CS 6156
Program Instrumentation with AspectJ

Owolabi Legunsen

Fall 2020

Slides based in part on lectures by Klaus Havelund

Some logistics

- HW0 is due today (9/15) 11.59 AoE

- Readings for future classes and suggested leads have been released
    - Any questions, comments, or complaints?

- You should start thinking actively about projects
    - We'll discuss more in class on 9/17

What is instrumentation?

- “By program instrumentation here we mean the process of inserting additional statements into a program for information gathering purposes.”[1]
- “Program instrumentation is a way of learning about the effect individual tests have on a program.”[2]

[1] J.C. Huang, Detection of Data Flow Anomaly Through Program Instrumentation, TSE 1979
[2] E. F. Miller, Program Testing, IEEE Computer 1978

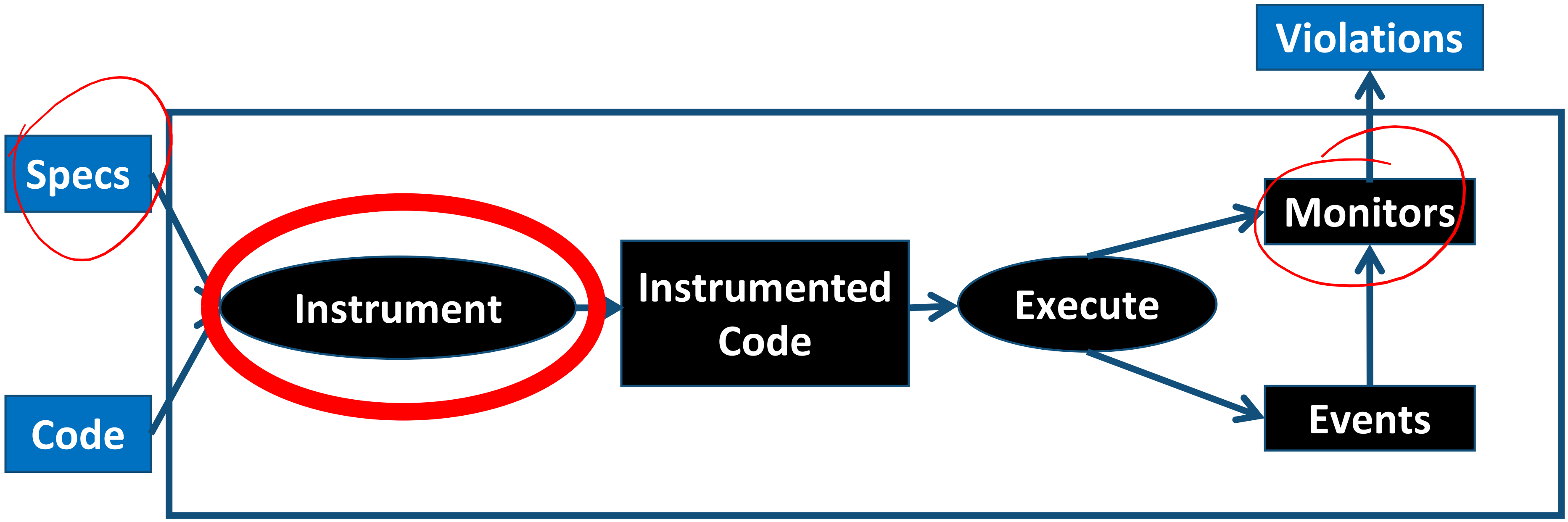
Instrumentation in practice

- How do debuggers know what code to step through?

- How does your code coverage tool know what statements, blocks, methods, etc., are covered?

- Did you ever write “printf” statements to know what (parts of) your code does?

Recall: what you'll learn in CS 6156



- How to instrument code to obtain runtime events?
- Compile-time vs. runtime instrumentation
- Problems and challenges of instrumentation

Some instrumentation frameworks

- ASM
- Javassist
- BCEL
- AspecJ, AspectC, AspectWerkz, etc.
- JVMTI
- JMX
- Spring AOP
- …

Why AspectJ?

- RV requires instrumentation and specification

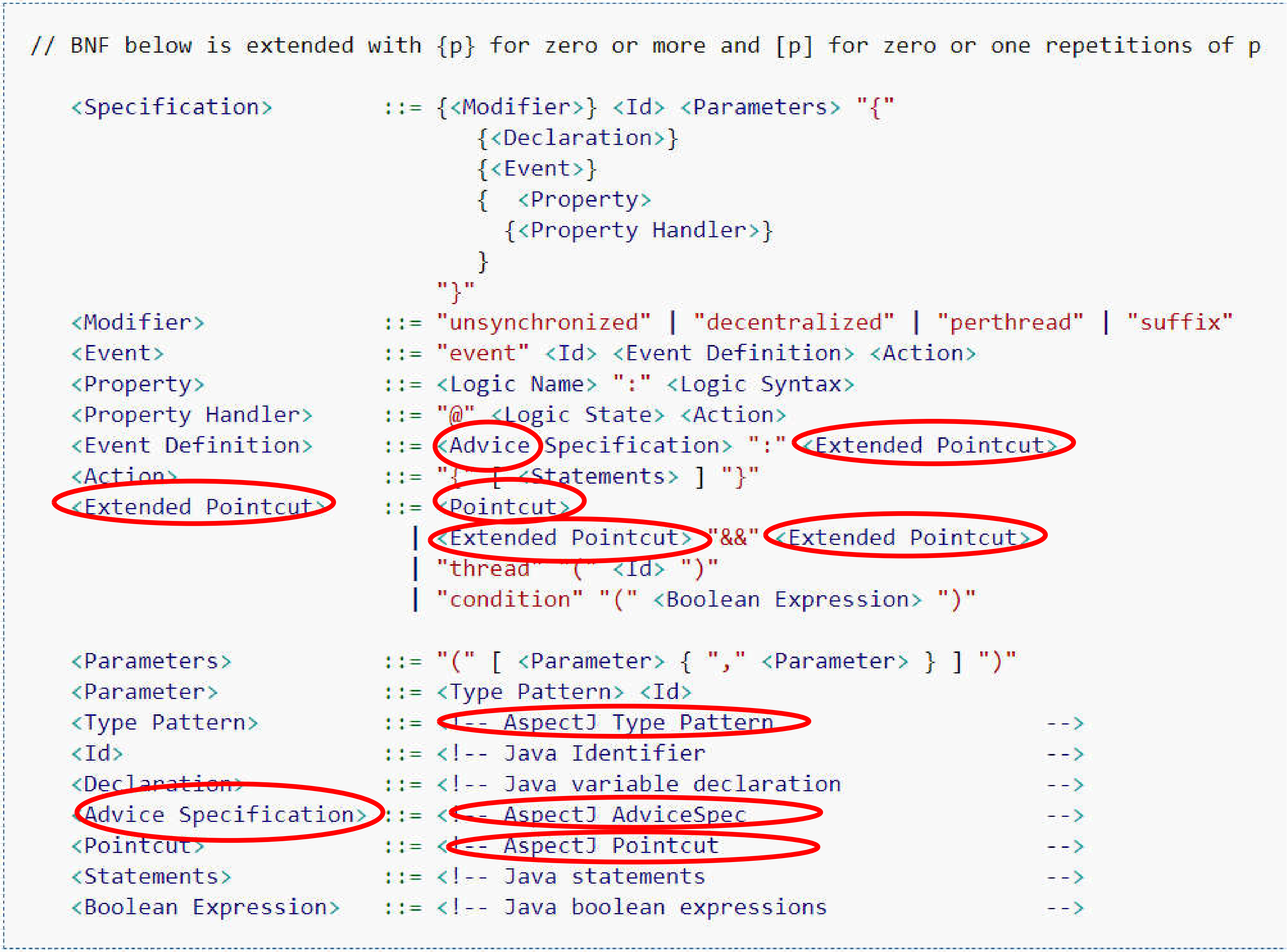
- AspectJ can provide both elements[3]

