Aspect-Oriented Programming and the AspectJ

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Contents

- Need for a novel paradigm
- Aspect-Oriented Software Development
  - Aspect-Oriented Design
  - Aspect-Oriented Programming
    - AspectJ (language and tools)
    - Other languages and tools
  - Applications, examples
- Related technologies

Schedule

- Need for a novel paradigm
  Separation of concerns
  Aspect-Oriented Programming
- AspectJ
- Aspect-Oriented Software Development
  Related technologies

Popular paradigms

- High-level languages (5*-6*)
- Structured programming (6*-7*)
- Modular programming (7*-8*)
- Object-oriented programming (8*-9*)
- Component-oriented programming (9*-0*)

?

Further important paradigms

- Declarative programming (e.g. functional, logic)
- Generic programming
- Metaprogramming
- Application of design patterns

Nowadays

- Aspect-Oriented Programming
- Generative programming
- Intentional programming
- Multi-paradigm programming
- Service-oriented programming

Managing complexity

- Driving force
  - Methodologies
  - Programming languages
- Abstraction and modularity

Increase reusability

- Nice dream
- Only partially achieved

- Modularity and abstraction

Paradigm	Abstraction	Modularization
High-level languages	machine independence	instruction
Structured programming	control flow	control structure
Procedural programming	computations	procedure
Modular programming	libraries, data types	module
Object-oriented programming	data types	class/object
Component-O. programming	scenarios	component

Modularity

- Methodology
  - decomposition
  - hierarchy
  - cohesion within components
  - narrow interface between components
- Language
  - encapsulation, information hiding
  - subprograms, classes, packages
  - compilation units, libraries

Decomposition

- Separation of concerns (Dijkstra)

- Based on
  - functionality (features)
  - data structures (objects)
  - control flow (concurrency)
  - services, technologies (framework)

  …

Example by [OT'99]

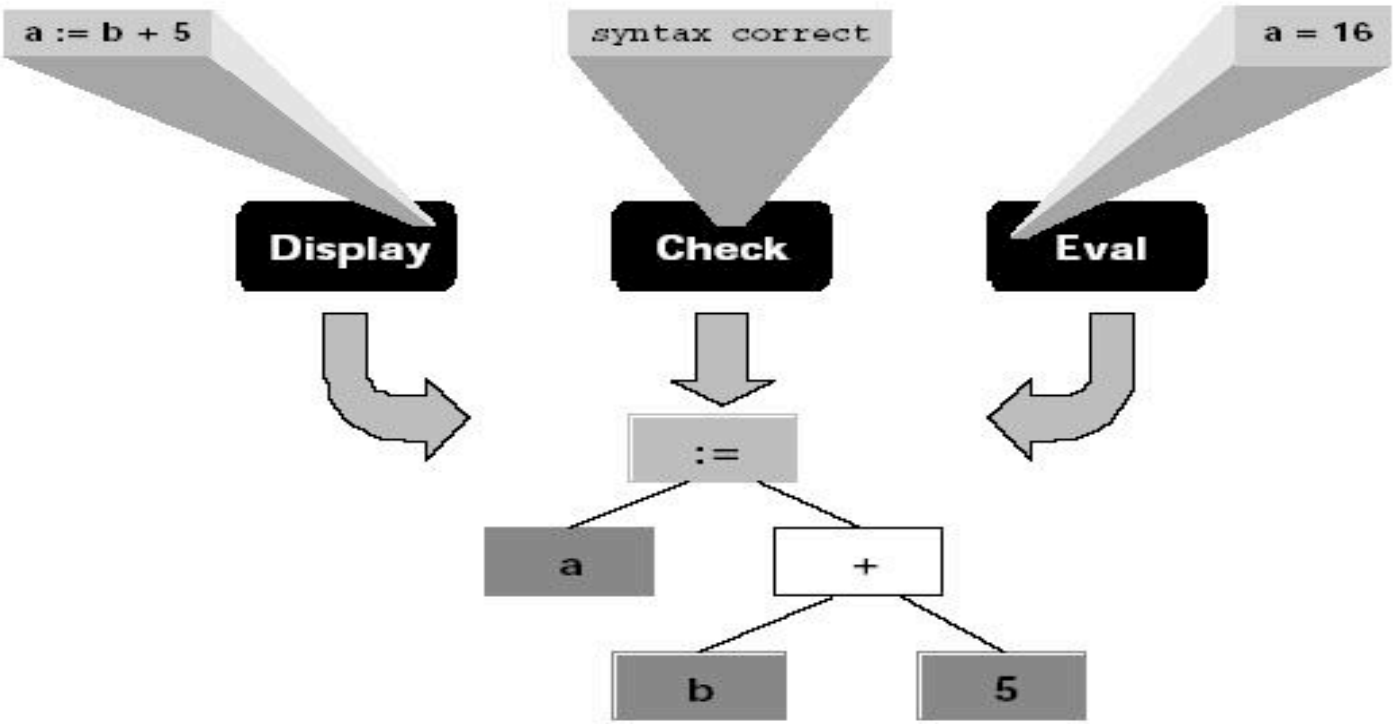


Figure 1. Tools and Shared AST in the Expression SEE.

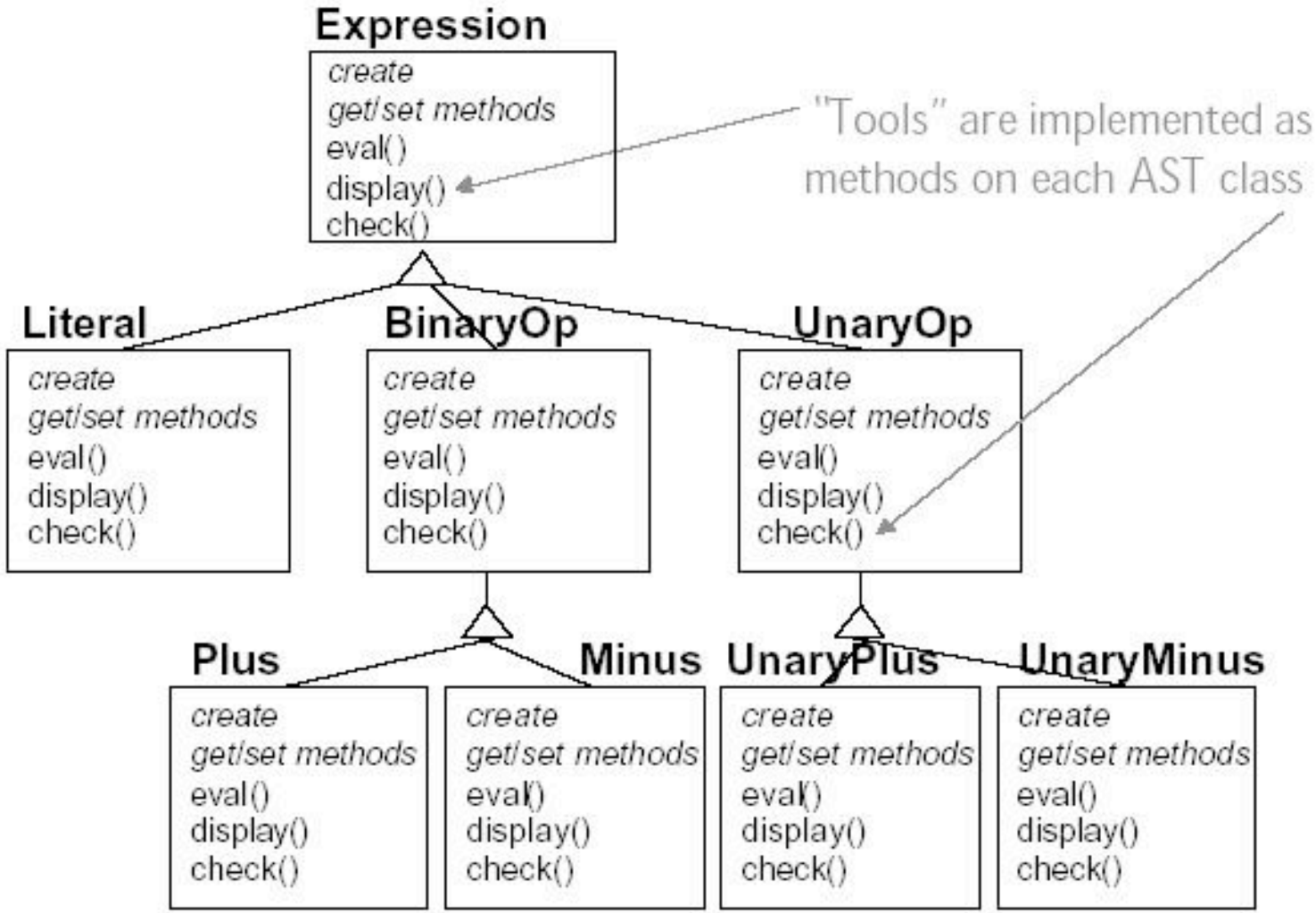


Figure 3. Partial UML Design for the Expression SEE

Problems with this design

- Consider e.g. the concern “display”
- Scattering and tangling
- Bad decomposition? Need another one?

- No!

Tyranny of the Dominant Decomposition [OT'99]

- Arbitrariness of the decomposition hierarchy [MO'05]
- Current methodologies/languages have DD
- Need to overthrow the tyranny
- Need for decomposition in multiple dimensions simultaneously
- Several approaches…

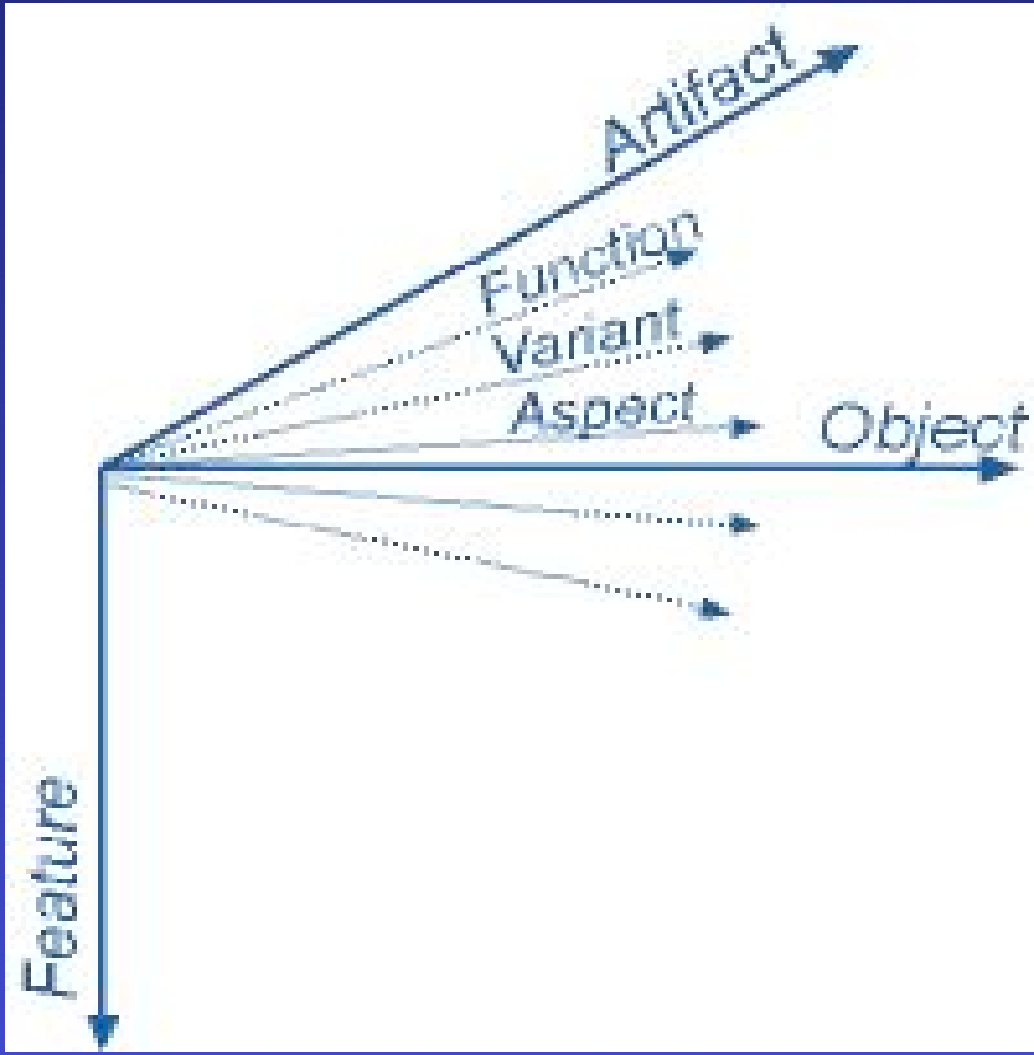
Multi-Dimensional Separation of Concerns

