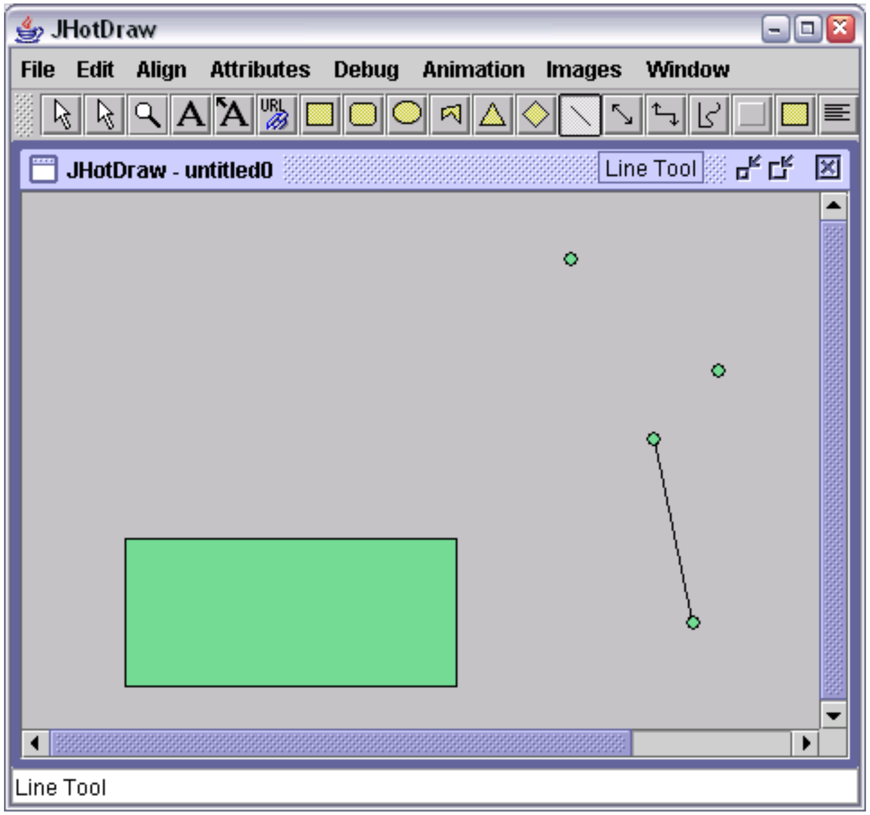
Continuation Models for AOP

Christopher Dutchyn

University of Saskatchewan

Software Research Lab

How Might We Program Display Updating?




```
class Point extends Shape {
  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; }
}
```

```
class Line extends Shape {
  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; }
}
```

Object-Oriented Solution

- Separate declaration of behaviour for operations
  - setX
  - setY
  - setP1
  - setP2
- Each operation does its own thing
- Each operation
  - updates display in a way
  - consistent with others

```
class Point extends Shape {
  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(); }
}
```

```
class Line extends Shape {
  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(); }
}
```

Same Behaviour … Different Modularity

```
aspect DisplayUpdating {
  pointcut change():
     execution(void Shape+.set*(*));

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

```
class Point extends Shape {
  p
  i
  i
  v
  v
}
```

```
class Line extends Shape {
  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; }
}
```

- Aspect declares
  - Some points in execution represent a display state change
    - execution of methods matching this pattern
  - After a change occurs
    - update the display

Simple Comparison

AO Solution

- Display updating is modularized into a single location
- Behaviour of
  - each shape is manifest in single module
  - display updating is manifest in single module
- Interaction between display updating and shape movement is explicit

OO Solution

- Display updating is
  - *scattered* across multiple data modules
  - *tangled* with the code in those modules
- Behaviour of each shape and *associated* display updating is manifest in single module
- Interaction between display updating and *each* shape's movement is explicit

AOP Provides a New Kind of Modularity

```
class Point extends Shape {
  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; }
}
```

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

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

  void setP1(Point p1) { this.p1 = p1; }
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}
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aspect DisplayUpdating {
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class Point extends Shape {
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}
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class Line extends Shape {
  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; }
}
```

Join point

```
aspect DisplayUpdating {
  pointcut change():
    execution(void Shape+.set*(*));

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

Advice

AOP Provides a New Kind of Modularity

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

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

```
class Line extends Shape {
  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; }
}
```

Join point

Pointcut

```
aspect DisplayUpdating {
  pointcut change():
    execution(void Shape+.set*(*));

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

Advice

AOP Provides a New Kind of Modularity

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

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

```
class Line extends Shape {
  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; }
}
```