- AspectJ is probably the most popular aspect-oriented programming (AOP) framework

[3] Bodden et al., Collaborative Runtime Verification with Tracematches, RV 2007

http://fsl.cs.illinois.edu/index.php/JavaMOP_Syntax

JavaMOP syntax extends AspectJ



```
// BNF below is extended with {p} for zero or more and [p] for zero or one repetitions of p

   <Specification>        ::= {<Modifier>} <Id> <Parameters> "{"
                                 {<Declaration>}
                                 {<Event>}
                                 {  <Property>
                                   {<Property Handler>}
                                 }
                              "}"
   <Modifier>             ::= "unsynchronized" | "decentralized" | "perthread" | "suffix"
   <Event>                ::= "event" <Id> <Event Definition> <Action>
   <Property>             ::= <Logic Name> ":" <Logic Syntax>
   <Property Handler>     ::= "@" <Logic State> <Action>
   <Event Definition>     ::= <Advice Specification> ":" <Extended Pointcut>
   <Action>               ::= "{" [ <Statements> ] "}"
   <Extended Pointcut>    ::= <Pointcut>
                            | <Extended Pointcut> "&&" <Extended Pointcut>
                            | "thread" "(" <Id> ")"
                            | "condition" "(" <Boolean Expression> ")"

   <Parameters>           ::= "(" [ <Parameter> { "," <Parameter> } ] ")"
   <Parameter>            ::= <Type Pattern> <Id>
   <Type Pattern>         ::= <!-- AspectJ Type Pattern                -->
   <Id>                   ::= <!-- Java Identifier                     -->
   <Declaration>          ::= <!-- Java variable declaration           -->
   <Advice Specification> ::= <!-- AspectJ AdviceSpec                  -->
   <Pointcut>             ::= <!-- AspectJ Pointcut                    -->
   <Statements>           ::= <!-- Java statements                     -->
   <Boolean Expression>   ::= <!-- Java boolean expressions            -->
```

AspectJ implements AOP

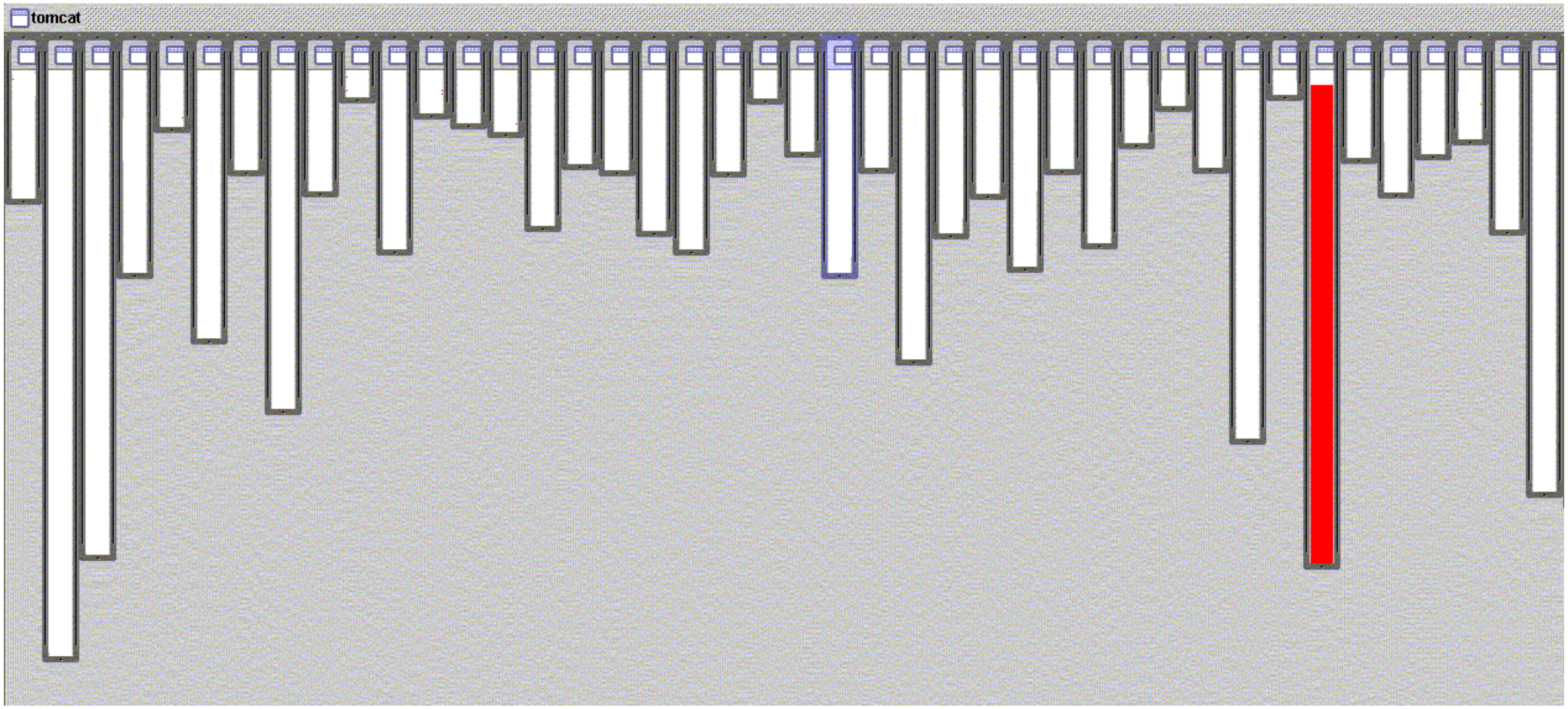
- AOP modularizes programs differently than OOP