- IBM Research, Ossher, Tarr
- General solution
- For every artifact in software development
- A realization: Hyperslices
- An implementation: Hyper/J
- later…

Concerns

- A dimension of concerns
  - Decomposition is based on ~
  - Functionality, data structures, control flow, etc.
- Concern
  - Obtained by decomposition
  - An element of a dimension of concerns
  - A program feature, a class, a process
  - BinaryOp, Plus, Display, Evaluation

Decompose simultaneously



Dimensions

- Artifacts
  - Specification, Design docs, Code, Test suite
- Functionality (features)
  - Evaluation, Display, Persistence
- Data structures (classes)
  - Expression, UnaryOp, Plus
- Variants
  - For different configurations (e.g. style checks)
- Units of change

The overall system

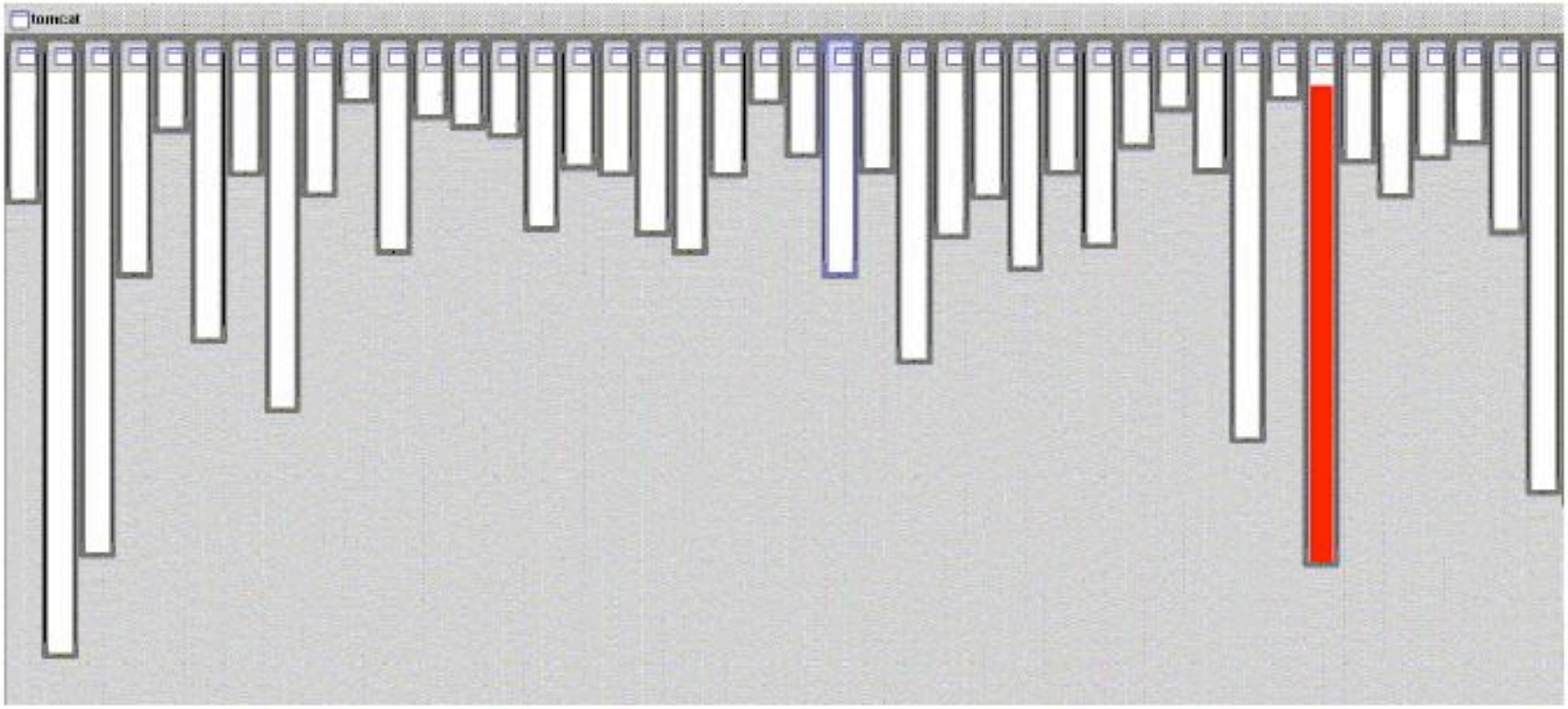
- Can be viewed and modified in different dimensions of concerns
  - Different developers
  - Same developer at different times
- The dimensions and the decompositions
  - are coequal
  - can evolve

Aspect-Oriented Software Development

- A less general solution
- Base functionality + crosscutting concerns
- Simple and powerful
- Became popular and wide-spread
- Many approaches, many implementations
- Aspect-Oriented Programming
- Most famous: AspectJ

good modularity

XML parsing



- **XML parsing in org.apache.tomcat**
  - red shows relevant lines of code
  - nicely fits in one box

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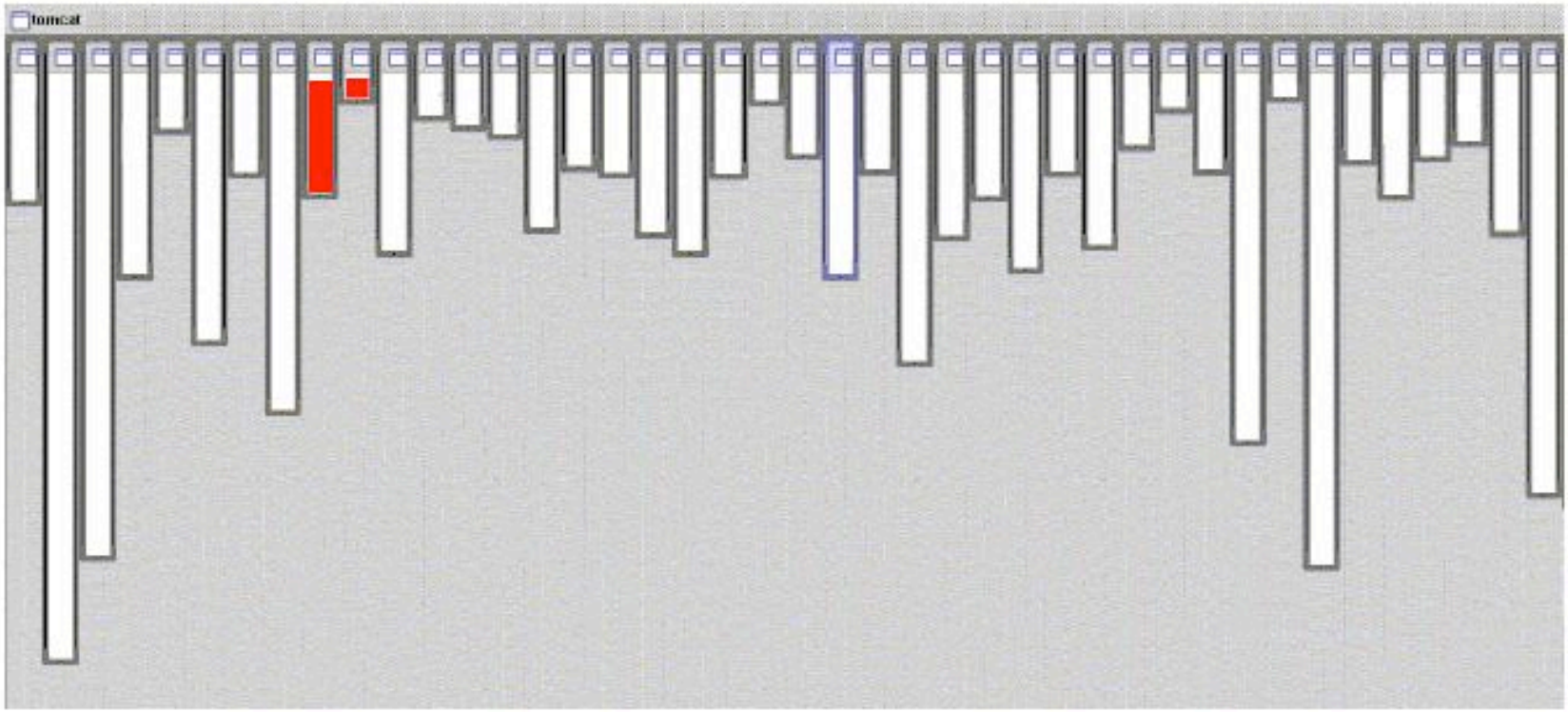
good modularity

URL pattern matching



- **URL pattern matching in org.apache.tomcat**
  - red shows relevant lines of code
  - nicely fits in two boxes (using inheritance)

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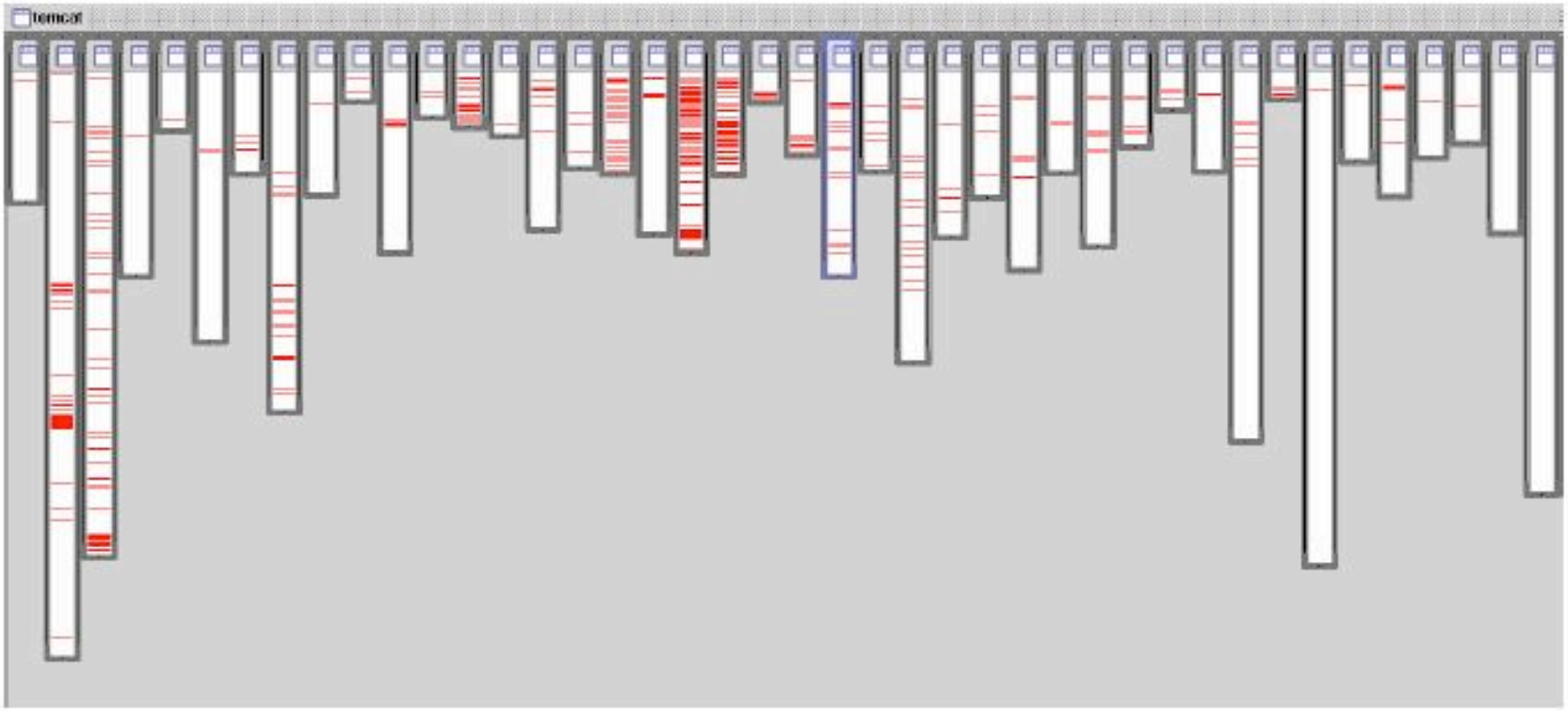
problems like…

logging is not modularized



- **where is logging in org.apache.tomcat**
  - red shows lines of code that handle logging
  - not in just one place
  - not even in a small number of places

