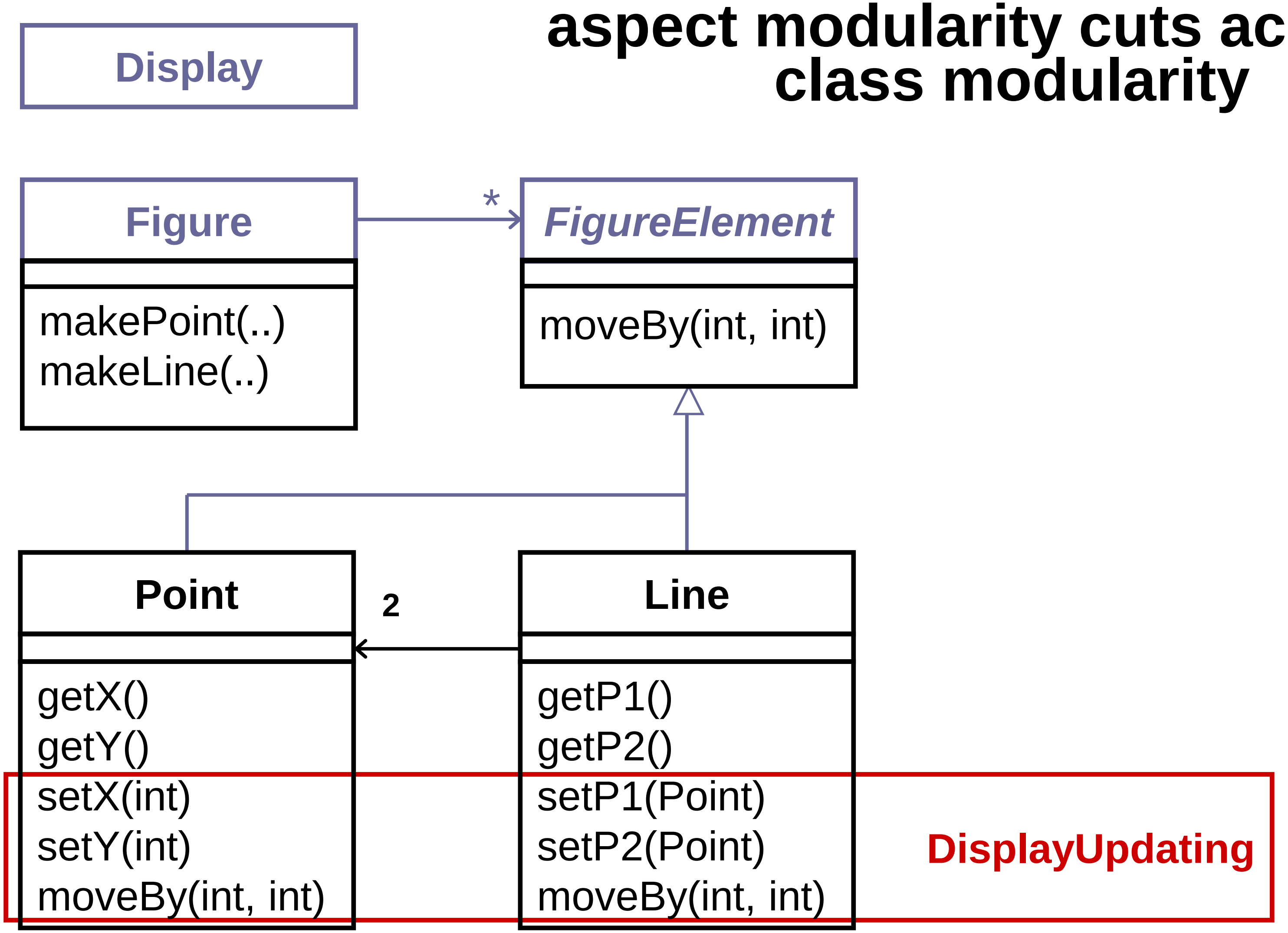
DisplayUpdating v2

```
class Line {
  private Point p1, p2;

  Point getP1() { return p1; }
  Point getP2() { return p2; }

  void setP1(Point p1) {
    this.p1 = p1;
  }

  void setP2(Point p2) {
    this.p2 = p2;
  }
}


class Point {
  private int x = 0, y = 0;

  int getX() { return x; }
  int getY() { return y; }

  void setX(int x) {
    this.x = x;
  }

  void setY(int y) {
    this.y = y;
  }
}
```

```
aspect DisplayUpdating {

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


  after() returning: move() {
    Display.update();
  }
}
```