- Separates out cross-cutting concerns: code for one *aspect* of the program is collected in one place

- We will not delve into AOP as a paradigm
  - But we briefly explain the more general purpose of AOP
  - Focus: enough AspectJ to understand/write JavaMOP specs

XML parsing

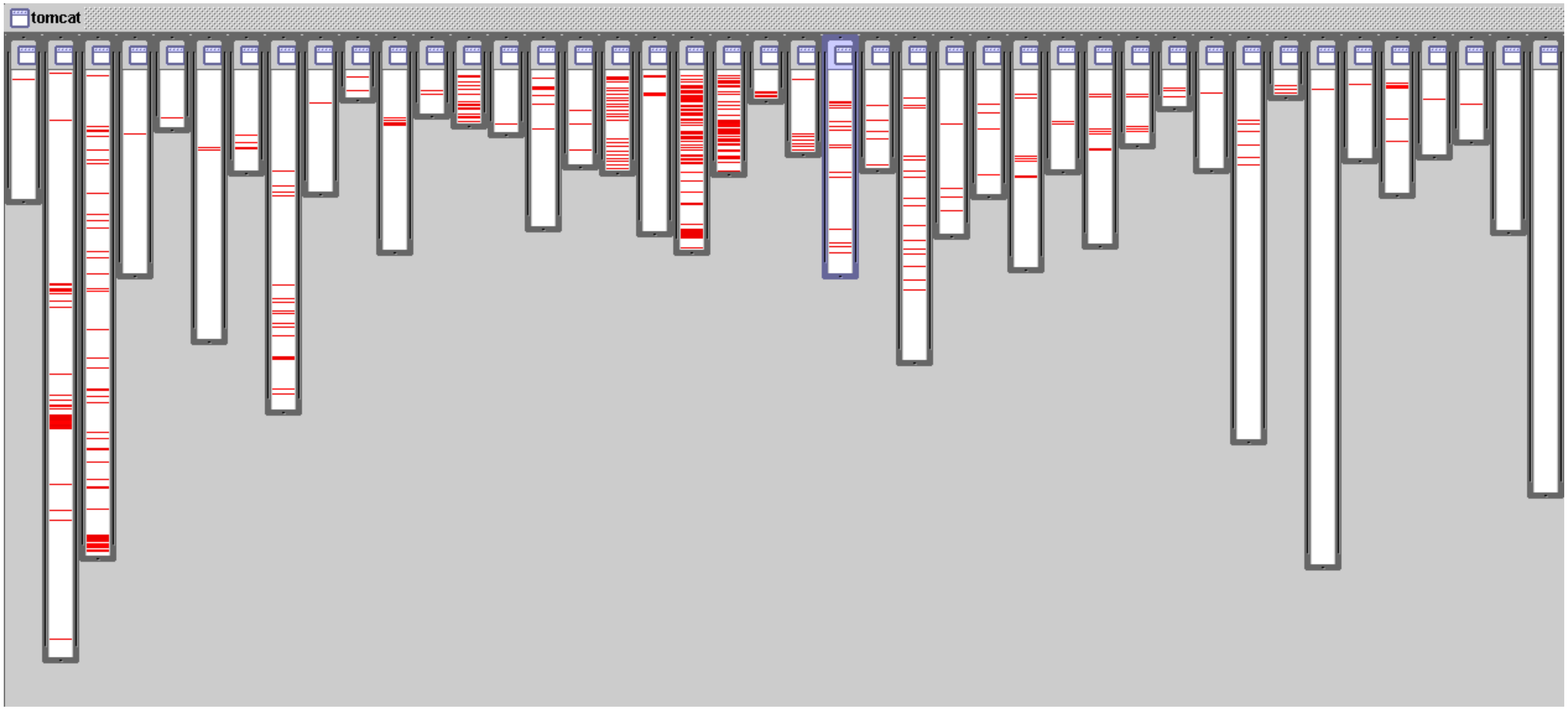
Good modularity



- XML parsing in org.apache.tomcat circa 2009(?)
  - red shows relevant lines of code
  - nicely fits in one box (object)

logging

Bad modularity



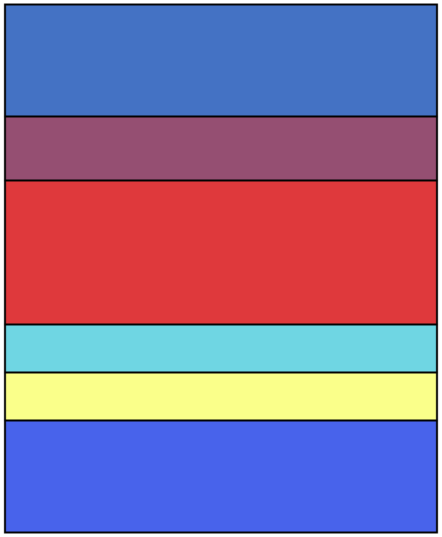
- Where is logging in org.apache.tomcat?
  - red shows lines of code that handle logging
  - not in just one place
  - not even in a small number of places