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problems like…

session expiration is not modularized

ApplicationSession

StandardSession

SessionInterceptor

StandardManager

StandardSessionManager

ServerSession

ServerSessionManager

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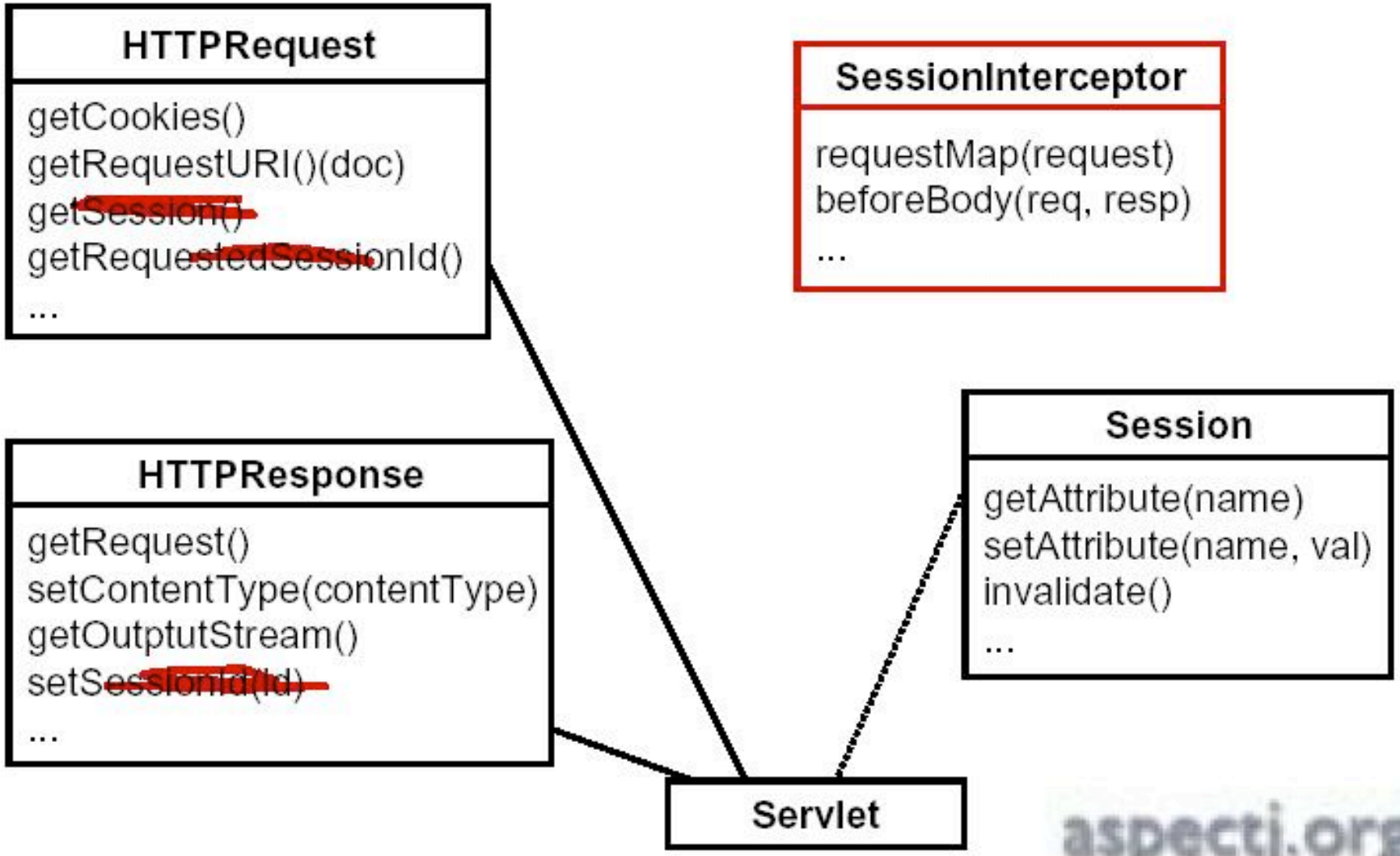
problems like…

session tracking is not modularized



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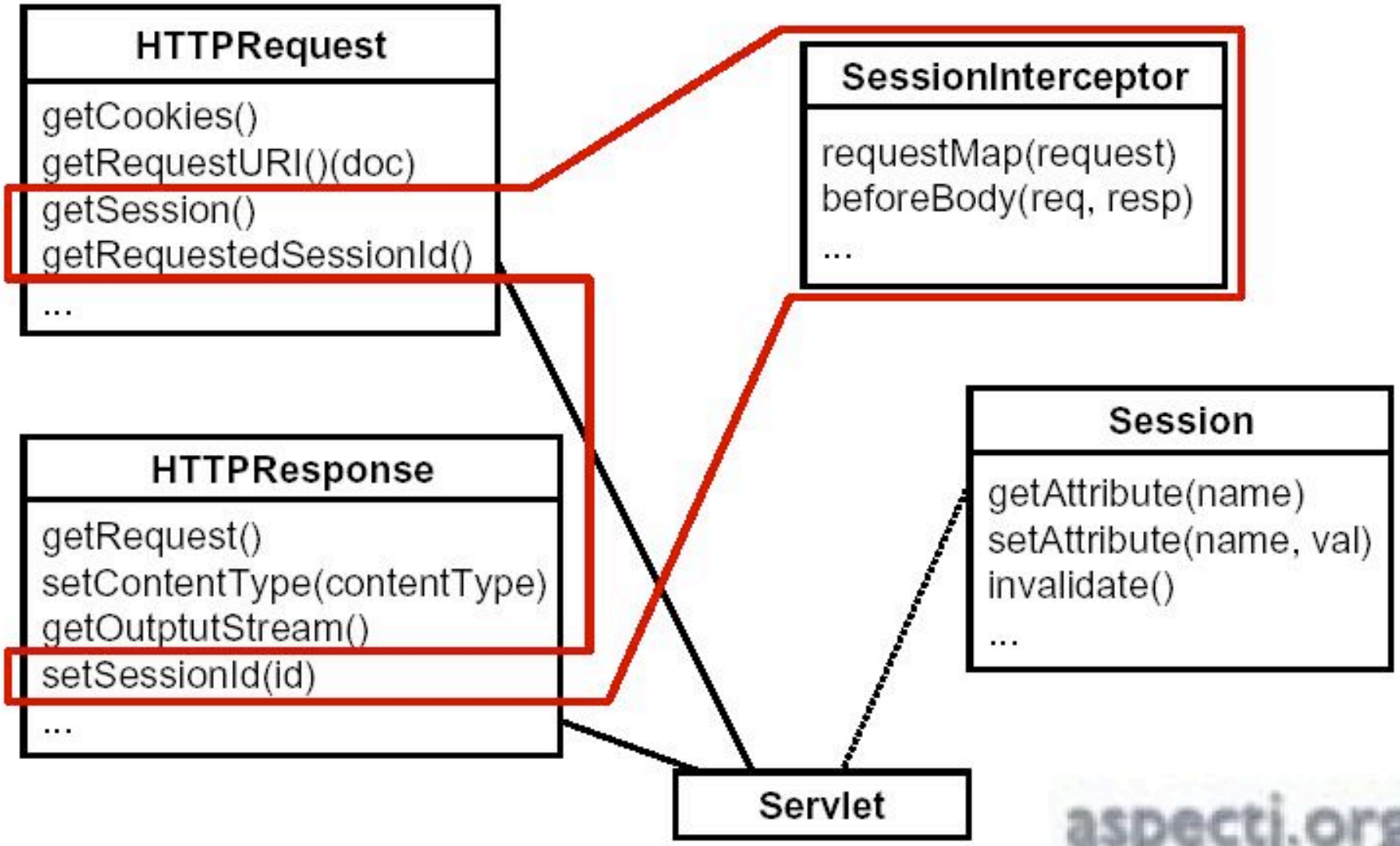
Crosscutting concern

- A concern that appears at many different places in the program
- Scattering
- Tangling

- Physical separation: in an aspect
- Pluggable

crosscutting concerns



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language support to…

ApplicationSession

StandardSession

SessionInterceptor

StandardManager

StandardSessionManager

ServerSession

ServerSessionManager

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Examples of crosscutting

- Tracing and profiling
- Logging
- Configuration management
- Exception handling
- Security
- Synchronization
- Verifying correctness
- Visualization

Example of aspect

```
import java.io.*;
aspect SimpleLogging {
     pointcut loggedCalls():
          call(public * *.*(..));

     after() throwing (IOException e):
     loggedCalls() {
          System.err.println(e);
     }
}
```

AOP terminology

- Crosscut: affect more modules
- Aspects: modules implementing crosscutting behaviour
- Obliviousness: base code not referring to aspects
- Join points: where composition happens
- Quantification: reference to more join points
- Aspect-weaver: composes aspects with base code

“Traditional” techniques

- Application of design patterns
- Tool support (e.g. profilers)
- Macros and pre-compilers
- Frameworks

Macros and pre-compilers

- Tracing (debugging), configuration management
- Certain aspects become pluggable
- Crosscutting concerns are not separated

Frameworks

- CORBA, J2EE etc.
- Certain concerns of components handled by framework
  - Services
  - Security, transaction management, persistence, remote access, multithreading, life cycle, pooling, clustering, …
- Provided in specific languages
  - J2EE: deployment descriptor
- Fixed concerns with fixed possibilities
- No obliviousness

Development of AOP languages

- "Special purpose" approach
  - Frameworks
    (like deployment descriptors of J2EE)
  - Concern-specific AOP languages

- **"General purpose" approach**
  - E.g. AspectJ

My story of AOP

- (Multi-agent) simulations
- Concerns
  - Modelling
  - Observation
- OOP: tangling and scattering
  - Conceptual separation
  - Publishing models
  - Multiple observers
- Multi-Agent Modelling Language (MAML), 1999. [GK'99]

The beginning of AOP [Lopes'05]

- Much related research from early 90'
- Special purpose AOP languages [K…'97]
  - Concurrency: D framework [Lopes'97]
    - Cool: coordination
    - Ridl: remote access
  - Performance
    - RG: image processing [MKL'97]
    - AML: sparse matrix manipulation [I…'97]
- DJ, DJava, AspectJ
- AspectJ (general purpose) [LK'98]
- Further general purpose AOP languages and technologies

General purpose AOP language

- Not concern-specific
- Different concerns expressed with same language constructs
- Basic constructs for
  - modularization
  - composition
- Usually built over a host language

Some examples [AOSD]