Join point

Pointcut

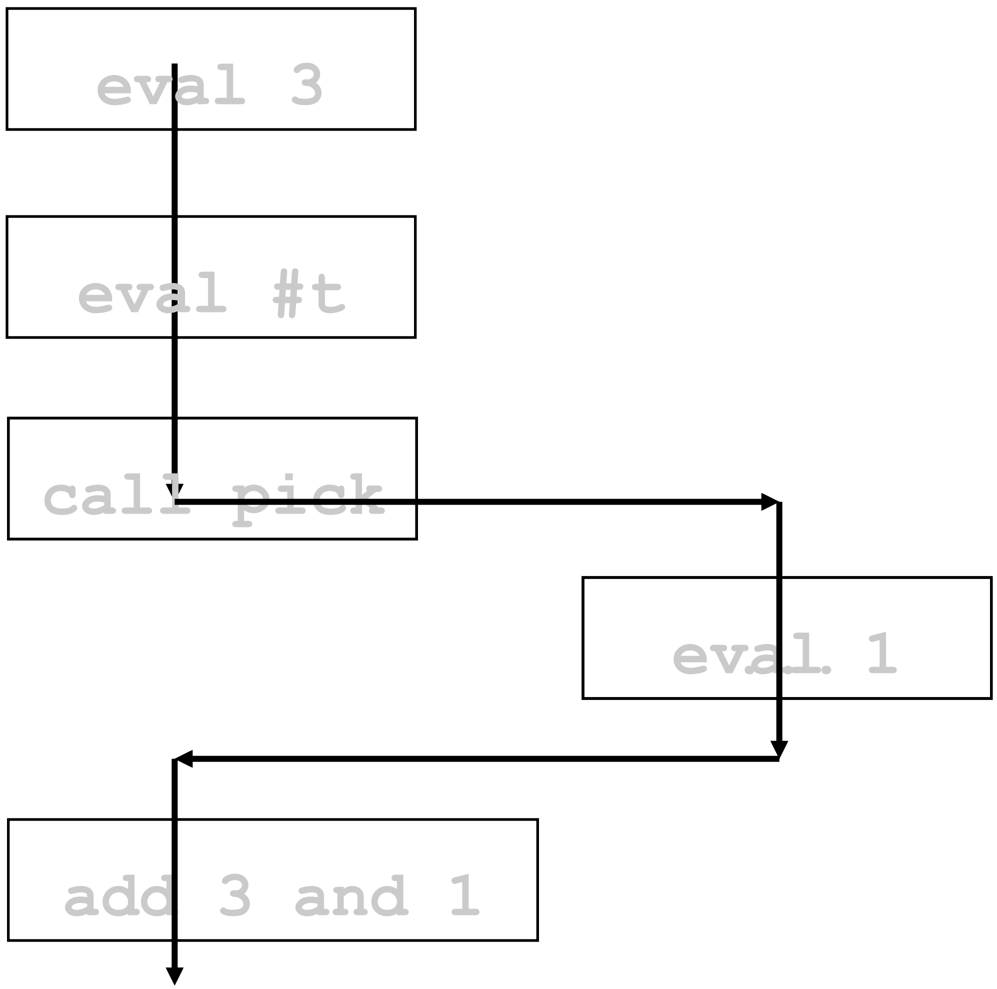
```
aspect DisplayUpdating {
  pointcut change():
     execution(void Shape+.set*(*));

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

Advice

Join Points, Pointcuts, and Advice

An Intellectual Model of AOP

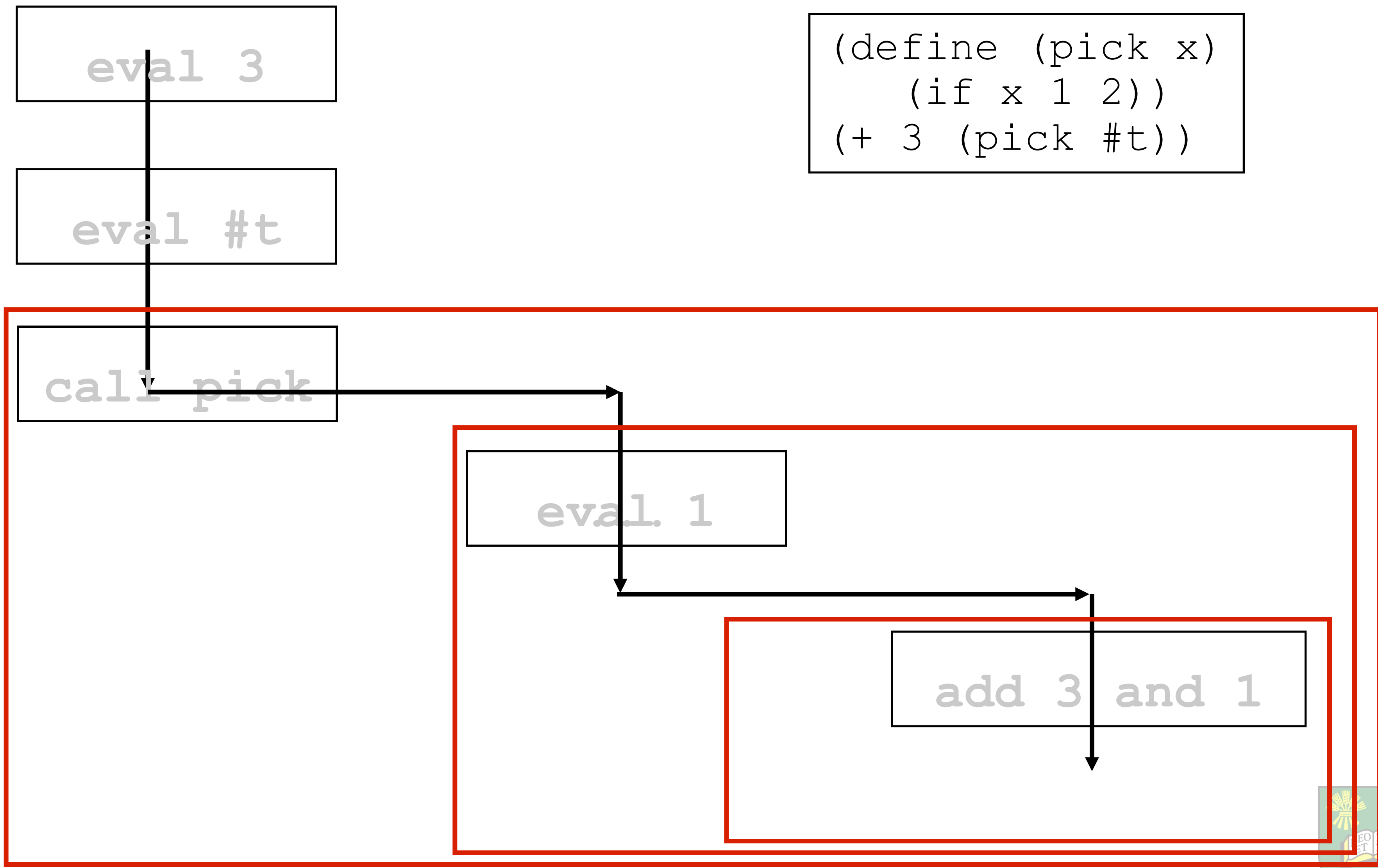
Without Continuations