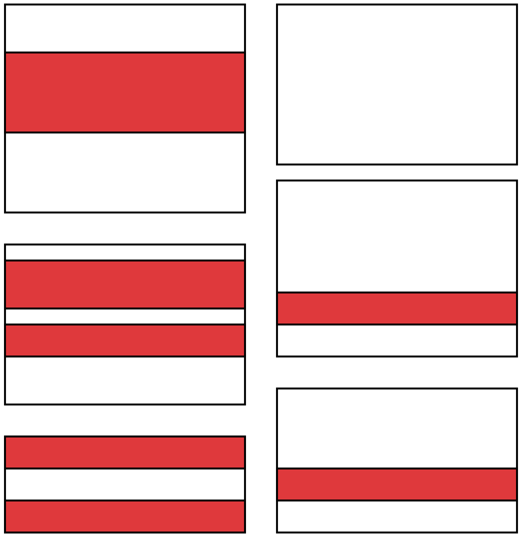
Two problems AOP tries to solve

code tangling:
one module
many concerns

example:
logging

code scattering:
one concern
many modules





Discuss: what are the effects of tangling and scattering?

refactoring is more difficult

more difficult to understand

leads to importing more than needed

increases the impact of changes

The effects of the two problems

- Core logic becomes harder to comprehend when it is tangled with other code

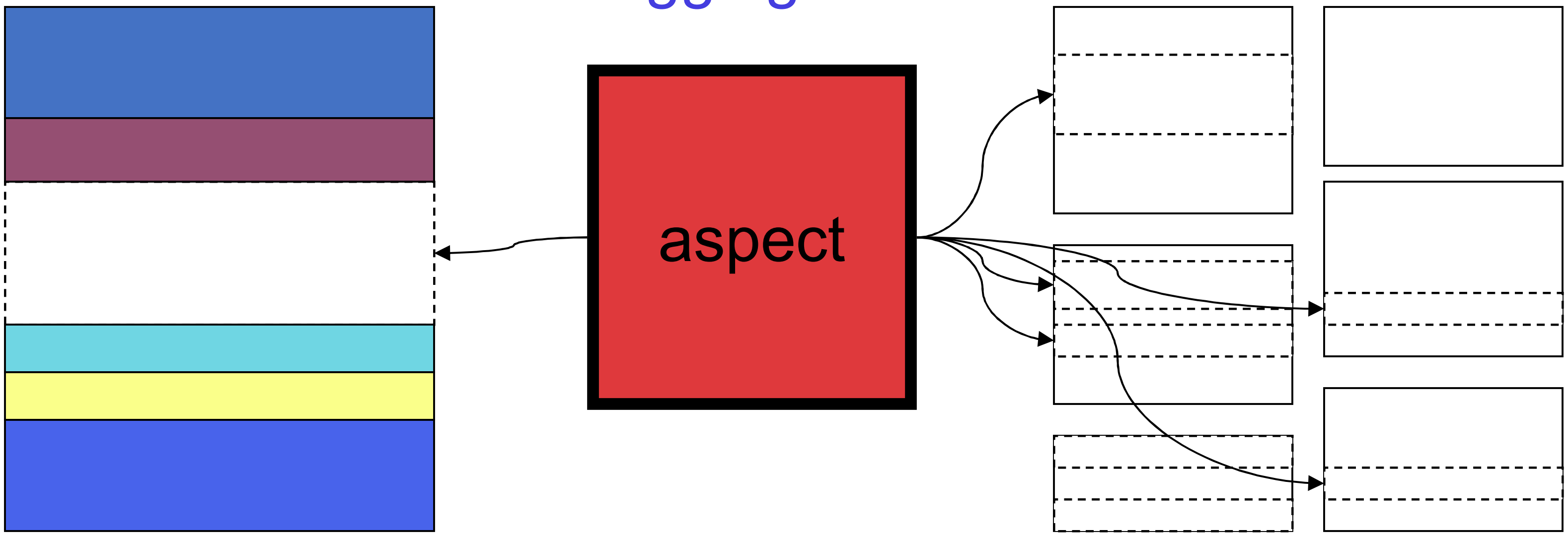
- Scattering similar logic in the code base results in
  - lots of typing, difficult to change code
  - missing the big picture (in one place)
  - increased probability of consistency errors