- AspectC++
- AspectC
- Aspect#, AspectDNG, LOOM.NET, AspectC#, EOS
- Aspect-Oriented Perl, Aspect.pm
- Aspects, Pythius (Python)
- AspectR (Ruby)
- AspectS, Apostle, MetaclassTalk (Squeak/Smalltalk)
- AspectXML
- AOPHP, AspectPHP
- Object Teams
- UMLAUT

Some examples for Java [AOSD]

- Caesar
- Java Aspect Components
- JMangler, JOIE, JMunger
- DJ
- ComposeJ, ConcernJ, JCFF
- Java Layers
- JPiccola
- Pragma
- AspectWerkz
- JBoss-AOP
- Lasagne/J

AspectJ

- How does it work
- The language
- Tool support
- Integration
- Why AOP/AspectJ

How AspectJ works

- Download from [AspectJ]
  - Stable: 1.2.1
  - Experimental: 1.5M
- Install
  - Requires JDK 1.3 or 1.4
  - Tools (e.g. **`ajc`**) and docs
- Command line, PATH and CLASSPATH

The AspectJ language

- Join points (concept)

- Pointcuts
- Advice (constructs)
- Inter-type declarations
- Aspects

The first program: a class

```
public class Hello {
        void greeting(){
                System.out.println("Hello!");
        }
        public static void main( String[] args ){
                new Hello().greeting();
        }
}
```

The first program: an aspect

```
public aspect With {
        before() : call( void Hello.greeting() ) {
                System.out.print("> ");
        }
}
```

The first program: compile and run

- **`example-01`**
- Source file for aspects: **`.java`** or **`.aj`**
- **`PATH`** includes <aspectj>/**`bin`**
- **`CLASSPATH`** includes <aspectj>/**`lib`**/**`aspectjrt.jar`**

```
ajc Hello.java With.aj
java Hello
```

ajc

- Aspect weaver
- Compiles Java and AspectJ
- Produces efficient code
- Incremental compilation
- Accepts bytecode

The first program: after weaving (Simplified view!!!)

```
public class Hello {
        void greeting(){ System.out.println("Hello!"); }
        public static void main( String[] args ){
                Hello dummy = new Hello();
                System.out.print("> ");
                dummy.greeting();
        }
}
```

Join points

- New concept
- Well-defined points in the program flow
  - call of a method or constructor
  - execution of a method or constructor
  - execution of a **`catch`**
  - getting/setting a field
  - initialization of a class, object or aspect
  - execution of advice

Pointcut

- A language construct
- Picks out certain join points (and values): quantification
- Composition

```
call( void Hello.greeting() )
call( * Hello.*(..) )
call( void Hello.greeting() )   &&   target(f)
```

Advice

- A language construct
- Code to be executed at certain join points
  - **`before`**, **`after`** or **`around`**

```
before() : call( void Hello.greeting() ) {
        System.out.print("> ");
}
```

Inter-type declaration

- A language construct
- Modify the static structure of a program
  - introduce new members
  - change relationship between classes

Aspect

- A language construct
- The unit of modularity for crosscutting concerns
- May contain pointcuts, advice and inter-type declarations

```
public aspect With {
        before() : call( void Hello.greeting() ) {
                System.out.print("> ");
        }
}
```

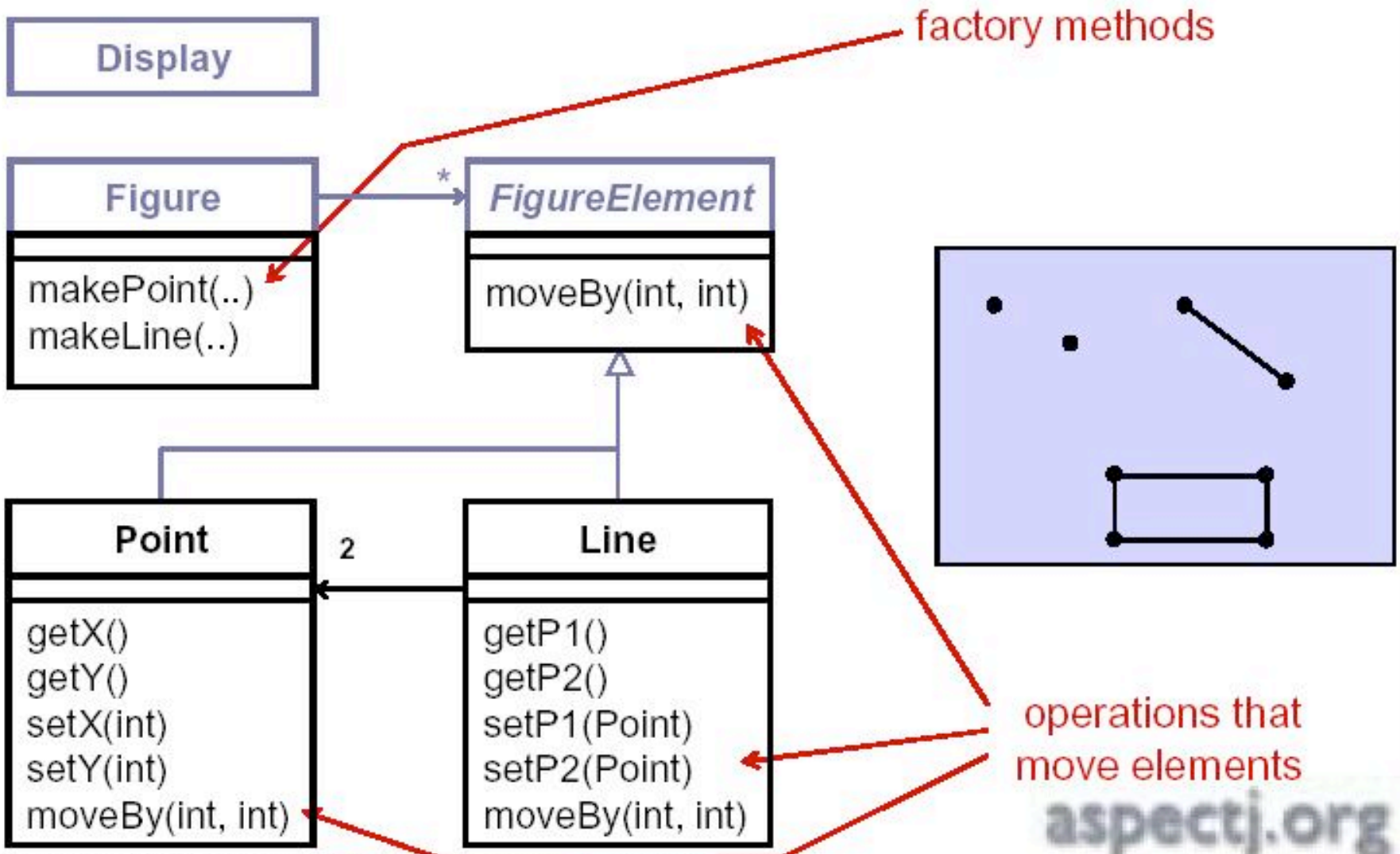
Concerns to implement as aspects

- Development aspects
  - Tracing, Profiling, Logging
  - Pre- and postconditions, Contract enforcement
  - Configuration management
- Production aspects
  - Change monitoring
  - Context passing
  - Providing consistent behavior
  - Collaboration-based design
- Reusable aspects

Tracing

- Info at certain events
- Code discovery, debugging, profiling
- During program development/maintenance
- Should be separated
- Should be easily modified
- **Should be modularized**

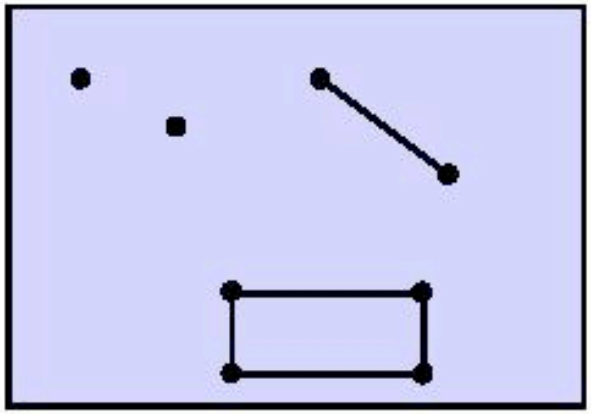
a simple figure editor



a simple figure editor

```
class Line implements FigureElement{
  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; }
  void moveBy(int dx, int dy) { ... }
}

class Point implements FigureElement {
  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; }
  void moveBy(int dx, int dy) { ... }
}
```



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Dynamic joint point model

- Joint point model – classification of AOP languages
- AspectJ: dynamic j.p.m.
- Run-time events
- Containment
  - Dynamic context of a joint point

Composing pointcuts

- Pointcut: pick up joint points
- Composition operators: `&&` `||` `!`
- The result is a pointcut

```
call(void Point.setX(int)) ||
call(void Point.setY(int))
```

(Name-based) crosscutting

```
call(void FigureElement.moveBy(int,int))
|| call(void Point.setX(int))
|| call(void Point.setY(int))
|| call(void Line.setP1(Point))
|| call(void Line.setP2(Point))
```

- Affects multiple types

Named pointcuts

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

- Declares a pointcut named **`move`**
- May be used many times

Using named pointcuts

- example-02

```
before() : move() {
  System.out.println("moving something");
}
```

Property-based crosscutting

```
call( public * Figure.* (..) )
call( * Figure.make*(..) )
```

- Wildcards in the signature
- Not only syntactical, but also lexical match
- Semantical match?

Dynamic context of a joint point

```
cflow(move())
cflowbelow(move())
```

- Join point selection based on dynamic semantics

```
before() : move() && (! cflowbelow(move())) {
        System.out.println("moving something");
}
```

Exercise

Give a pointcut expression

- for calling a public method of any class returning an int
- for calling a setter method in the control flow of a make* in Figure

Solution of exercise

```
call( public int *.*(..) )

cflow( call(* Figure.make*(..)) )
&& call( void *.set*(..) )
```

Advice

- Provide code to execute at a join point

- before
- after
  - if succeeds
  - if fails
- around

before advice

- Right before the join point

```
before() : call( * *.set*(..) ) {
      System.out.println("about to set");
}
```

- Before method call
- After the arguments are evaluated

after advice

- Right after the join point

```
after() : call( * *.set*(..) ) {
    System.out.println("after setting");
}
```

- Variants for testing success

After success

```
after() returning : call(* *.set*(..)) {
    System.out.println("setting OK");
}
```

- When method exited normally

After failure

```
after() throwing : call( * *.set*(..) ) {
    System.out.println("setting failed");
}
```

- When method exited with an exception

around advice

- Instead of, or around join points

```
void around() : call(void Figure.moveBy(..)) {
        System.out.print("Press Y to really move figure: ");
        try {
                if (System.in.read() == 'Y')   proceed();
        } catch (java.io.IOException e) {}
}
```

Parametrized advice

- Formal parameter list in advice
- Bound by the pointcut

```
before( Figure f ) :
call(* Figure.moveBy(..)) && target(f) {
    System.out.println("before move: " + f);
}
```

Exposing context in pointcuts

- With three primitive pointcuts:

  `this` **`target`** **`args`**

```
before(  Figure f, FigureElement fe, int x, int y ):
         call( void FigureElement.moveBy(int,int) ) &&
         this(f) && target(fe) && args(x,y)
{
         ...
}
```

With named pointcuts (1)

- Formal parameter list in pointcut

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

pointcut moveFE(FigureElement fe):
   move() && target(fe);
```

With named pointcuts (2)

```
pointcut moveFE(FigureElement fe):
      move() && target(fe);

before(FigureElement fe): moveFE(fe) {
      System.out.println("moving " + fe);
}
```

Pointcuts with or without parameters

```
pointcut setByLine() :
  call(* Point.set*(..)) && this(Line)

pointcut setByLine(Line line) :
  call(* Point.set*(..)) && this(line)
```

- The same join points selected

Context in “after returning”

```
after() returning (int n):
call(public int Point.get*()) {
     System.out.println(n);
}
```

- Capturing return value
- Type in **`returning`** matches type of method

Context in “after throwing”