```
(define (pick x)
   (if x 1 2))
(+ 3 (pick #t))
```

Without Continuations

```
(define (pick x)
   (if x 1 2))
(+ 3 (pick #t))
```



Continuations

[Strachey+ ’74; Reynolds ’74; Meyers ’85; …]

- Continuations reify control state
  - Escape semantics ⇒ not composable

```
(define (pick x) (if x 1 2))
(+ 3 (pick #t))
```

evaluation of operands has continuation

```
(evlis (pick #t) ρ (λ(f b) (eval (body f)
                      (extend (env f) (id f) b)
                      (λ(i) (+ 3 i))))
```

Sub-Continuations *[Felleisen '88; Hieb+ '94; Shan '02; Agere+'05; …]*

- Structure within continuations
  - composable

(define (pick x) (if x 1 2))
(+ 3 (pick #t))

evaluation of operands has continuation

execution sub-continuation

(evlis (pick #*t*) ρ (push 〈*exec-proc*〉 κ)

…

⇒ (<CLO> #t) ↦ (λ(f b) (eval (body f)
(extend (env fun) (id fun) b)
κ))

…

⇒ 1 ↦ (λ(i) (+ 3 i))))

⇒ 4

Join Points Modeled by Sub-Continuations

- "Principled points in execution"
  - join points correspond to sub-continuations
  - call join point ≡ dispatch sub-continuation

```
(send aPoint setX 7)

(evlis (aPoint,7) ρ (push ⟨dispatch setX⟩  κ))
   ...
 ⇒ ( ⟨obj⟩ ,7)    ↦  (λ(o v) (apply (dispatch o setX)
                  (push ⟨exec-method o v⟩  κ))
   ⇒   ⟨METH⟩       ↦  (λ(m) (apply-method m o v κ)))

   ⇒ (eval (body m) [this→o (ids m)→v] κ)
 ...
   ⇒  ?                ↦  k
```

  - execution join point ≡ exec-method sub-continuation
  - field get/set join points …

Procedures Transform Continuations *[Filinski '89; Griffin '91; Murthi '92]*

- Procedures have two different modes of application:
  - Applied to a value: they yield another value
  - Applied to a continuation: they yield another continuation

(define (pick x) (if x 1 2))

(+ 3 (pick #t))

Transforms value

Transforms continuation

(+ 3 1)

Takes **(λ(i) (+ 3 i))**

to **(λ(b) ((λ(i) (+ 3 i))**
(if b 1 2)))

Takes **#t** to **1**

pick :: Bool → Int

pick :: ¬Int → ¬Bool

Advice Modeled as Sub-Cont Transformers

- Advice body extends sub-continuation behaviour

```
(pointcut change (execution (Point setX)))

(around change (λ(o v)
            (proceed o v)
            (send display update o))))
```

(send aPoint setX 7)

(evlis (aPoint,7) ρ (push (advise 〈*dispatch* setX〉) κ))

...

⇒ (〈obj〉 ,7) ↦ (λ(o v) (apply (dispatch o setX)
(push (advise 〈*exec-method* o v〉) κ))

...

⇒ 〈METH〉 ↦ (λ(m) (apply-advice ADV m o v κ))

⇒ (eval (body ADV) [o→o v→v proceed→(λ(o v κ) (apply-method m o v κ))] κ)

...

⇒ (eval 〈proceed o v〉 [...] (push 〈*next* 〈send display update o〉 [...]〉 κ))

...

⇒ (apply-method m o v (push 〈*next* 〈send display update o〉 [...]〉 κ))

...

⇒ ? ↦ (λ(_) (eval (send display update o) [...] κ))

...

⇒ ? ↦ κ

original behaviour

Pointcuts Modeled as Sub-Cont Identifiers

- Pointcuts match sub-continuation structures

```
(pointcut change (execution (Point setX)))
(around change (λ(o v)
              (proceed o v)
              (send display update o))))
```

```
(send aPoint setX 7)

(eval aPoint ρ (push (advise 〈dispatch setX ρ〉 ) κ))

⇒ 〈obj〉 ↦ (λ(o) (dispatch o setX (push 〈eval-rands 7 ρ〉 κ))
⇒ 〈METH〉 ↦ (λ(m) (eval 7 ρ (push (advise 〈apply-method m o〉 ) κ))
⇒ 7 ↦ (λ(v*) (eval (body m)
              [this→o (ids m)→v*]
      (push 〈after send display update o
              [o→o (v)→v*]〉
        κ))

⇒ ↦ (λ(_) (eval send display update o [o->o (v)->v*] k)