How AOP solves the two problems

code tangling:
one module
many concerns

code scattering:
one concern
many modules

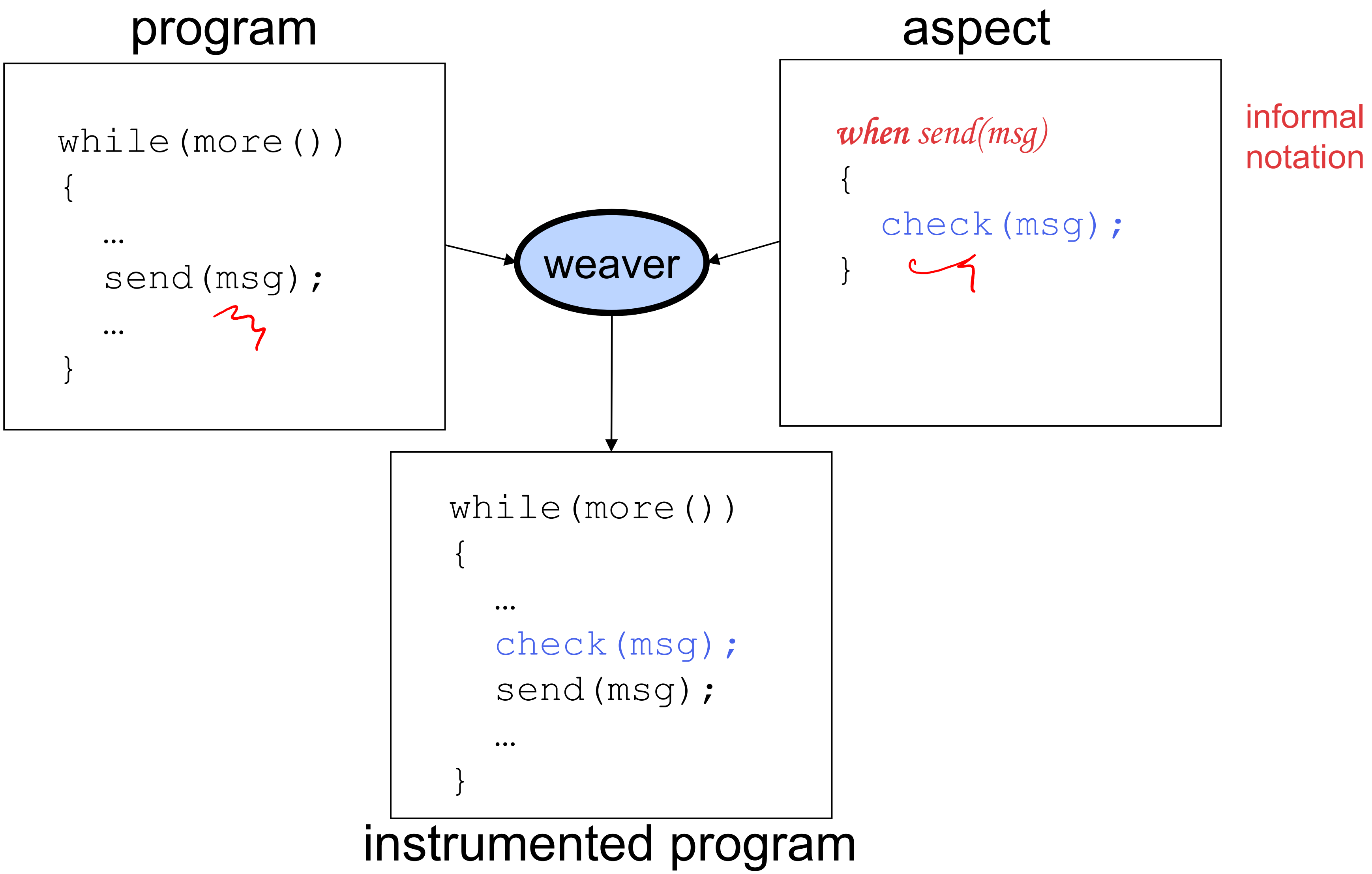
example:
logging



Cross-cutting concerns are common

- logging (tracking program behavior)
- verification (checking program behavior)
- policy enforcement (correcting behavior)
- security management (preventing attacks)
- profiling (exploring where programs spend time)
- memory management
- visualization of program executions
- …

A very simplified view of AOP



program

```
while(more())
{
   …
   send(msg);
   …
}
```

aspect

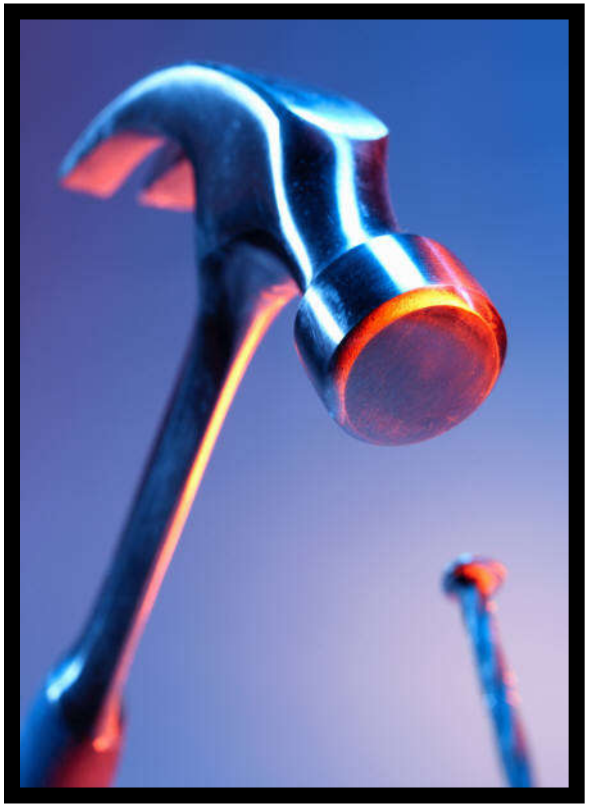
```
when send(msg)
{
   check(msg);
}
```

informal notation

```
while(more())
{
   …
   check(msg);
   send(msg);
   …
}
```

instrumented program

That’s it



except for notation, all the details, usage, …

Basic mechanisms

- Join points
  - points in a Java program
- Three main additions to Java
  - **Pointcut:** picks out join points and values at those points (primitive and user-defined pointcuts)
  - **Advice:** additional action to take at join points matching a pointcut
  - **Aspect:** a modular unit of crosscutting behavior (normal Java declarations, pointcut definitions, advice)

AspectJ terminology

Joinpoint = well-defined point in the program

Pointcut = Joinpoint-set

Advice = Kind × Pointcut × Code
    where Kind = {before, after, around}

Aspect = Advice-list

Example code

```
class Account {
  int balance;

  void deposit(int amount) {
    balance = balance + amount;
  }

  boolean withdraw(int amount) {
    if (balance - amount > 0) {
      balance = balance - amount;
      return true;
    } else return false;
  }
}
```

Logger class

```
class Logger {
  private PrintStream stream;

  Logger() {
    ... create stream
  }

  void log(String message) {
    stream.println(message);
  }
}
```