- **clear display-updating module**
  - all changes in single aspect
  - evolution is modular

aspects crosscut classes



aspect modularity cuts across class modularity

aspect using *target* of call

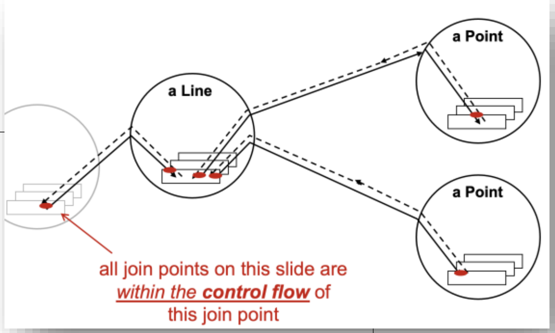
DisplayUpdating v3

can expose and use values at join points

```
aspect DisplayUpdating {

 pointcut move(FigureElement fe):
    target(fe) &&
    (call(void FigureElement.moveBy(int, int)) ||
     call(void Line.setP1(Point))              ||
     call(void Line.setP2(Point))              ||
     call(void Point.setX(int))                ||
     call(void Point.setY(int)));

  after(FigureElement fe) returning: move(fe) {
    Display.update(fe);
  }
}
```

only *top-level* moves

DisplayUpdating v4



all join points on this slide are *within the* ***control flow*** of this join point

```
aspect DisplayUpdating {

  pointcut move(FigureElement fe):
    target(fe) &&
    (call(void FigureElement.moveBy(int, int))  ||
     call(void Line.setP1(Point))               ||
     call(void Line.setP2(Point))               ||
     call(void Point.setX(int))                 ||
     call(void Point.setY(int)));

  pointcut topLevelMove(FigureElement fe):
    move(fe) && !cflowbelow(move(FigureElement));

  after(FigureElement fe) returning: topLevelMove(fe) {
    Display.update(fe);
  }
}
```

“role” types and reusability

Model-View Controller

```
abstract aspect Observing {

  protected interface Subject  { }
  protected interface Observer { }

  public void    addObserver(Subject s, Observer o) { ... }
  public void removeObserver(Subject s, Observer o) { ... }

  abstract pointcut changes(Subject s);

  after(Subject s): changes(s) {
    Iterator iter = getObservers(s).iterator();
    for ( Observer obs: getObservers(s) ) {
      notifyObserver(s, obs);
    }
  }
  abstract void notifyObserver(Subject s, Observer o);
}
```

abstract aspects for reuse

DisplayUpdating v5

```
aspect DisplayUpdating extends Observing {

  declare parents: FigureElement implements Subject;
  declare parents: Display       implements Observer;

  pointcut changes(Subject s):
    target(s) &&
    (call(void FigureElement.moveBy(int, int)) ||
     call(void Line.setP1(Point))              ||
     call(void Line.setP2(Point))              ||
     call(void Point.setX(int))                ||
     call(void Point.setY(int)));

  void notifyObserver(Subject s, Observer o) {
    ((Display)o).update(s);
  }
}
```

property-based crosscutting

DisplayUpdating v6

```
aspect DisplayUpdating extends Observing {

  declare parents: FigureElement implements Subject;
  declare parents: Display       implements Observer;

  pointcut changes(Subject s):
    target(s) &&
    (call(void FigureElement.moveBy(int,int)) ||
     call(void FigureElement+.set*(..)));

  void notifyObserver(Subject s, Observer o) {
    ((Display)o).update(s);
  }
}
```