⇒ ...
```

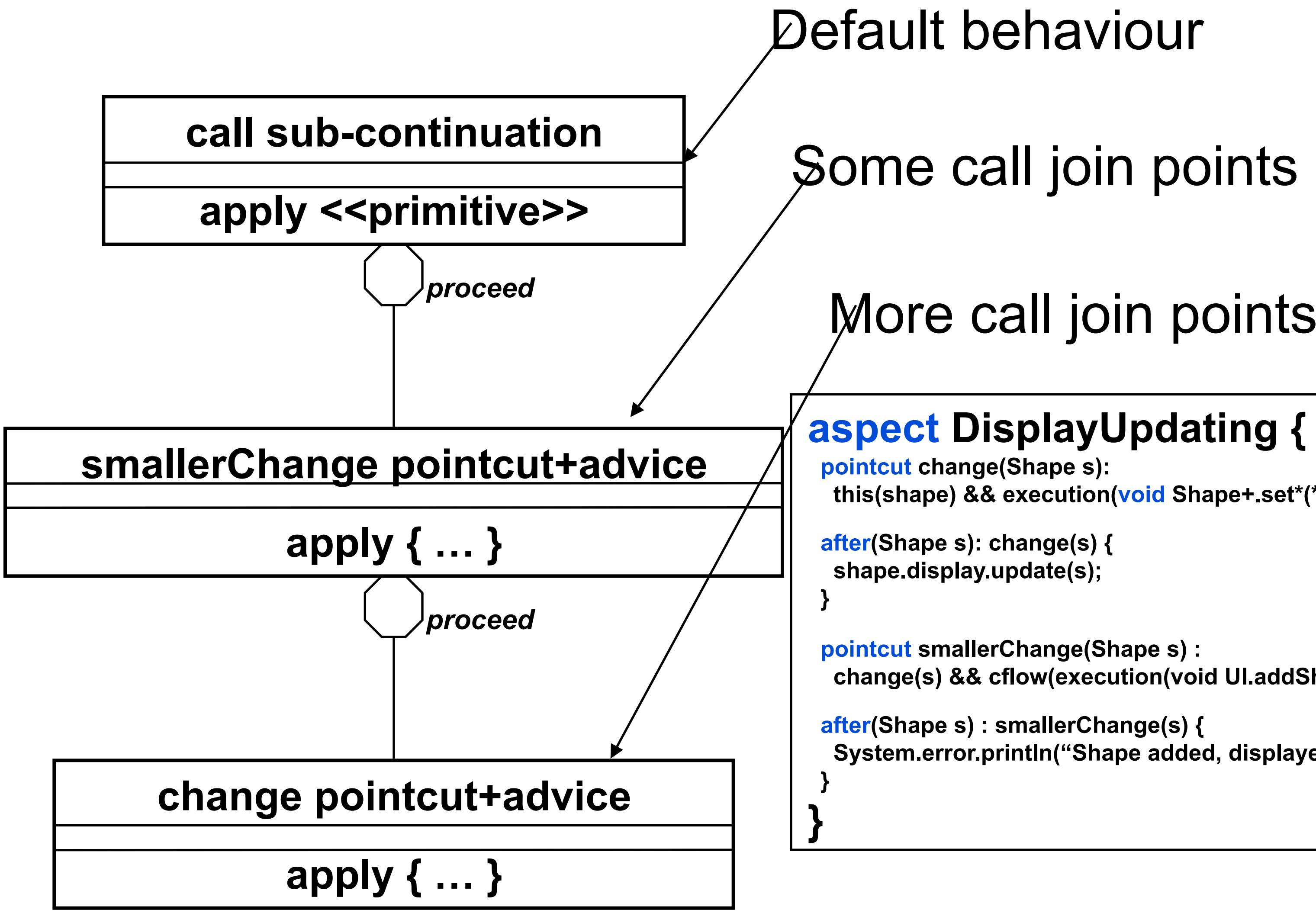
Join Points Modeled by Sub-Conts

- “Principled points in execution”
  - join points correspond to sub-continuations
  - call join point ≡ dispatch sub-continuation

```
(send aPoint setX 7)
 (evlis (aPoint,7) ρ (push 〈dispatch setX〉 κ))
  ⇒ (〈obj〉,7) ↦  (λ(o v) (apply (dispatch o setX)
                  (push 〈exec-method o v〉 κ))
  ⇒ 〈METH〉 ↦ (λ(m) (eval (body m) [this→o (ids m)→v] κ))
  ⇒ ...
```

  - execution join point ≡ execution sub-continuation
  - field get/set join points …

Structuring: Applicability Determines Proceed

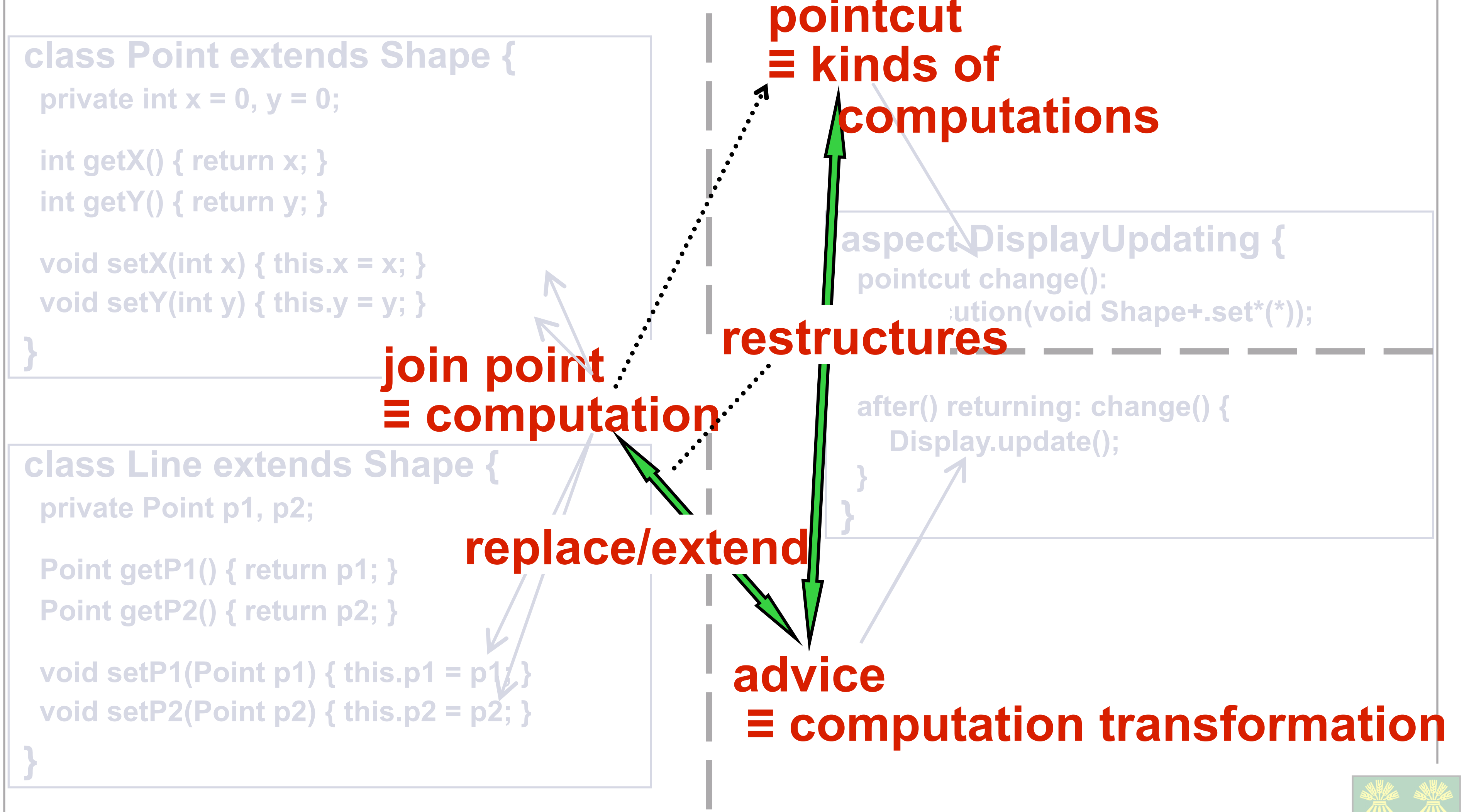



