Specializing Continuations

a Model for Dynamic Join Points

Christopher Dutchyn
University of Saskatchewan

actually: What is an Aspect?

- Give examples
  - Distribution / tracing / instrumentation / …
- Give implementations
  - It's what AspectJ (and any number of others) do
- … lead to poor insight regarding
  - *what aspects are good for*
  - *how to best use them*

The key is *Modularity*

- So the question is

What do aspects modularize?

In general: crosscutting concerns

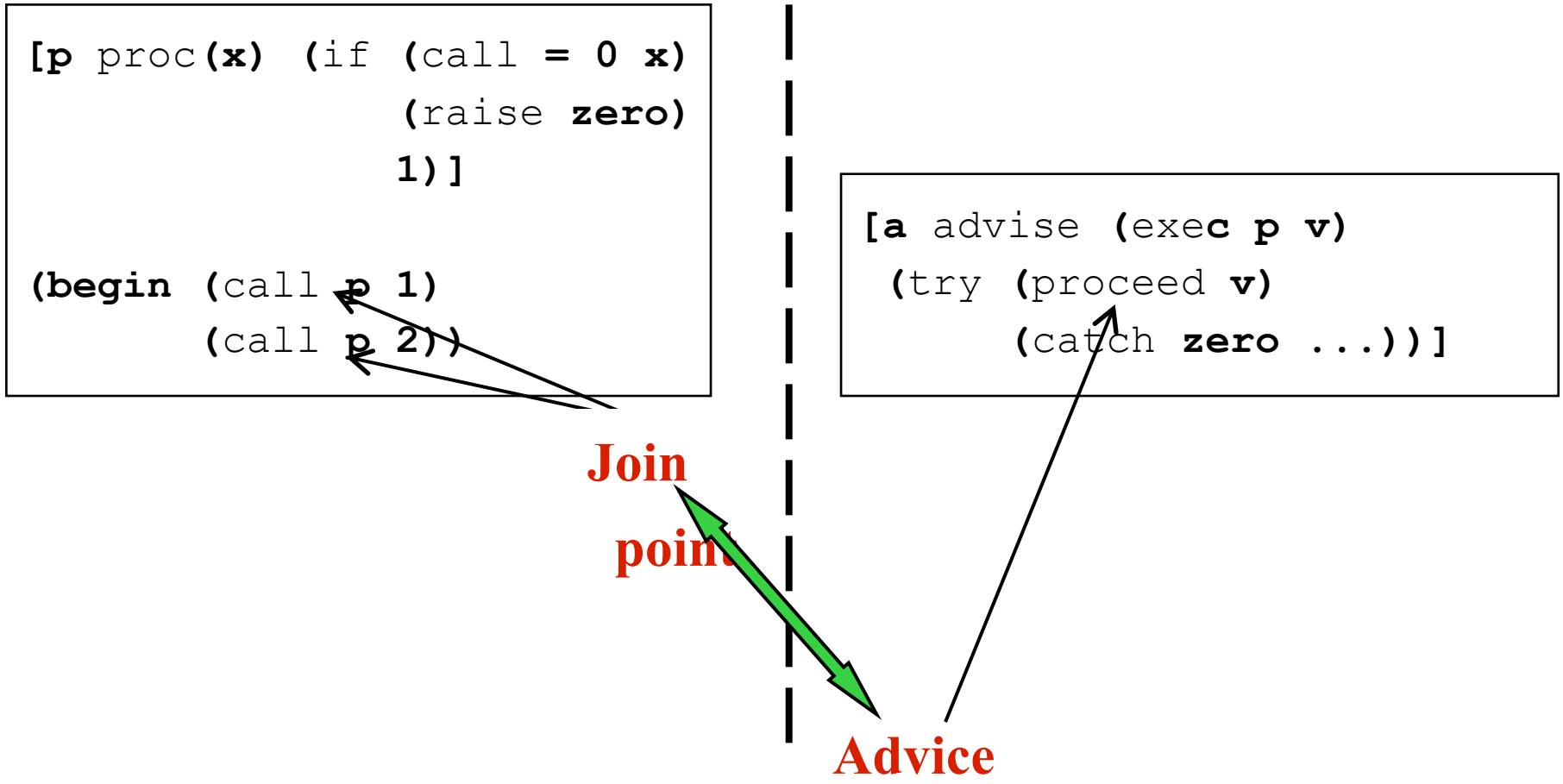
- Static aspects
  - Open classes
- Composition filters
- Object graph traversal (*Demeter*)
- Dynamic join points, pointcuts, and advice