neatly captures “set” interface

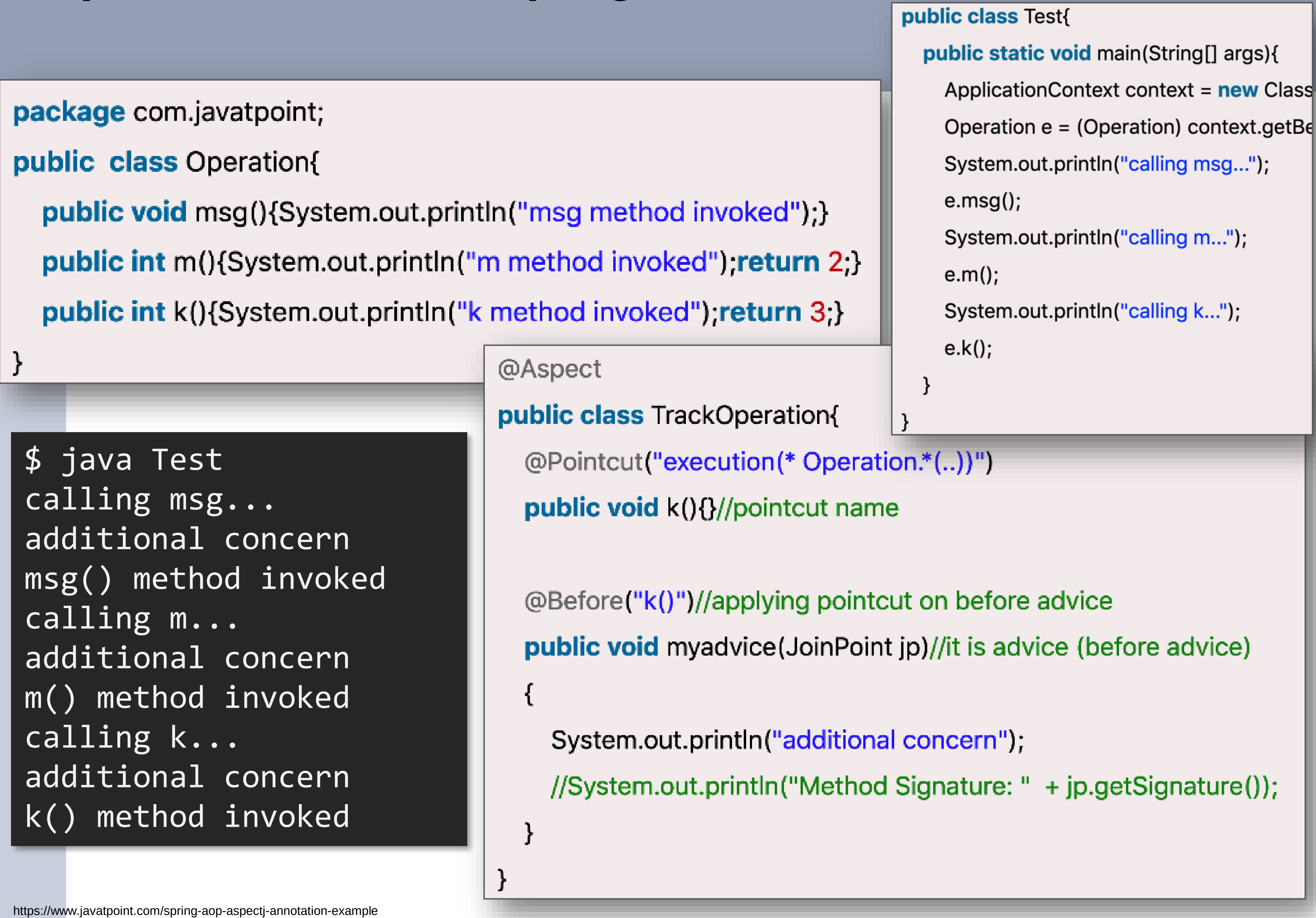
consider code maintenance

- **another programmer adds a set method**
  - i.e., extends public interface – this code will still work
- **another programmer reads this code**
  - “what’s really going on” is explicit

enforcing design invariants

```
aspect FactoryEnforcement {

  pointcut newFigElt():
    call(FigureElement.new(..));

  pointcut inFactory():
    within(* Figure.make*(..));

  pointcut illegalNewFigElt():
    newFigElt() && !inFactory();


  declare error: illegalNewFigElt():
    "Must call factory method to create figure elements.";

}
```

AspectJ is now often programmed w/ Annotations



```
package com.javatpoint;
public  class Operation{
   public void msg(){System.out.println("msg method invoked");}
   public int m(){System.out.println("m method invoked");return 2;}
   public int k(){System.out.println("k method invoked");return 3;}
}
```