```
aspect DisplayUpdating {
  pointcut change(Shape s):
    this(shape) && execution(void Shape+.set*(*));

  after(Shape s): change(s) {
    shape.display.update(s);
  }

  pointcut smallerChange(Shape s) :
    change(s) && cflow(execution(void UI.addShape()));

  after(Shape s) : smallerChange(s) {
    System.error.println("Shape added, displayed.");
  }
}
```

Model Abstracts Computations

- Well-founded in prog. language theory
  - Join points ≡ sub-continuation
  - Advice ≡ procedure-like transform to join point
  - Pointcuts ≡ sub-continuation identifiers
- Abstraction: Control
  - Pointcuts identify join points
    - computations delimited by continuations
- Interface: Extension/Replacement
  - Advice captures those computations and
    - extends/replaces those computations
  - altering their control structure

AOP Provides a New Kind of Modularity



Characterizing Control

Values are Characterized by Types *[Cousot '97; Pierce '02]*

- **Int**
  - 32-bit 2's-complement
  - Primitives
    - **(printf "%d" …)**
    - +, -, *, /, =
  - Passed as argument
- **Bool → Int**
  - closures
  - Application
  - Passed as argument
- Static checking
  - Safety
  - Machine-checked compliance to annotated intent
  - Enables optimizations

Join Points Carry Effects *[Jouvelot+ 89; Sabry+ 92; Danvy+ 92; …]*

- Exceptions
  - May throw division by zero
- State
  - Reads value
  - Mutates value
- Input/Output
  - Reads file
  - Writes file
- Concurrency
  - Generates new thread
  - Blocks on visible thread
- Sequencing
- Non-determinism
- Partiality

- Walk the AST and determine
    - Throw/Catch
    - Read
    - Display
    - SetField
    - GetField
    - Fork
    - Exit
    - Wait
  - Used in the join point *shadows*
- Can determine effect type of join point shadows

Pointcuts Have Merged Join Point Effect Type

- Merger provides opportunity to examine types

```
(pointcut change (or (execution (Point setX))
                     (execution (Line setP1))))
```

```
change:    mutates(receiver field x)
        or mutates(receiver field p1)
```

- Check
  - Excluded join points with similar effect type?
    - Were these ones missed?
  - All the join points have same effect type, except one?
    - Was this one accidentally included?

Advice Composes Additional Effects

Logging: I/O

```
(pointcut action ...)

(around action (λ args
           (write "before: ... ")
           (apply proceed args)))
```

Transaction: remove state

```
(pointcut update ...)

(around update (λ args
           (let ([saved (get-state)])
            (with-handlers (λ(exc)
                            (rollback-state saved))
             (apply proceed args)))))
```

Asynchronous: add concurrency

```
(pointcut operation ...)