```
import java.io.*;
aspect SimpleLogging {
     pointcut loggedCalls():
          call(public * *.*(..));

     after() throwing (IOException e):
     loggedCalls() {
          System.err.println(e);
     }
}
```

Exercise

- Print which FigureElement and with which vector

```
void around() : call(void FigureElement.moveBy(..)) {
        System.out.print("Press Y to really move FE: ");
        try {
                if (System.in.read() == 'Y')   proceed();
        } catch (java.io.IOException e) {}
}
```

Solution of exercise

```
void around( FigureElement fe, int dx, int dy) : target(fe) &&
    args(dx,dy)  &&  call(void FigureElement.moveBy(..))
{
    System.out.print("About to move " + fe + "with " + dx + ", " + dy);
    System.out.print(". Press Y to really move figureElem.: ");
    try {
        if (System.in.read() == 'Y')   proceed();
    } catch (java.io.IOException e) {}
}
```

Inter-type declarations

- Modify the structure of the program
- Compile-time effect
- Addition of fields, methods or constructors to a class
- Or to multiple classes (crosscutting)
- Change the inheritance hierarchy

Introducing line labels

- Point, Line: geometrical properties of FigureElements
  - translate, rotate, reflect, etc.
- Labels for lines
  - relevant for displaying lines
  - another aspect (part of displaying aspect)

Labelling aspect

```
public aspect Labelling {
      private String Line.label;
      public void Line.setLabel(String s){
            label = s;
      }
      public String Line.getLabel(){
            return label;
      }
      …
}
```

Inter-type scope

- Public, package-visible or private
- No protected
- Private: relative to aspect
- Package-visible: relative to aspect's package

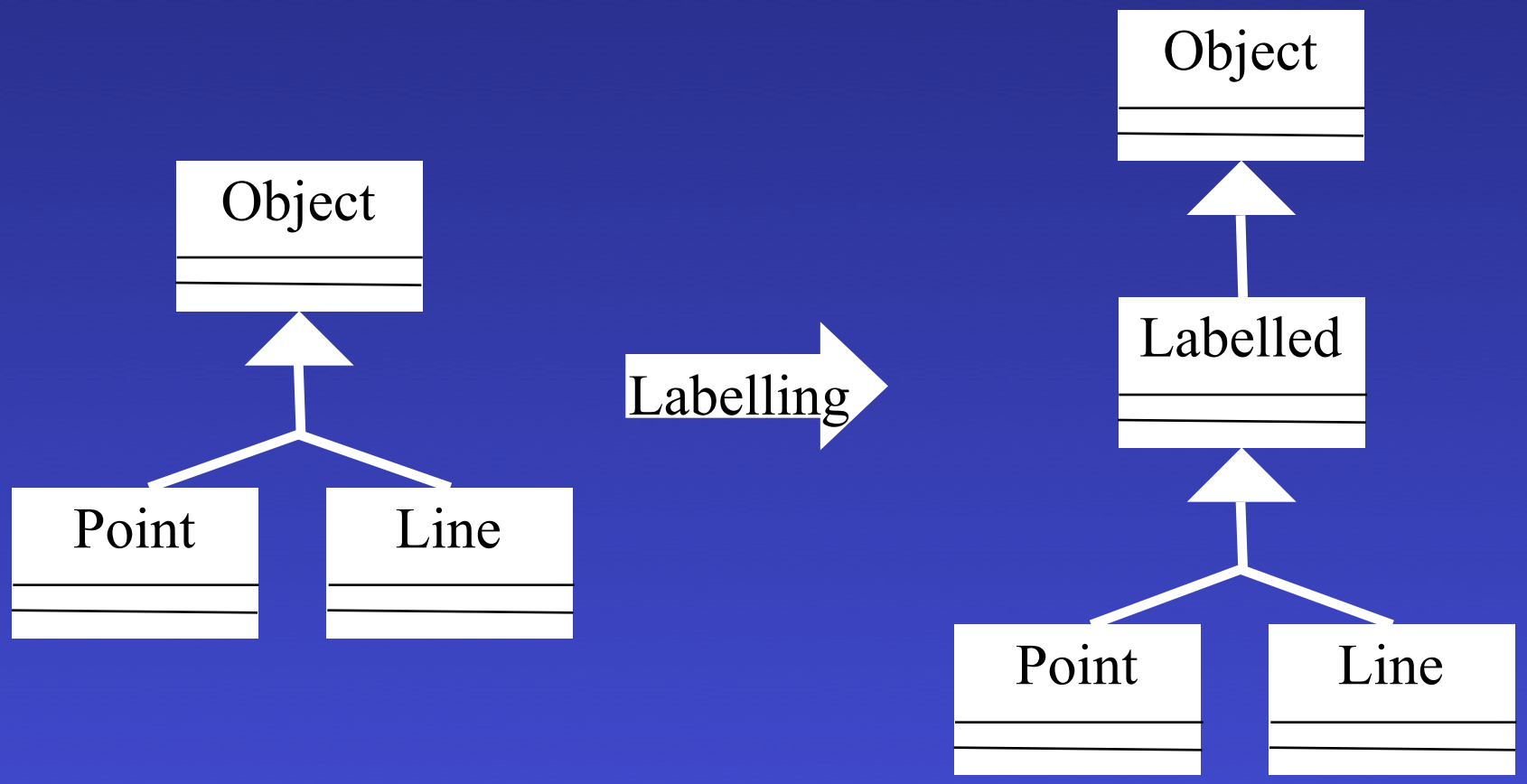
Changing the “implements” relation

```
declare parents:
            Point implements Clonable;


public int Point.compareTo(Object p){
      …
}
declare parents:
            Point implements Comparable;
```

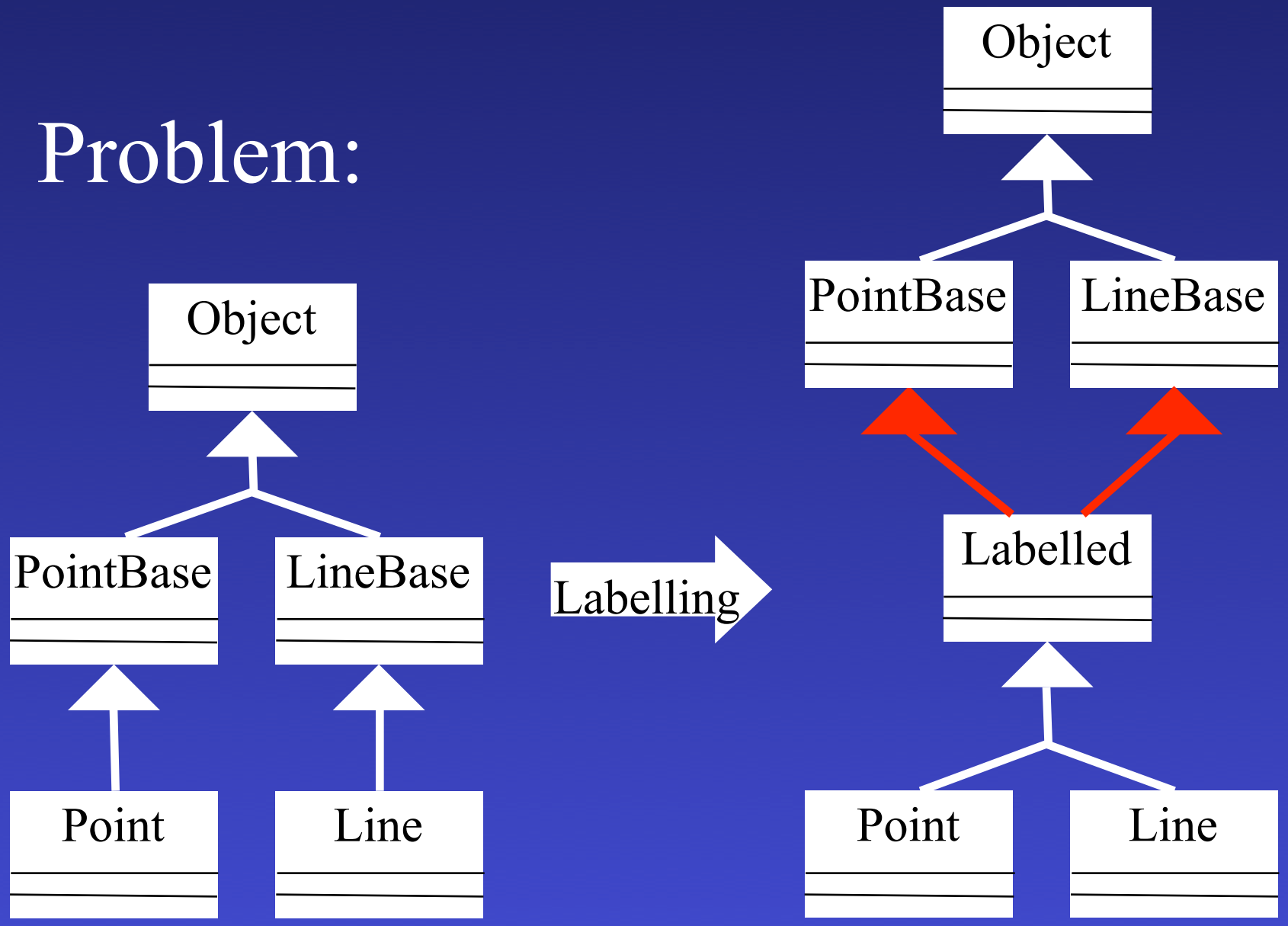
Changing the “extends” relation

```
public aspect Labelling {
  public static class Labelled {
      private String label;
      public void setLabel(String s){…}
      public String getLabel(){…}
  }

  declare parents:
      (Point || Line) extends Labelled;
}
```

Mixin-like technique



Problem:


Object
PointBase
LineBase
Point
Line
Labelling
Object
PointBase
LineBase
Labelled
Point
Line

Crosscutting labels

```
public aspect Labeling {
        private String FigureElement.label;
        public void FigureElement.setLabel(String label){
                this.label = label;
        }
        public String FigureElement.getLabel(){
                return label;
        }
        …
}
```

Let's make another problem!