Logging without AOP

logging

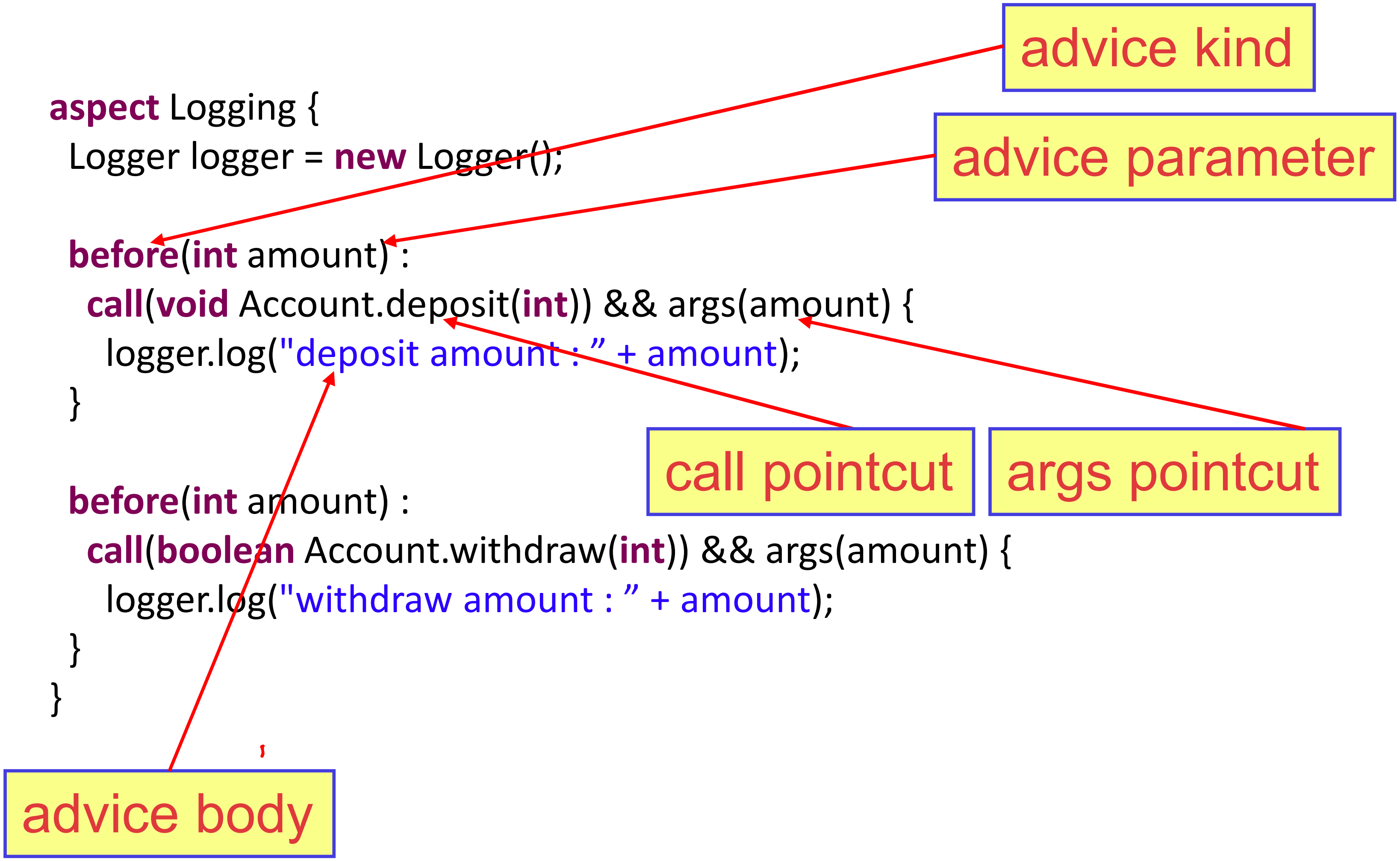
```
class Account {
  int balance;
  Logger logger = new Logger();

  void deposit(int amount) {
    logger.log("deposit amount: " + amount);
    balance = balance + amount;
  }

  boolean withdraw(int amount) {
    logger.log("withdraw amount: " + amount);
    if (balance - amount >= 0) {
      balance = balance – amount;
      return true;
    } else return false;
  }
}
```

Logging with AOP

```
aspect Logging {
  Logger logger = new Logger();

  when deposit(amount){
    logger.log("deposit amount : " + amount);
  }

  when withdraw(amount){
    logger.log("withdraw amount : ” + amount);
  }
}
```

Logging code is in exactly one place

Logging in AspectJ



```
aspect Logging {
 Logger logger = new Logger();

 before(int amount) :
  call(void Account.deposit(int)) && args(amount) {
   logger.log("deposit amount : ” + amount);
 }

 before(int amount) :
  call(boolean Account.withdraw(int)) && args(amount) {
   logger.log("withdraw amount : ” + amount);
 }
}
```

advice kind

advice parameter

call pointcut

args pointcut

advice body

Primitive pointcuts

- A pointcut is a predicate on join points that:
  - can match or not match any given join point
  - can extract some values at matching join points

Example:

```
call(void Account.deposit(int))
```

matches any join point that is a call of a method with this signature

Explaining advice parameters

- Variables are bound by advice declaration
- Pointcuts supply values for variable
- Values are available in the advice body

typed variable in place
of type name

advice parameter

```
before(int amount) :
   call(void Account.deposit(int)) && args(amount) {
     logger.log("deposit amount : ” + amount);
  }
```

Advice parameter data flow

- Value is ‘pulled’
  - right to left across ‘:’ from pointcuts to advice
  - and then to advice body

```
before(int amount) :
    call(void Account.deposit(int)) && args(amount) {
     logger.log("deposit amount : ” + amount);
  }
```

Pointcut naming and patterns

named pointcut

```
aspect Balance {

  pointcut accountChange(Account account) :
    (call(* deposit(..)) || call(* withdraw(..)))
    && target(account);

  after(Account account) : accountChange(account) {
    System.out.println("balance = " + account.balance);
  }

}
```