(around operation (λ args
           (if (fork)
               (apply proceed args))))
```

Effects Compose in Layers *[Jones+ 96; Filinski '99; …]*

- Exceptions over State $Ta = (1,s)+(a,s)$
  ⇒Transaction

- State over Concurrency $Ta = [a],s$
  ⇒Global store
  ⇒Atomicity is a potential problem

- Concurrency over State $Ta = [(a,s)]$
  ⇒Thread-local store

- Java $Ta = ([(1+a),s_{local}],s_{global})$
  – Exceptions over state over concurrency over state

Some Compositions are Wrong

- Examples
  - Transaction over IO
    - output cannot be undone
    - some input cannot be undone
  - Transaction over Concurrency
    - Concurrent operations may see incomplete transaction
- Effect checking summarizes behaviour
  - Enables identifying inconsistent interactions

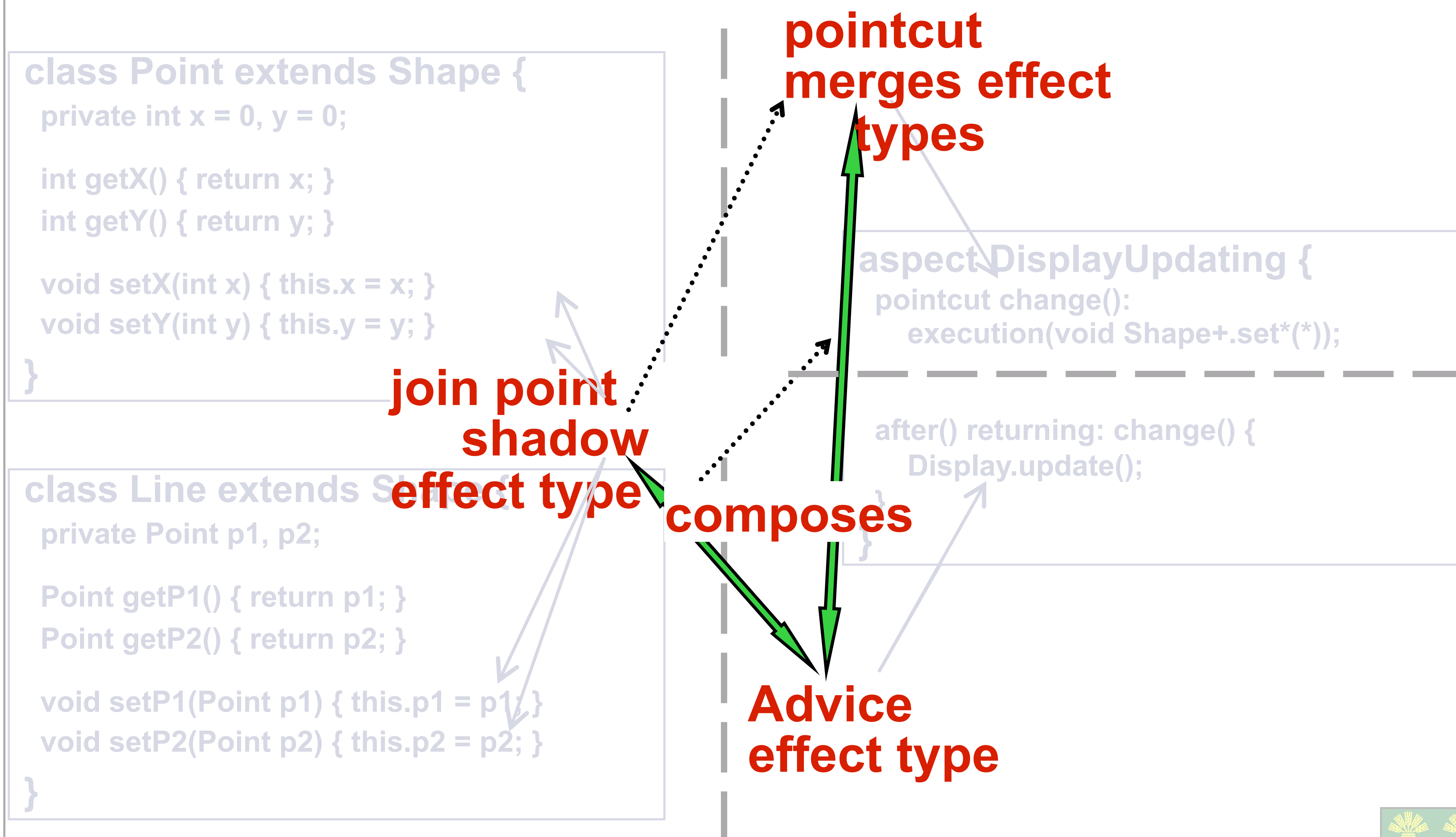
Some Compositions are Potentially Wrong

- Examples:
  - Concurrency and State
    - Either order is valid – but which is desired?
      - Thread-local state
      - Shared state
  - Concurrency over IO
    - With shared communication channels, reads and writes can interfere
- The programmer knows the intent and needs to decide
  - We can provide report to locate trouble spots

Some Correct Interactions may be Flagged Wrong

- Example:
  - Logging in a Transaction
    - Stderr output in a transactional context?
- The checker complains
  - This is called *slack* in a type system
  - Need some work-around

AOP Provides a New Kind of Modularity



Advice Description is Informative

```
(class Point Shape
 (field x)
)
```

```
(class Line Shape
 (field p1)
 (field p2)

 (method getP1 () p1)
 (method getP2 () p2)

 (method setP1 (p) (field-set p1 p))
 (method setP2 (p) (field-set p2 p))
)
```

```
change:   mutates(receiver field x)
       or mutates(receiver field y)
       or mutates(receiver field p1)
       or mutates(receiver field p2)
```

```
(pointcut change (or (execution (Point setX))
                 (execution (Point setY))
                 (execution (Line setP1))
                 (execution (Line setP2)))

(around change (λ(o v)
            (proceed o v)
            (send display update o))))
```

```
advice: sequence after
    input/output(file: stdout)
```

Advice Description is Informative

```
(class Point Shape
  (field x)
)
```

```
(class Line Shape
  (field p1)
  (field p2)

  (method getP1 () p1)
  (method getP2 () p2)

  (method setP1 (p) (field-set p1 p))
  (method setP2 (p) (field-set p2 p))
)
```

```
(pointcut change (or (execution (Point setX))
                     (execution (Point setY))
                     (execution (Line setP1))
                     (execution (Line setP2)))