```
class FigureElement {…}
class Point extends FigureElement {…}
class Line extends FigureElement {…}
class CompoundObject {…}
class Figure extends CompoundCobject {…}
```

- Add labels to **`Point`**, **`Line`** and **`Figure`**!

Marker interface

```
public aspect Labelling {
  interface Labelled {}
  private String Labelled.label;
  public void Labelled.setLabel(String s)
                    { label = s; }
  public String Labelled.getLabel()
                    { return label; }

  declare parents: (Point||Line||Figure)
                     implements Labelled;
}
```

Aspects

- Unit of modularity
- Implementation of a crosscutting concern
- Pointcuts, advice, inter-type declarations
- Own methods, fields, initializers
- Default: singleton

Local state of an aspect

```
aspect Logging {
  OutputStream logStream = System.err;
  before(): move() {
      logStream.println("about to move");
  }
}
```

- A single instance of **`Logging`**
- A single **`logStream`** variable

Special variables

- E.g. thisJointPoint
- Bound to an object describing current join point

```
aspect SimpleTracing {
  pointcut traced(): call(* *.set*(..));
  before(): traced() {
  System.out.println("Entering: " +
                                thisJoinPoint);
  }
}
```

Modularized tracing

- Expressed separately
- Easy to change

```
aspect SimpleTracing {
  pointcut traced(): call(* *.set*(..));
  before(): traced() {
  System.out.println("Entering: " +
                                thisJoinPoint);
  }
}
```

Weaving tracing

- Turning tracing on or off
- Can be removed from production built
- Alternative tracing modules

Profiling

- Flexible: programmatically

```
aspect SetsInRotateCounting {
    int rotateCount = 0;
    int setCount = 0;
    before(): call(void Line.rotate(double)) { rotateCount++; }
    before(): call(void Point.set*(int)) &&
                cflow(call(void Line.rotate(double)))
                    { setCount++; }
}
```

Pre- and postconditions

- Design by contract

```
aspect PointBoundsChecking {
    before(int x): call(void Point.setX(int)) && args(x) {
        if ( x < MIN_X || x > MAX_X )
                throw new IllegalArgumentException(
                                "x is out of bounds.");
    }
    // same for y
}
```

setXY

```
public class Point {
        private int x = 0, y= 0;
        public void setX( int x ){ this.x = x; }
        public void setY( int y ){ this.y = y; }
        public void setXY( int x, int y ){
                this.x = x;  this.y = y;
        }
        …
}
```

setX and setXY handled

```
aspect PointBoundsChecking {
    pointcut setX(int x): (call(void Point.setX(int)) && args(x))
                    || (call(void Point.setXY(int,int)) && args(x,*));
    before(int x): setX(x) {
        if ( x < MIN_X || x > MAX_X )
                    throw new IllegalArgumentException(
                                        "x is out of bounds.");
    }
    // same for y
}
```

Handle non-setter methods

- E.g. moveBy
- Using the **`set`** pointcut

```
aspect PointBoundsChecking {
    before(int x): set(Point.x) && args(x) {
        if ( x < MIN_X || x > MAX_X )
                throw new IllegalArgumentException(
                                "x is out of bounds.");
    }
    // same for y
}
```

Contract enforcement

- **`withincode`** pointcut

```
static aspect RegistrationProtection {
  pointcut register():
      call(void Registry.register(Figure));
  pointcut canRegister():
      withincode(* Figure.make*(..));
  before(): register() && !canRegister() {
      throw new IllegalStateException(…);
  }
}
```

Static contract enforcement

- **`declare error`**, based on static information

```
static aspect RegistrationProtection {
  pointcut register():
      call(void Registry.register(Figure));
  pointcut canRegister():
      withincode(* Figure.make*(..));
  declare error:
      register() && !canRegister() :
      "Illegal call";
  }
}
```

Concept checking

- `declare error`
- `declare warning`

- Have the compiler issue (programmed) compilation errors/warnings
- Extend the compiler with additional grammatical and static semantical rules

Configuration management

- Configuration-specific aspects of code
- Each configuration implemented in an `aspect` definition
- Add one of them to the make file at compile time
- Or even at load time

Production aspects

- Used in production builds
- Add real functionality to apps
- E.g. the Labeling aspect

- Let's see some examples
  - Change monitoring
  - Context passing
  - Providing consistent behaviour

Change monitoring

- Indicate whether any of the FigureElement has moved since last display
- Dirty flag introduced
- Setting the dirty flag at each method that moves a figure element

Implementation in an aspect

```
aspect MoveTracking {
    private static boolean dirty = false;
    public static boolean testAndClear(){
        boolean result = dirty;   dirty = false;   return result;
    }
    …
    after() returning: move() { dirty = true; }
}
```

Advantages

- The structure of the concern is made explicit
- Evolution is easier [ECOOP 01]
- Plug in or out
- More stable implementation

Context passing

- Let's set the color of FigureElements upon creation
- Pass a color (or a color factory) to **`make*`**
- This may influence many methods:
  on the control flow from client to **`make*`**
- Non-AOP solution: additional arg to those methods

Passing context with aspect

```
aspect ColorControl {

  after (ColorControllingClient c)
  returning (FigureElement fe):
     call(* Figure.make*(..)) &&
     cflow( call(* * (..)) && target(c) )
  { fe.setColor(c.colorFor(fe)); }

}
```

A fragment of ajc

```
aspect ContextFilling {
        pointcut parse( JavaParser jp ):
                call(* JavaParser.parse*(..)) && target(jp)
                && !call(Stmt parseVarDec(boolean));
        around(JavaParser jp) returns ASTObject: parse(jp) {
                Token beginToken = jp.peekToken();
                ASTObject ret = proceed(jp);
                if (ret != null) jp.addContext(ret, beginToken);
                return ret;
        }
}
```

Consistent behaviour

- Advising 35 methods
  - **`parseMethodDec`**, **`parseThrows`**, **`parseExpr`** etc.
- Explicit exclusion of **`parseVarDec`**
- Clear expression of a clean crosscutting modularity
- Java → AspectJ refactoring revealed two bugs

Synchronization

- Not thread-safe

```
public class Account {
  ...
  public int getBalance(){...}
  public void deposit( int amount ){...}
  public void withdraw( int amount ){...}
}
```

Mutual exclusion

```
aspect Mutex {
     Object around(Account a):
     call(* Account.*(..)) && target(a) {
          synchronized(a){
               return proceed(a);
          }
     }
}
```

- `Object` has special meaning in this case!

Readers/writers (1)

```
private int Account.readers = 0;
private boolean Account.writing = false;

pointcut reader(Account a):
     target(a) && call(int getBalance());

pointcut writer(Account a):
     target(a) &&
     ( call(void deposit(int)) ||
       call(void withdraw(int)) );
```

Readers/writers (2)

```
before(Account a): reader(a) {
  boolean canGo = false;
  while( !canGo )
     synchronized(a){
          canGo = !a.writing;
          if( canGo ){ a.readers++; }
          else {  try { a.wait(); }
                  catch (Exception e){}
          }
     }
}
```

Evaluation of Mutex and R/W

- Separation of concerns
- Decreased redundancy
- Aspect-private variables
- Easier to improve

- Tied to Account

Reusable aspects

- Implementation of “reusable” concerns
- Binding to base code
- Interference with other aspects

- E.g. mutual exclusion, readers/writers

Abstract pointcut/aspect

```
abstract aspect Mutex {

  abstract pointcut callToSync(Object o);

  Object around(Object o): callToSync(o){
      synchronized(o){
          return proceed(o);
      }
  }

}
```

Extending an aspect

```
aspect MutexForAccount extends Mutex {

  pointcut callToSync(Object o):
      call(* Account.*(..)) && target(o);

}
```

Monitor versus Critical section

- So far: monitor-like mutex
  - 1 semaphore for the methods of 1 object
- Critical section
  - More control over the semaphores
  - E.g. mutex for **all** methods of **all** accounts

More reusable Mutex

```
abstract aspect Mutex {
 interface Sync{ Object getSemaphore(); }

 abstract pointcut callToSync(Sync s);

 Object around(Sync s): callToSync(s){
      synchronized(s.getSemaphore()){
          return proceed(s);
      }
 }
}
```

Critical section for Account

```
aspect CritSecForAccount extends Mutex {
  private static Object s = new Object();
  public Object Account.getSemaphore(){
     return s;
  }
  declare parents:
     Account implements Sync;
  pointcut callToSync(Sync a):
     call(* Account.*(..)) && target(a);
}
```

Monitor for Account

```
aspect MonitorForAccount extends Mutex {
  public Object Account.getSemaphore(){
     return this;
  }
  declare parents:
     Account implements Sync;
  pointcut callToSync(Sync a):
     call(* Account.*(..)) && target(a);
}
```

Reusable R/W (1)

```
abstract aspect RW {

    interface Sync {}

    private int Sync.readers = 0;
    private boolean Sync.writing = false;

    abstract pointcut reader(Sync s);
    abstract pointcut writer(Sync s);

    ...
```

Reusable R/W (2)

```
...
before(Sync s): reader(s) {
boolean canGo = false;
    while( !canGo )
        synchronized(s){
            canGo = !s.writing;
            if( canGo ) s.readers++;
            else try { s.wait(); }
                catch (Exception e){}
        }
}
```

Exercise

- Define more reusable R/W implementation
  - More control over object to synchronize on
- Define normal (per account) rw synch.
- Define per Account class rw synch.

Ignoring pointcut arguments

```
pointcut setCoord(Point p): target(p) &&
          ( call(void Point.setX(int)) ||
            call(void Point.setY(int)) );

pointcut setCoordNoArg():setCoord(Point);
```

- No overloading...

A deeper look at the join points

- Describing events
  - Calling a method: **`call`**
  - Setting a field: **`set`**
- Describing context
  - Static context: **`withincode`**
  - Dynamic context: **`cflow`**, **`cflowbelow`**
  - Exposing context: **`this`**, **`target`**, **`args`**
- Composing pointcuts (**`&&`**, **`||`**, **`!`**)

Picking up further join points: describing events

`call(`*MethodPattern*`)`
`call(`*ConstructorPattern***`)`**
`execution(`*MethodPattern***`)`**
`execution(`*ConstructorPattern***`)`**
`set(`*FieldPattern*`)`
`get(`*FieldPattern***`)`**
`initialization(`*ConstructorPattern***`)`**
`preinitialization(`*ConstructorPattern***`)`**
`staticinitialization(`*TypePattern***`)`**
`handler(`*TypePattern***`)`**
`adviceexecution()`

Accessing fields

set(*FieldPattern***)**

get(*FieldPattern***)**

```
set( int Point.x )
get( * Point.* )
```

Initializing objects and classes

- Objects
  - constructor call/execution
  - (pre)initialization

- Classes: when loading a class

```
staticinitialization( TypePattern )
staticinitialization( java.util.* )
```

Exception handling

- When catching an exception
- Only **`before`** advice

`handler(`*TypePattern***`)`**

```
handler( java.sql.SQLException )
handler( IOException && !EOFException)
handler( java.lang.*Error )
```

Call versus Execution (1)

- Call: in the caller
- Execution: in the callee

- Additional pointcut clauses can make a difference
- Call+restrictions: not every execution of a method

```
execution( * Point.get*() )
call( * Point.get*() )  &&  this(Line)
```

Method versus Constructor

`call(`*MethodPattern***`)`**

`call(`*ConstructorPattern***`)`**

`execution(`*MethodPattern***`)`**

`execution(`*ConstructorPattern***`)`**

```
call( * Point.setX(..) )
call( Point.new(..) )
```

Example

- example-huge
- A **`Huge`** object stores a byte array

- First aspect: add IllegalArgumentException
- Second aspect: optimize representation

Privileged aspects

- Can access members that are otherwise not visible
- In aspect **`OptimizeHuge`**
  field **`data`** of **`Huge`** is accessed

```
privileged aspect … { … }
```

Construction of objects

- Constructor call
  - not in case of **`this`** or **`super`** calls
  - returns an object of the class
- Constructor execution
  - object accessible by pointcut **`this`**
- Object pre-initialization
- Object initialization
  - object accessible by pointcut **`this`**

The process of the construction

- call constructor
- call this(..) *(optional: 0, 1 or more)*
- call super(..)
- …
- return from super(..)
- execute initializers *(hm. almost...)*
- execute rest of this(..) and return *(optional: 0, 1 or more)*
- execute rest of constructor
- return from constructor

“Constructor call” join point

- call constructor
- call this(..)
- call super(..)
- …
- return from super(..)
- execute initializers
- execute rest of this(..) and return
- execute rest of constructor
- return from constructor

“Object pre-initialization” join point

- call constructor
- call this(..)
- call super(..)
- …
- return from super(..)
- execute initializers
- execute rest of this(..) and return
- execute rest of constructor
- return from constructor

“Object initialization” join point

- call constructor
- call this(..)
- call super(..)
- …
- return from super(..)
- <u>execute initializers</u>
- <u>execute rest of this(..) and return</u>
- <u>execute rest of constructor</u>
- return from constructor

“Constructor execution” join point

- call constructor
- call this(..)
- call super(..)
- …
- return from super(..)
- execute initializers
- execute rest of this(..) and return
- <u>execute rest of constructor</u>
- return from constructor

“Constructor execution” join point

- call constructor
- call this(..)
- call super(..)
- …
- return from super(..)
- <u>execute initializers</u>

- <u>execute rest of constructor</u>
- return from constructor

Call versus Execution (2)

- Constructors: when **`super`** or **`this`** is called
  - there is no *constructor call* join point
  - there is a *constructor execution* join point

- Methods: when called on **`super`**
  - there is no *method call* join point
  - there is a *method execution* join point

Join points and subtyping

- Join points are “subtype-polymorhic”