pointcut patterns

target pointcut

“after” advice

Privileged aspects

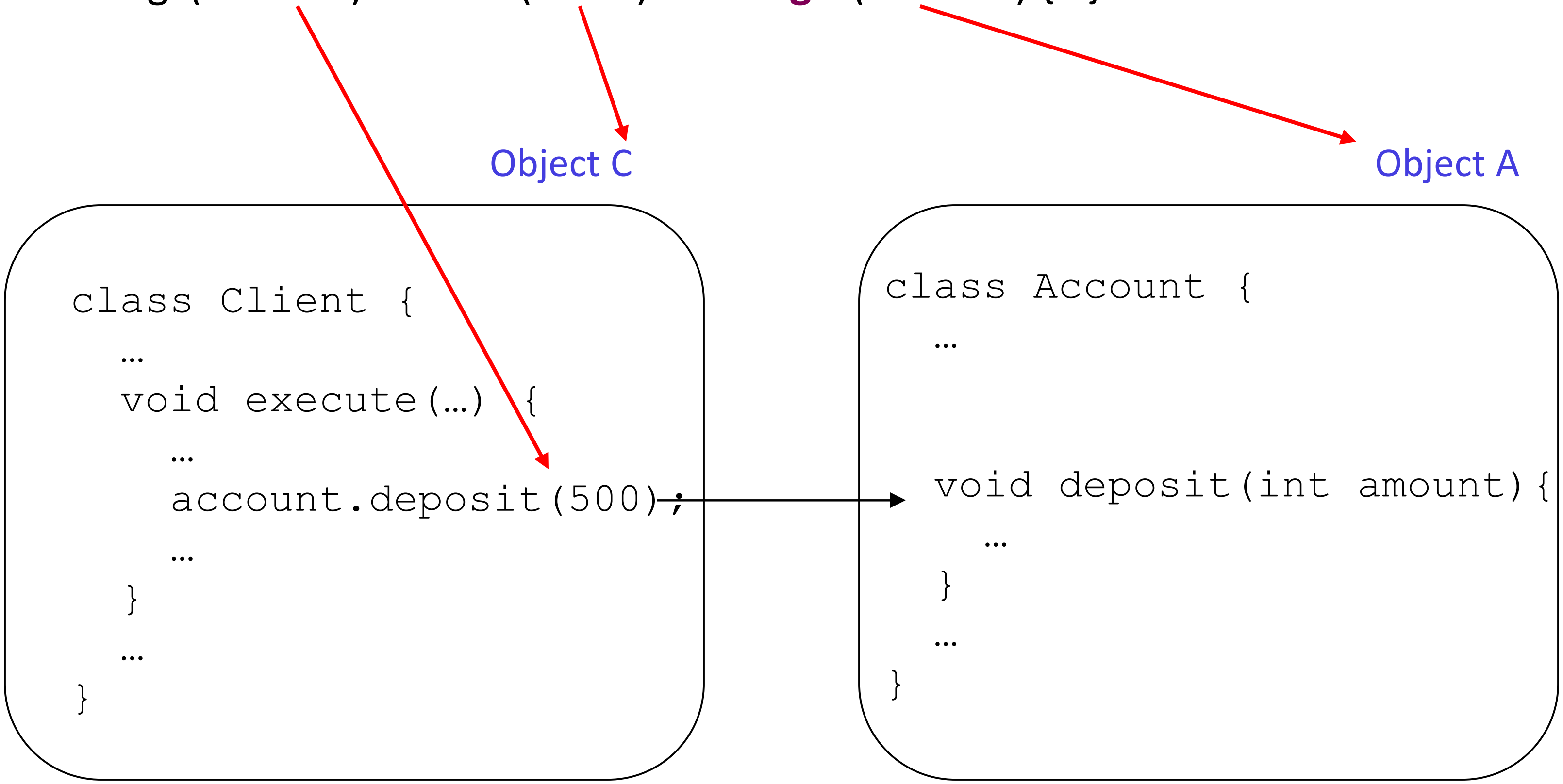
- Aspects that can access private fields and methods

```
privileged aspect Balance {

  pointcut accountChange(Account account) :
    (call(* deposit(..)) || call(* withdraw(..)))
    && target(account);

  after(Account account) : accountChange(account) {
    System.out.println("balance = " + account.balance);
  }
}
```

suppose account.balance is a private variable. Then the aspect must be privileged.

args, this and target pointcuts

```
before(Client client, Account account, int amount) :
   call(void Account.deposit(int))
   && args(amount) && this(client) && target(account) {…}
```



Object C

```
class Client {
  …
  void execute(…) {
    …
    account.deposit(500);
    …
  }
  …
}
```

Object A

```
class Account {
  …


  void deposit(int amount){
    …
  }
  …
}
```

target pointcut

target(*TypeName* | *VariableName*)

Does two things:

- predicate on join points - any join point at which target object is an instance of *TypeName* or of same type as *VariableName*.
- exposes target if argument is a variable name

target(Account) :

- matches when target object is of type Account

`Account` is a type

target(account) :

- matches too, since account is of type Account
- in addition, it binds the target object to account

`account` is a variable

Parameter data flow again

- Value is ‘pulled’
  - right to left from pointcuts to user-defined pointcuts
  - from pointcuts to advice
  - and then to advice body

```
pointcut accountChange(Account account) :
   (call(* deposit(..)) || call(* withdraw(..)))  && target(account);

 after(Account account) : accountChange(account) {
   System.out.println("balance = " + account.balance);
 }
```

The proceed “method”

- **For each around advice with the signature:**

  ***T* around(*T1* arg1, *T2* arg2, …)**

- **There is a special method with the signature:**

  ***T* proceed(*T1*, *T2*, …)**

- **Calling “proceed” means:**

  “run what would have been run if this around advice had not been defined”

Reflexive information available at all joinpoints

- thisJoinPoint
  - getArgs() : Object[]
  - getTarget() : Object
  - getThis() : Object
  - getStaticPart() : JoinPointStaticPart
- thisJoinPointStaticPart
  - getKind() : String
  - getSignature() : Signature
  - getSourceLocation() : SourceLocation

Fun activity: implement a code coverage tool in AspectJ

Examples of patterns

Type names:

Command

*Command

java.*.Date

Java..*

Javax..*Model+

Combined Types:

!Vector

Vector || HashTable

java.util.RandomAccess+ && java.util.List+

ArrayList

Method Signatures:

public void Account.set*(*)

boolean Account.withdraw(int)

bo* Po*.wi*w(i*)

!static * *.*(..)

rover..command.Command+.check(int,..)

Challenges in instrumentation

- Cost: instrumentation can slow programs down
- Heisenbugs[4]: slowing program execution can introduce hard-to-debug timing-related bugs
- Can produce hard to read (binary) code
- Instrumentation tools can conflict

[4] Recall “Heisenberg’s” uncertainty principle in physics

Relating to Reading-3

- Can you think of properties whose specs require the proposed features?

- What are advantages and disadvantages of instrumenting lower-granularity program constructs?