(around change (λ(o v)
                 (proceed o v)
                 (send display update o))))
```

- Observes state changes
  - Each join point mutates object-local state
  - Pointcut abstracts local -state changes only
- Augments state changes
  - Adds IO effect to join point behaviour
  - Single unconditional proceed maintains existing sequential control flow
- Advice unconditionally couples shape state mutation with display state updating

Effect Typing for Aspects

- Provides summary report of behaviour of
  - join point shadows
  - point cuts
  - advice
- Developer can use reports to find
  - Anomalous join point shadows in pointcuts
  - Understand composed behaviour of
    - join point
    - advice

Related Work

- *[Rinard '04]*
  - weaves AspectJ code then checks
  - applies pluggable data-flow and control-flow analyses

- MiniMAO *[Clifton '05]*
  - distinguish two categories
  - recommend 'surround' to syntactically denote simple case

- *[Sihman+ '03]*
  - distinguishes three categories
  - model-checking

Summary

AOP Provides Modularity over Control

```
class Point extends Shape {
  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; }
}
```

```
class Line extends Shape {
  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; }
}
```

```
aspect DisplayUpdating {
  pointcut change():
          ution(void Shape+.set*(*));

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

pointcut
≡ kinds of
computations

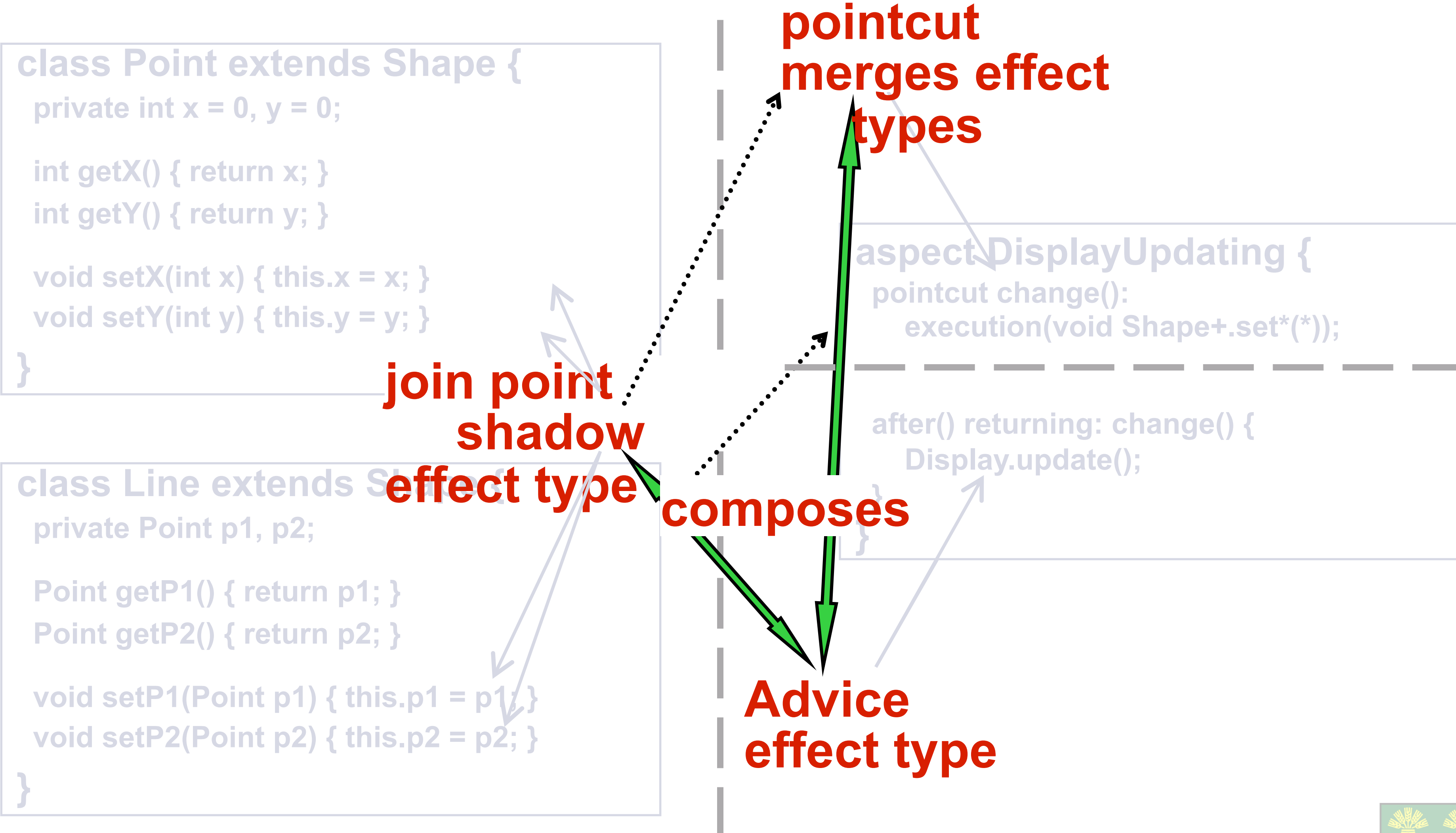
join point
≡ computation

restructures

replace/extend

advice
≡ computation transformation

Effect Typing Helps Understand Composition



Contribution: Semantic Model

- Shows how AOP fits naturally within PL theory
  - No separate artifact required
    - meta-programs
    - weavers
- Subsumes other models:
    - first-class context labels *[Dantas+ ’04]*
    - continuation marks *[Dutchyn+ ’06]*
    - weavers *[Wand+ ’04; Bruns+ ’04; Masuhara+ ’03; Clifton ’05]*
    - predicate dispatch *[Orleans ’05]*
- Clarifies AOP $\Leftrightarrow$ reflective meta-programming

… What's Missing?