```
class B { void m(){} }
class C extends B { void m(){} }
aspect A {
  after() : call(void B.m()) { … }
}
```

```
(new C()).m()
```

Picking up further join points: describing context

- Static context
  - **`withincode(`***MethodPattern or ConstructorPattern***`)`**
  - **`within(`***TypePattern***`)`**
- Dynamic context:
  - **`cflow(`***Pointcut***`)`**
  - **`cflowbelow(`***Pointcut***`)`**
  - **`if(`***boolean-expr***`)`**
- Exposing context: **`this`**, **`target`**, **`args`**

Static context

- **`withincode(`***MethodPattern***`)`**
  `withincode(`*ConstructorPattern***`)`**
- **`within(`***TypePattern***`)`**, e.g. **`within(Point)`**
- When the executing code belongs to Point

```
pointcut jdbcCall():  call(* java.sql.*(..))  || call(* javax.sql.*(..));
pointcut inDataLayer():  within(com.xyz.persistence..*);
declare warning:  jdbcCall()  &&  !inDataLayer() : "Illegal JDBC call";
```

within versus sender

```
within( Point ) && call( * *.get*() )
```

- Call of a getter in the Point class

```
this( Point ) && call( * *.get*() )
```

- Call of a getter by a Point object

Exercise

```
!within( Point ) &&
this( Point ) &&
call( * *.get*() )

within( Point ) &&
!this( Point ) &&
call( * *.get*() )
```

Dynamic context

- Based on control flow:
  - `cflow()`
  - `cflowbelow()`

- Based on run-time value:

  `if (` *boolean-expr* `)`

The `if` pointcut

```
abstract class Figure {
     boolean isWhite(){ ... }
     ...
}

aspect ChessTracer {
  pointcut whiteSteps( Figure f ):
     call(void Figure.moveTo(int,int)) &&
     target(f) && if(f.isWhite());
  ...
}
```

Exercise

cflow(P && Q)	cflow(P) && cflow(Q)
cflow(P || Q)	cflow(P) || cflow(Q)
cflow(! P)	! cflow(P)

Exposing context

- Primitive pointcuts
  - **`this(`***Type or Id***`)`** : currently executing object
  - **`target(`***Type or Id***`)`** : whose member is accessed
  - **`args(`***Type or Id or "`..`" or "`*`", ...***`)`** : arguments of method call / field set / exc. handler

- after returning/throwing, around

Examples

```
args(int,String)

args(int,Object)

pointcut setter(int v):
     call(void *.set*(..)) && args(v);

args(int,*)

args(int,..,String)
```

Patterns

`execution(`*MethodPattern***`)`**

`execution(`*ConstructorPattern***`)`**

`set(`*FieldPattern***`)`**

`within(`*TypePattern***`)`**

- Pattern matching and wildcards

Field patterns

- "Signature" of fields
  - Name
  - Type
- Wildcards

```
Point.x    Point.*    Point.*Id
```

- Setting a field: args

Type patterns

- Exact type names
  - Qualified names
  - Subtyping: **`call`** vs. **`within`**
- Composing type patterns:

```
FigureElement && !(Point ||
  Line)
```

- Including subtypes: **`Point+`**
- Array types: **`Point[]`**
- Wildcards: **`*`** and **`..`**

Wildcards in type patterns

- Type names consist of name components (packaging and nesting)

```
java.util.*          java.lang.*Error
java.*.List          java..List
java..*              java..Map.*
```

Only from subtypes

```
pointcut callToUndefinedMethod():
     call(* Point+.*(..)) &&
     !call(* Point.*(..));

pointcut executionOfUndefinedMethod():
  execution(* *(..)) &&
     within(Point+) &&
     !within(Point);
```

Excluding subtypes

```
pointcut callNotOnSubtype( Point p ):
      call(* *(..)) && target(p) &&
      if(p.getClass() == Point.class);
```

Method and constructor patterns

`execution(`*MethodPattern***`)`**
`execution(`*ConstructorPattern***`)`**

- Based on method/constuctor "signature"
  - modifiers
  - argument (and return) types
  - declared exceptions
  - "qualifying type"
  - (name)

Matching methods

```
call(   public final void C.foo()
          throws java.io.IOException   )

call(   !public !final * *.*(..)
          throws java.io.IOException   )

call(   * create*(..,int) throws
        (Exception && !SecurityException)
    )
```

Declaring type

```
class Service implements Runnable {
  public void run() { ... }
}

Runnable[] threads = new Runnable[10];
threads[0] = new Service();
threads[0].run();

call(void Service.run())
call(void run()) && target(Service)
```

Negation in throws clause

```
call(  * *(..) throws  !IOException   )

call(  * *(..) throws (!IOException)  )

void m() throws SQLException, IOException
```

Matching constructors

```
call(  Foo.new()  )

call(  Foo+.new()  )


call(  !public *Handler+.new(int,..)
          throws java.io.IOException  )
```

Reflective information about join points

- thisJoinPoint, thisJoinPointStaticPart, thisEnclosingJoinPointStaticPart
- Useful for tracing
- Useful for metaprogramming
- Information about
  - signatures, names, types
  - program locations

Reflective programming

```
private final HashMap constraints = new HashMap();        // java.util
{    constraints.put ( "x", new int[] {1,640} );
     constraints.put ( "y", new int[] {1,480} );   }

before (int n) :   set(int Point.*)   &&   args(n)   {
    String attr  =  thisJoinPointStaticPart.getSignature().getName();
    int[] bounds  =  (int[]) constraints.get( attr );
    if (  n < bounds[0]  ||  n > bounds[1]  )
       throw new IllegalArgumentException( attr + " is out of bounds.");
 }
```

Aspect instances

- Aspects cannot be instantiated with **`new`**
- By default: singleton

```
aspect Logging { ... }
aspect Logging issingleton() { ... }
```

- Per-object and Per-control-flow aspects

```
aspect A perthis(Pointcut)    { ... }
aspect B pertarget(Pointcut)  { ... }
aspect C percflow(Pointcut)   { ... }
aspect D percflowbelow(Pointcut) { ... }
```

Precedence

```
declare precedence : TypePatternList ;

declare precedence: *..*Security*,
                    Logging+,
                    *;
```

- Only for concrete aspects
- Order of advice in aspect
- Subaspects have higher precedence

Aspect as specialization

- Aspect can extend a class / interface / aspect
- Aspect can be abstract
- Aspect cannot be extended by class
- Inheritance hierarchy

Nested aspects

- Nested in class/interface/aspect
- Must be static
- No “virtuality”
- Cf. Ceasar

Exceptions

- Not allowed to add to the throws clause
  - Only **`RuntimeException`** can be added
- Advice throwing a checked exception

```
before() throws Exception :
execution(void Point.set*()) { ... }
```

  - If the original code can throw it...
- Soften an exception

```
declare soft: Exception:
   execution(void Point.set*());
```

  - Wrap it in the (unchecked) **`org.aspectj.lang.SoftException`**

Infinite loops

```
aspect A {
  before(): call(* *(..)) {
      System.out.println("before");
  }
}
```

- Or aspects applied to each other...
- Possibly not causing stack overflow

No stack trace, just hungs

```
aspect A {
  before(): call(* *(..)) {
      System.out.println("before");
  }

  after(): call(* *(..)) {
      System.out.println("after");
  }
}
```

StackOverflowException with stack trace

```
aspect A {
  before(): call(* *(..)) {
      System.out.println("before");
  }

  after() returning: call(* *(..)) {
      System.out.println("after");
  }
}
```

Remove the loop

```
aspect A {
  before(): call(* *(..)) && !within(A){
      System.out.println("before");
  }

  after(): call(* *(..)) && !within(A){
      System.out.println("after");
  }
}
```

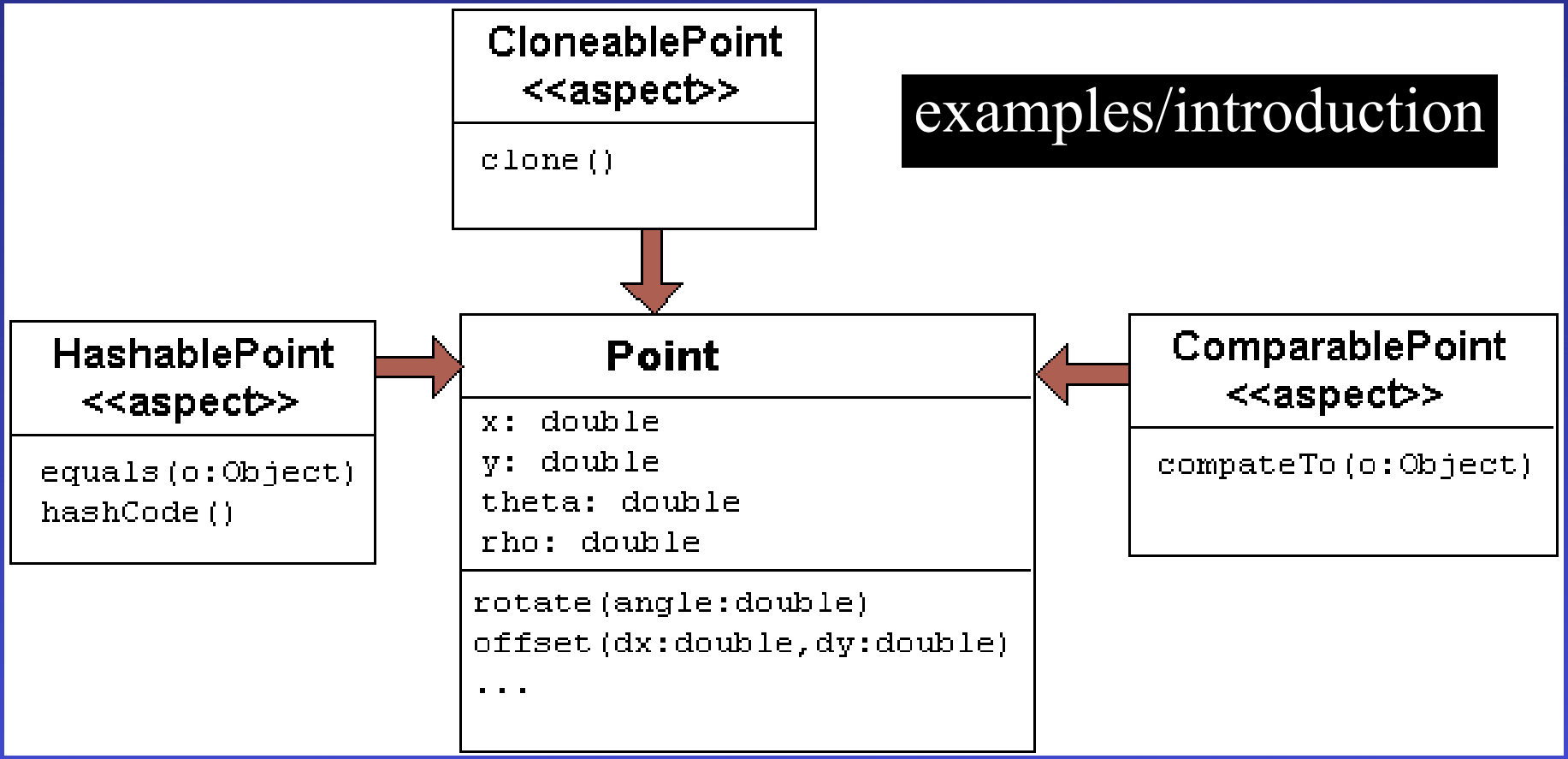
“Advice execution”

```
aspect A {

      before(): call(* *(..)) &&
                !cflow(adviceexecution())
      {
            System.out.println("before");
      }