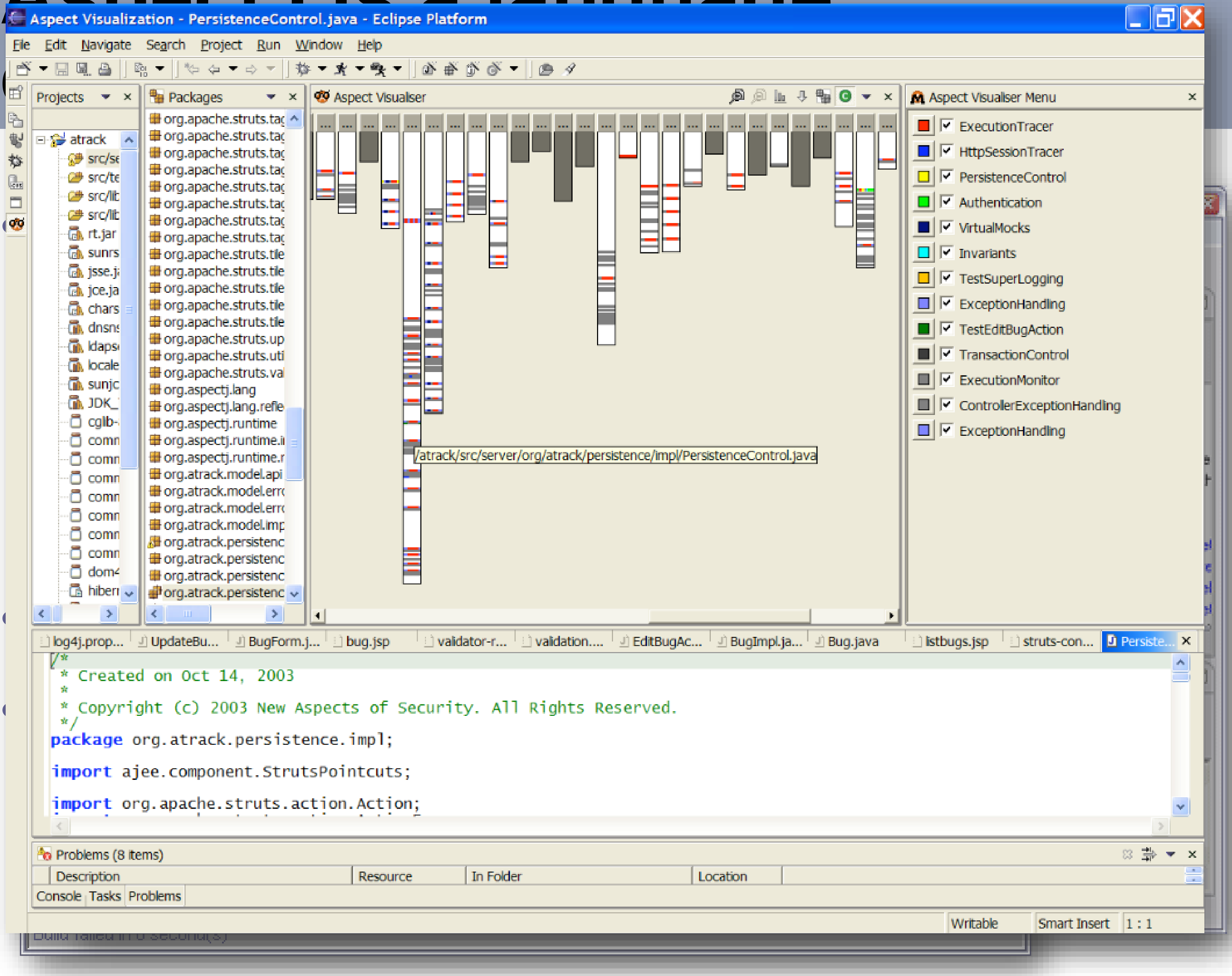
```
public class Test{
   public static void main(String[] args){
      ApplicationContext context = new Class
      Operation e = (Operation) context.getBe
      System.out.println("calling msg...");
      e.msg();
      System.out.println("calling m...");
      e.m();
      System.out.println("calling k...");
      e.k();
   }
}
```

```
@Aspect
public class TrackOperation{
   @Pointcut("execution(* Operation.*(..))")
   public void k(){}//pointcut name

   @Before("k()")//applying pointcut on before advice
   public void myadvice(JoinPoint jp)//it is advice (before advice)
   {
      System.out.println("additional concern");
      //System.out.println("Method Signature: "  + jp.getSignature());
   }
}
```

```
$ java Test
calling msg...
additional concern
msg() method invoked
calling m...
additional concern
m() method invoked
calling k...
additional concern
k() method invoked
```