Your questions from reading-3

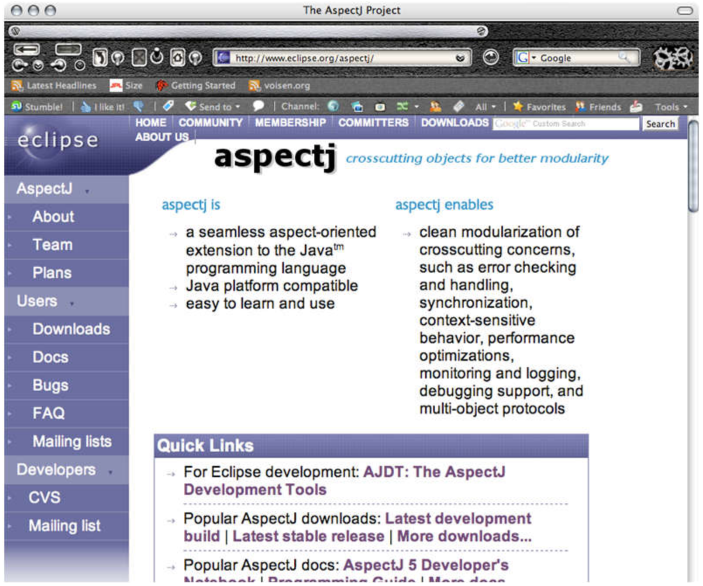
- How are monitors "weaved into" the source code?
- What’s the difference between AOP and MOP?
- Why does instrumentation slow programs down?
- Why was basic-block based weaving not used before?
- What is sampling-based instrumentation?

Food for thought (take home)

Is AspectJ/AOP the best way to instrument code for RV?

AspectJ Resources

- http://www.eclipse.org/aspectj



aspectj *crosscutting objects for better modularity*

aspectj is

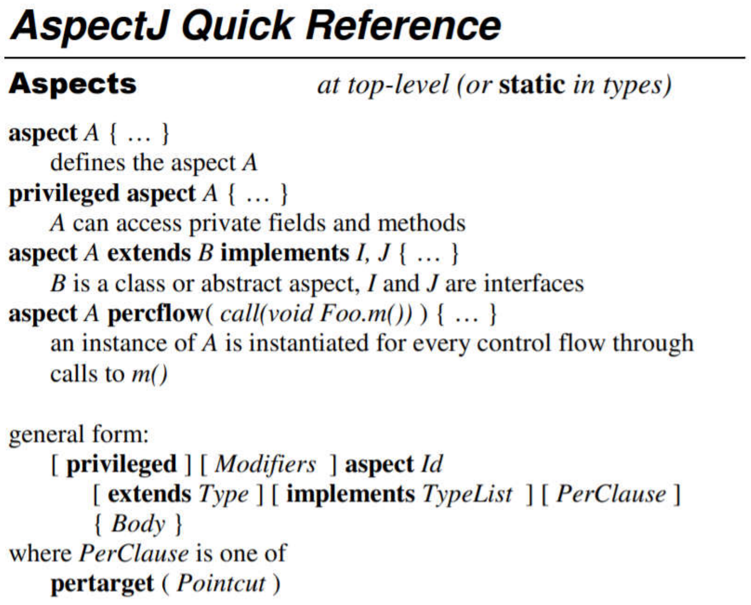
- a seamless aspect-oriented extension to the Java™ programming language
- Java platform compatible
- easy to learn and use

aspectj enables

- clean modularization of crosscutting concerns, such as error checking and handling, synchronization, context-sensitive behavior, performance optimizations, monitoring and logging, debugging support, and multi-object protocols

Quick Links

- For Eclipse development: **AJDT: The AspectJ Development Tools**
- Popular AspectJ downloads: **Latest development build** | **Latest stable release** | **More downloads...**
- Popular AspectJ docs: **AspectJ 5 Developer's Notebook** | **Programming Guide** | **More docs**



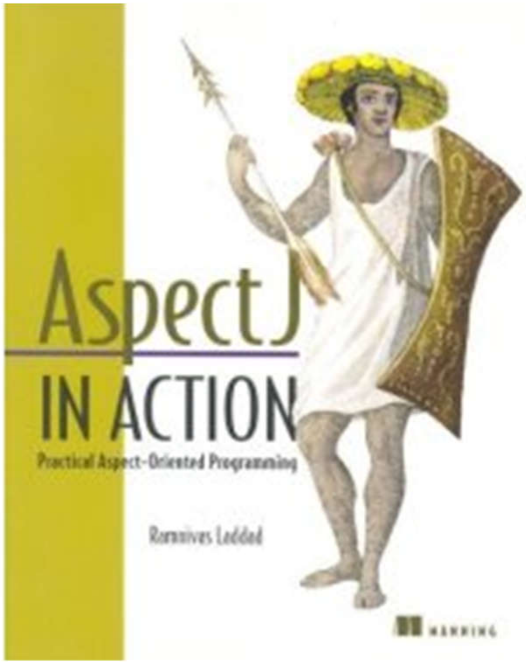
AspectJ Quick Reference

Aspects *at top-level (or* **static** *in types)*

aspect *A* { … }
  defines the aspect *A*
privileged aspect *A* { … }
  A can access private fields and methods
aspect *A* **extends** *B* **implements** *I*, *J* { … }
  B is a class or abstract aspect, *I* and *J* are interfaces
aspect *A* **percflow**(*call(void Foo.m())*) { … }
  an instance of *A* is instantiated for every control flow through calls to *m()*

general form:
  [**privileged**] [*Modifiers*] **aspect** *Id*
    [**extends** *Type*] [**implements** *TypeList*] [*PerClause*]
    { *Body* }
where *PerClause* is one of
  pertarget (*Pointcut*)

ICAOSDDP 2020: 14. International Conference on Aspect-Oriented Software Development, Design and Programming
September 24-25, 2020 in London, United Kingdom



Next class…

- Discuss project ideas, timeline, meetings, teams, etc.
- Answer more questions from readings 1-4
- (Maybe) start a preface to monitor synthesis

Reading for next class is assigned

- Goals
  - How to read software engineering papers
  - See some problems RV still needs to solve to become widely adopted

What we covered in this class

- Instrumentation is important in many software engineering tasks, including RV
- We learned the basics of one instrumentation tool
- An introduction to aspect-oriented programming
- Hands-on exposure to AspectJ