}
```

Examples

- JavaBean with bound properties
- Roles with inter-type declarations
- Abstract aspects/pointcuts: tracing
- Reusable aspects: tracing revisited
- Subject/observer (and other design patterns)
- Telecom simulation
- Spacewar game
- EJB with BMP (a,b)

Inter-type declarations: roles



The AspectJ tools

- ajc compiler
- ajdoc documentation generator
- AspectJ browser
- Ant tasks

ajc

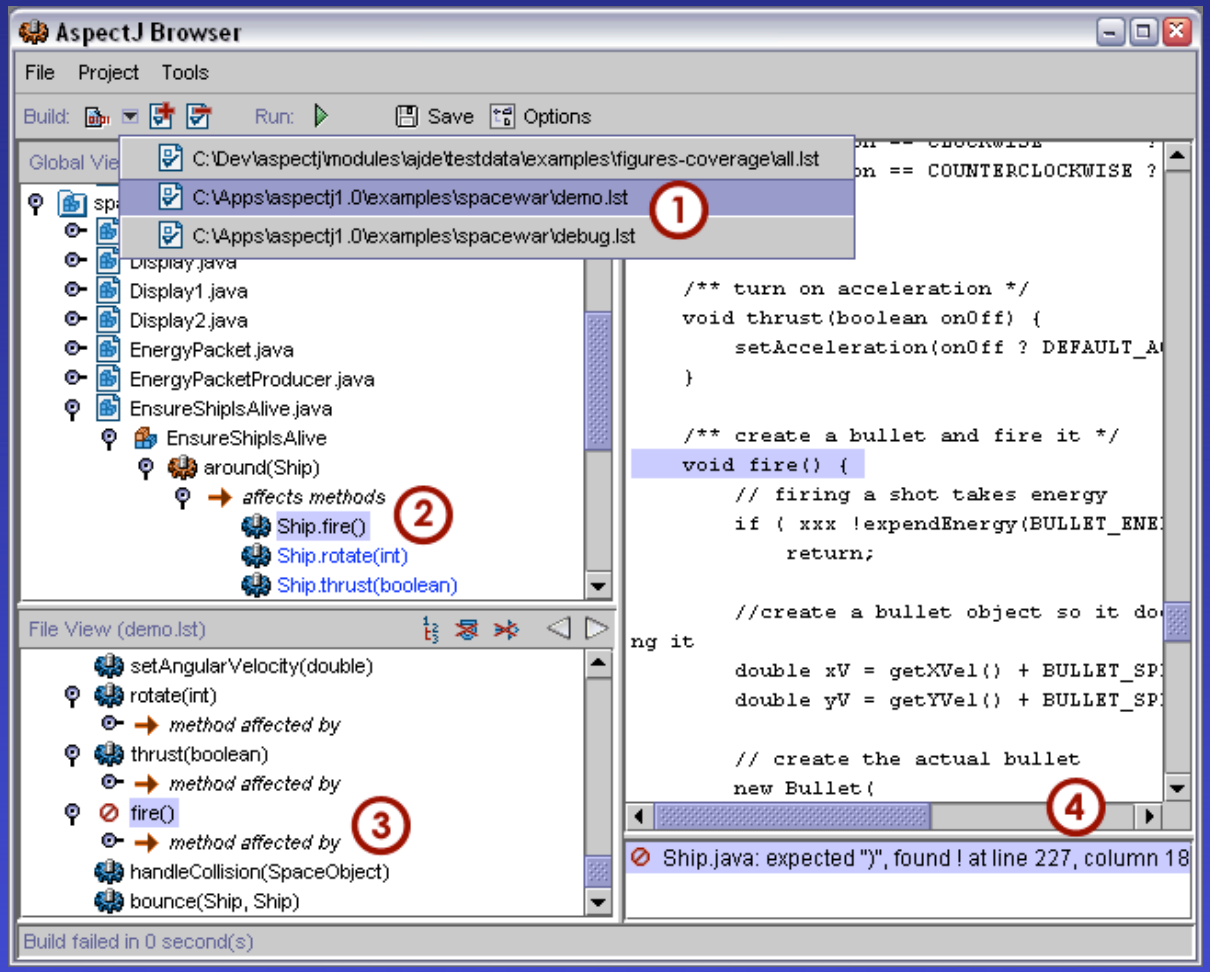
- Aspect weaver
- Compiles Java and AspectJ
  - for aspects: .java or .aj
- Produces efficient code
- Incremental compilation
- Accepts bytecode
  - e.g. in jars
  - both for java and aspect code
- Compiler API

ajdoc

- Similar to javadoc
- Generates HTML documentation
  - all pointcuts and advice
  - no inter-type declarations yet
- Links to affected methods
- Links to affecting advice

ajbrowser

- Editing,
- Compiling
- Weaving
- Navigating
- Running



Ant tasks

- Develop build scripts
- Use Jakarta Ant 1.5.1
- Too complicated for me...

Integrating AspectJ

- Eclipse (AJDT for 2.1, 3.0, 3.1)
- JBuilder (AJDE for 4-7, 9)
- NetBeans (for Forte 3+, NetBeans 3.3, 3.4, 3.5)
- JDeveloper (for 10.1.2 - 9.0.5.1)
- Emacs

- Vim???

AspectJ and Eclipse

- See [AJDT]
- Syntax highlight, AspectJ projects, Aspect Wizard
- Integrated ajc, ajdoc
- Navigation
  - Outline view
  - Visualizer perspective

Why AOP/AspectJ?

- Simple
- Small steps
- Matured concepts and tools
- Popular, well supported
  - Literature available
  - Foundations

Criticism of AspectJ

- More general approach?
- Why distinguish base code and aspects?
- More join points? (e.g. each instruction)
- More pointcuts?
- More support for reuse/composability? (aspectual polymorphism)
- More support on precedence?
- Advice based on history of prg. execution
- Simple programming model?
- Dynamic weaving and unweaving?

AOP language design

- Symmetry
- Joint point model
- Composition mechanism
- Quantification
- Encapsulation
- Type safety
- Obliviousness
- Domain specifity
- Reuse and parametrization
- Conflict resolution
- Legacy relationships
- Run-time aspect dynamics
- Analyzability
- Debugability
- Testability
- Software process
- Implementation
- Run-time environment

History of AspectJ

- XEROX Palo Alto Research Center
- Gregor Kiczales
- 1997

- Eclipse project: 2002

Other AOP solutions (1)

- Hyperspace [OT'99, Hyper] (Hyper/J [Hyper/J])
- Subject-Oriented Programming [SOP]
- Composition filters [CF]
  (Sina, Sina/st, CFIST, C++/CF, Compose*.NET, ComposeJ, ConcernJ, JCFF)
- Adaptive Programming [AP] (DJ)
- Collaboration Interfaces [MO'05] (Caesar)

Other AOP solutions (2) [FECA'05]

- Mixin layers (Java Layers)
- First-class namespaces (JPiccola)
- Reflection (MetaclassTalk)
- Program transformation (JMangler, JOIE)
- Object Infrastructure Framework (Pragma)
- Java Aspect Components

Composition Filters [CF]

- University of Twente, NL
- Filters modify messages sent and received
- Tied to OOP
- A set of filters may implement an aspect
  - concern, filtermodule, superimposition
- Also for delegation and dynamic inheritence
- Java, C++, .NET, Sina, Smalltalk

Adaptive Programming [AP]

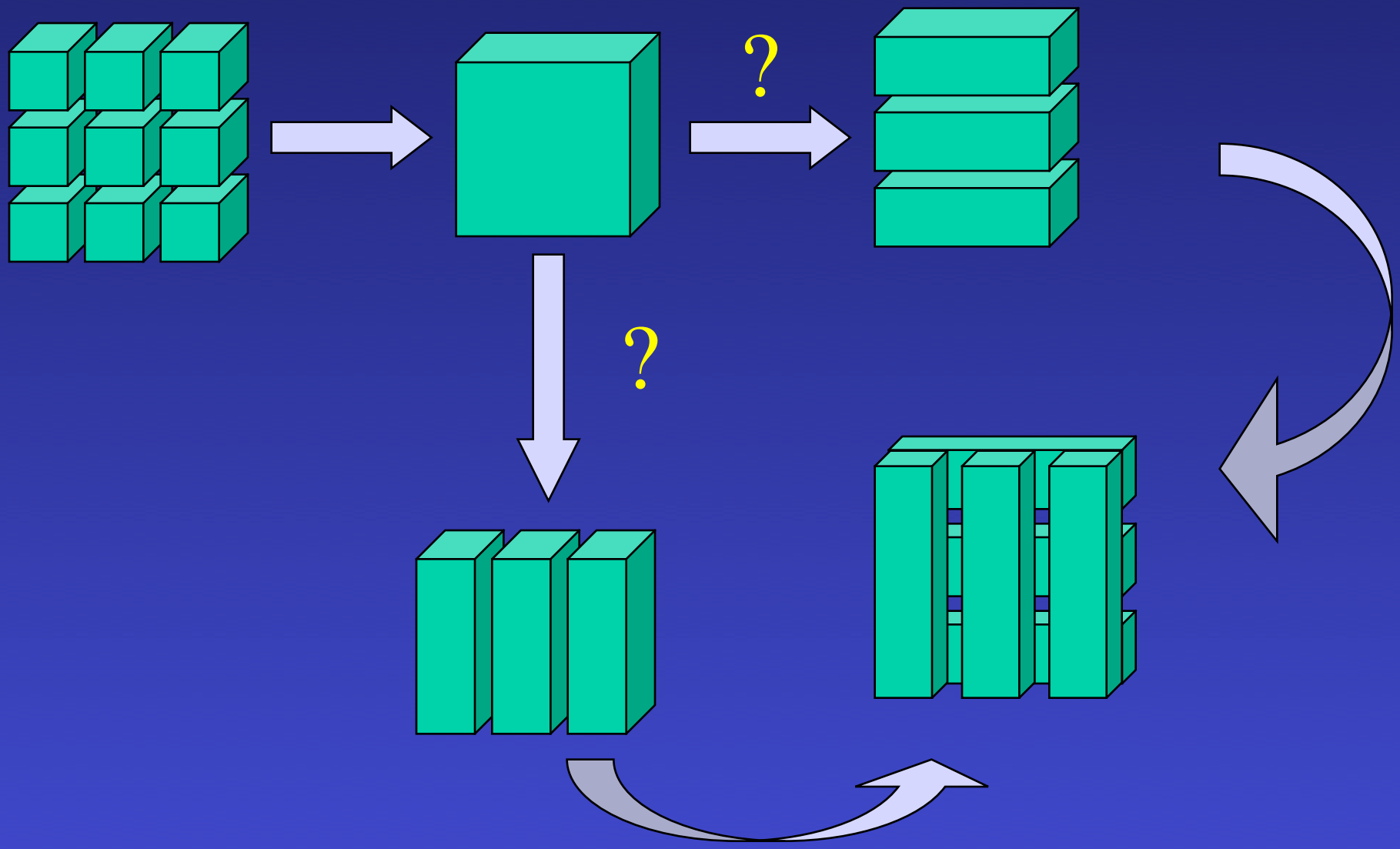
- Karl Lieberherr
- Northeastern University, Boston, U.S.A.
- Concern-shy programming
- Insensitive to small changes in interface
- Traversals over the object graph
- DJ, DAJ

Subject-Oriented Programming [SOP]

- IBM Research
- Based on OOP
- Subject: solve a subproblem
  - collection of classes and class fragments
- Compare to Point/Clonable/Comparable/...
- Roles, collaboration-based design
- Impl.: Extension to IBM Visual Age for C++

Multi-Dimensional Separation of Concerns [OT'99]

- IBM Research
- Symmetrical approach
- All artifacts of software development
- "Having divided to conquer, we must reunite to rule"
- Hyperspaces, Hyper/J [Hyper, Hyper/J]



Collaboration Interfaces [MO'05]

- Caesar
- Hierarchy in aspect structure
- More reusable
- Collaboration-based decomposition
- Aspect abstractions
- Aspectual polymorphism
- Virtual types
- Family polymorphism

And many more...

References

- Aspect-Oriented Software Development
- AspectJ
- Related technologies
- Own stuff

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