https://www.javatpoint.com/spring-aop-aspectj-annotation-example

AspectJ is a language



Aspect Visualization - PersistenceControl.java - Eclipse Platform

atrack
- src/se
- src/te
- src/lib
- src/lib
- rt.jar
- sunrs
- jsse.j
- jce.ja
- chars
- dnsns
- ldaps
- locale
- sunjc
- JDK_
- cglib-
- comn
- comn
- comn
- comn
- comn
- comn
- comn
- dom4
- hiberi

- org.apache.struts.tag
- org.apache.struts.tag
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- org.apache.struts.tile
- org.apache.struts.up
- org.apache.struts.uti
- org.apache.struts.val
- org.aspectj.lang
- org.aspectj.lang.refle
- org.aspectj.runtime
- org.aspectj.runtime.i
- org.aspectj.runtime.r
- org.atrack.model.api
- org.atrack.model.err
- org.atrack.model.err
- org.atrack.model.imp
- org.atrack.persistenc
- org.atrack.persistenc
- org.atrack.persistenc
- org.atrack.persistenc

/atrack/src/server/org/atrack/persistence/impl/PersistenceControl.java

- 🟥 ☑ ExecutionTracer
- 🟦 ☑ HttpSessionTracer
- 🟨 ☑ PersistenceControl
- 🟩 ☑ Authentication
- 🟦 ☑ VirtualMocks
- 🟦 ☑ Invariants
- 🟨 ☑ TestSuperLogging
- 🟪 ☑ ExceptionHandling
- 🟩 ☑ TestEditBugAction
- ⬛ ☑ TransactionControl
- ⬛ ☑ ExecutionMonitor
- ⬛ ☑ ControllerExceptionHandling
- 🟪 ☑ ExceptionHandling

```
/*
 * Created on Oct 14, 2003
 *
 * Copyright (c) 2003 New Aspects of Security. All Rights Reserved.
 */
package org.atrack.persistence.impl;

import ajee.component.StrutsPointcuts;

import org.apache.struts.action.Action;
```

Problems (8 items)

Description	Resource	In Folder	Location

Writable | Smart Insert | 1 : 1

AOP Summary

- **A feature/capability often crosscuts traditional OO modularity**
  - distribution of feature code across components
  - high gulfs of execution and evaluation
- **AOP enables the code to look like how the programmer thinks about it**
  - more modular features
  - lower gulfs of execution/evaluation compared to OO
- **IDEs provide PL-like features beyond the PL that further close the gulfs**
  - Where might my aspect execute?
  - (What methods might get executed at this call site?)

BACKUP SLIDES

Some Key Tools

Aspect-Oriented Software Development with Use Cases
Ivar Jacobson
Pan-Wei Ng
eclipse AspectJ
AspectJ in Action
Mastering AspectJ
Aspect-Oriented Programming in Java
AspectJ Cookbook
O'REILLY
Aspect-Oriented Programming with AspectJ

- **AspectJ/AspectWerkz**
  - mature
  - IDE support
  - documented, supported
  - *de facto* standard
  - Annotation-style aspect programming
- **Spring**
  - “interceptor-based” AOP; supports AspectJ
- **JBoss/WildFly**
  - “interceptor-based” AOP

How an aspect gets compiled

```
aspect DisplayUpdating {

  pointcut move():
    call(void Line.setP1(Point)) ||
    call(void Line.setP2(Point));

  after() returning: move() {
    Display.update();
  }
}
```

Example Java elsewhere in program:

```
FigureElement n1;
Line n2;

n1.setP1(newP1);
n1.setColor(RED);
n1.setP2(newP2);
n2.setDepth(2);
…
```

Gets compiled to byte codes as:

```
n1.setP1(newP1);
if (n1.instanceOf(Line))
   Display.update();
n1.setColor(RED);
n1.setP2(newP2);
Display.update();
n2.setDepth(2);
…
```

If there is a subclass of Line that defines its own setP2(Point), then would have to check type