- Intertype declarations
  - Join points exist in elaboration phase
    - Declare operation
    - Override implementation
    - Create class
- Cflow
    - Makes obvious that cflow adds state and breaks tail calls
    - Build as a sub-aspect construction
- Other meta-programming AOP systems (hyperJ, composeJ)
  - Given a precise dynamic semantics
    - Identifying sub-continuations is mechanical
  - Our construction goes through

Future Work

- Dynamic aspects modularize control
    - And associated operations
  - Just like objects modularize data
    - And associated operations

Frame Activation	Pointcut	AspectJ
$(\mathit{field}_{\text{location}}\ i) \blacktriangleright (\mathit{getfield}_{\text{frame}}\ o)$	getfield o.i	getfield o.i
$o \blacktriangleright (\mathit{setfield}_{\text{frame}}\ \mathit{field}_{\text{location}}\ i)$	setfield o i	setfield o.i
$v* \blacktriangleright (\mathit{dispatch}_{\text{frame}}\ o\ i)$	dispatch o.i(...)	call o.i(...)
$(\mathit{method}_{\text{location}}\ i) \blacktriangleright (\mathit{exec}_{\text{frame}}\ o\ v*)$	exec o.i(...)	exec o.i(...)
$v* \blacktriangleright (\mathit{allocate}_{\text{frame}}\ i)$	alloc i(...)	init i(...)
$(\text{class}\ i) \blacktriangleright (\mathit{init}_{\text{frame}}\ v*)$	init i(...)	preinitialize i(...)

Figure 51: Object-Oriented Dynamic Join Points

- Category theory?

Future Work

- Tantalizing aspects ⇔ classes duality

	OO	*AO*
Base	Value	Continuation
	↓ product	↓ sum
Bundle	Object	*Instance*
Abstract	Class	Aspect
	↓ sum	↓ product
Structure	Inheritance	*?*

	OO	*AO*
Dispatch	Method	*Constructor*
Order	Most-to -least specific	*Most-to -least applicable*
Static Structure	Super	Proceed

- Gives framework for understanding the kinds of manipulations that AOP enables

Future Work

- What annotations can scale-up aspect checking?
  - Showed tractable
  - Want practical
  - AspectJ?

```
aspect Atomic {
  pointcut operation() : ...;
  //@@ encapsulated state mutations disjoint from threads'
  ... around(): operation() {
    return proceed();
  }
}
```

- What optimizations can aspect effect -checking enable?
  - Related to effect hierarchy *[Tolmach '04]*
- What about other effect taxonomies? *[Thielecke '04]*

Future Work

```
aspect Barrier {
  private final int lastN = ...;
  private List<Thread> waiting = new ...;

  pointcut syncAfter(): ...;

  ... around(): syncAfter() {
    ... result = proceed ();
    if (waiting.size() == lastN) {
      for (Thread t : waiting) { t.notify();
      waiting.clear();
    } else {
      Thread t = Thread.currentThread(
      waiting.add(t);
      t.wait();
    }
    return result
  }
}
```

```
aspect ThreadSafety {
  boolean isSafeThread();
  private Queue<Runnable> q = new ...;

  pointcut unsafeOperation(): ...;

  void around(): unsafeOperation() {
    if (isSafeThread()) {
      for (Runnable r : q) { r.run(); }
      proceed();
    } else {
      q.add(new Runnable() {
          blic void run() {
          proceed();
```

```
aspect Logging {
  pointcut action(): ...;

  ... around(): action() {
    System.out.println("before: ... ");
    return proceed();
  }
}
```

```
aspect Transaction {
  private Object savedState;

  pointcut update(): ...;

  boolean around(): update() {
    savedState = getState();
    try {
      return proceed();
    } catch (Exception e) {
      rollBackTo(savedState);
      return false;
    }
  }
}
```

```
aspect Asynchronous {

  pointcut operation(): ...;

  void around(): operation() {
    new Thread(new Runnable() {
          public void run() {
            proceed(); }}).run();
  }
}
```

Power of the Abstraction

- Cω : C# + join calculus
- Their additions can be characterized by two abstract aspects
  - Asynchronicity
  - Barriers (Chords)
- Aspects are more general and more expressive

```
aspect Barrier {
  private final int lastN = ...;
  private List<Thread> waiting = new ...;

  pointcut syncAfter(): ...;

  ... around(): syncAfter() {
    ... result = proceed ();
    if (waiting.size() == lastN) {
      for (Thread t : waiting) { t.notify(); }
      waiting.clear();
    } else {
      Thread t = Thread.currentThread();
      waiting.add(t);
      t.wait();
    }
    return result;
  }
}
```

```
aspect Asynchronous {

  pointcut operation(): ...;

  void around(): operation() {
    new Thread(new Runnable() {
              public void run() {
                proceed(); }}).run();
  }
}
```

Discussion

Questions?

Supporting Slides

Other Analyses – Rinard+

- *[Rinard ’04]* weaves AspectJ code, then checks
  - DFA identifies state interactions
    - ***Orthogonal*** ≡ aspect and base have independent state
    - ***Independent*** ≡ aspect doesn’t read base mutable state
    - ***Observational*** ≡ aspect reads base mutable state
    - ***Actuation*** ≡ aspect writes into base immutable state
    - ***Interference*** ≡ both write into each others state

Other Analyses – Rinard+

- *[Rinard '04]* weaves AspectJ code, then checks
  - CFA identifies control interactions
    - ***Augmentative*** ≡ state effect, always proceeds
    - ***Narrowing*** ≡ conditional single proceed
    - ***Replacement*** ≡ unconditional no proceed
    - ***Combinational*** ≡ all other

Other Analyses – Clifton+, Katz+

- *[Clifton '05]* MiniMOA distinguishes
  - ***Spectators*** ~ observational and augmentative
    - Can be ignored for (some) code understanding
  - ***Assistants*** ~ all else
    - Require them to documented in the affected module
- *[Katz+ '04]* model-checks woven code to identify
  - ***Spectative*** ~ observational and augmentative
  - ***Regulative*** ~ observational and narrowing /replacement
  - ***Invasive*** ~ interference and/or combinational

The End

Really!

University of Saskatchewan

Software Research Lab