- **Space is too large for a coherent answer**

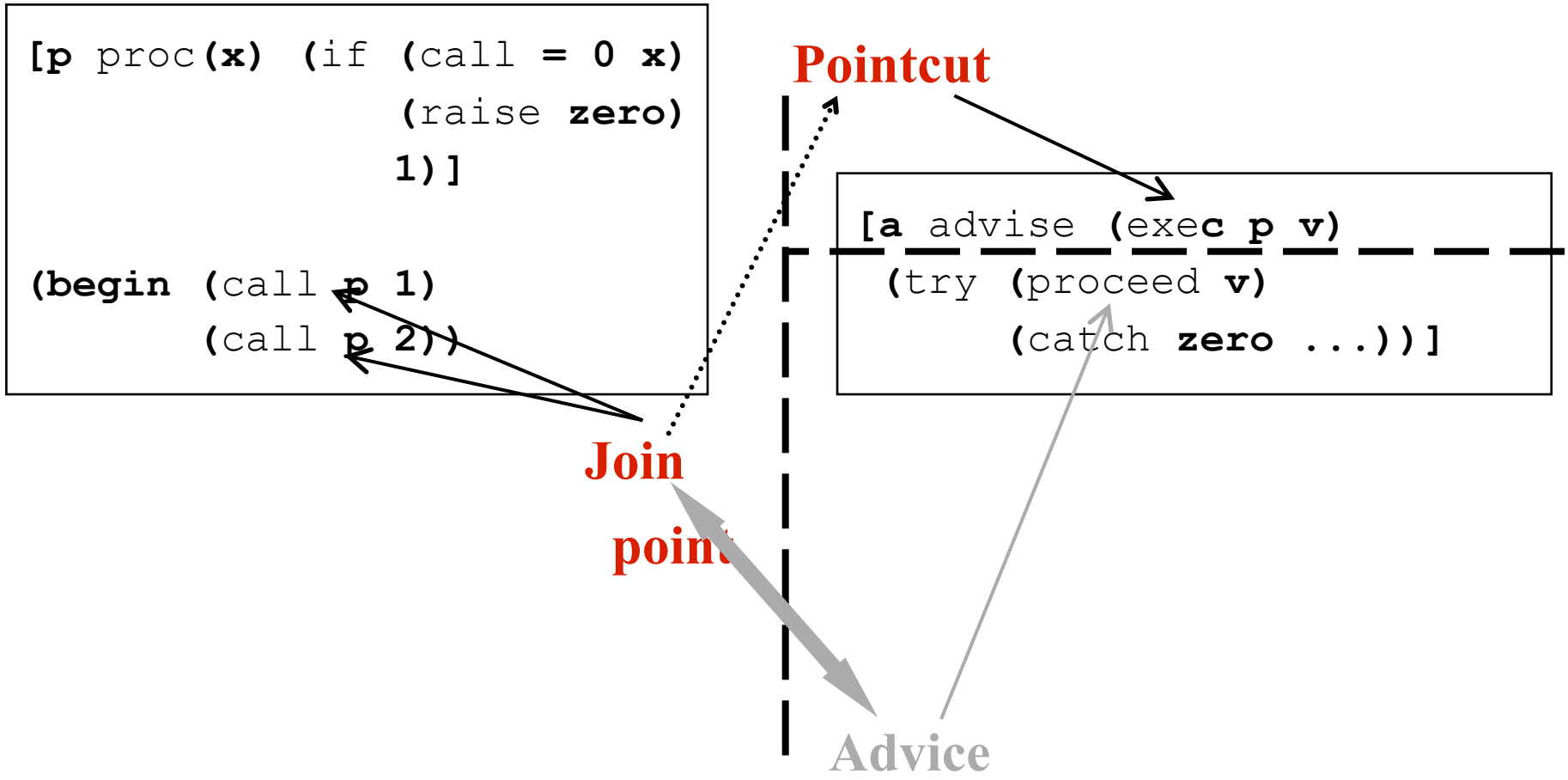
Modeling Dynamic Aspects

- Join points
  - *"**principled** points in the execution"*
- Pointcuts
  - *"a means of identifying join points"*
- Advice
  - *"a means of affecting the semantics at those join points"*

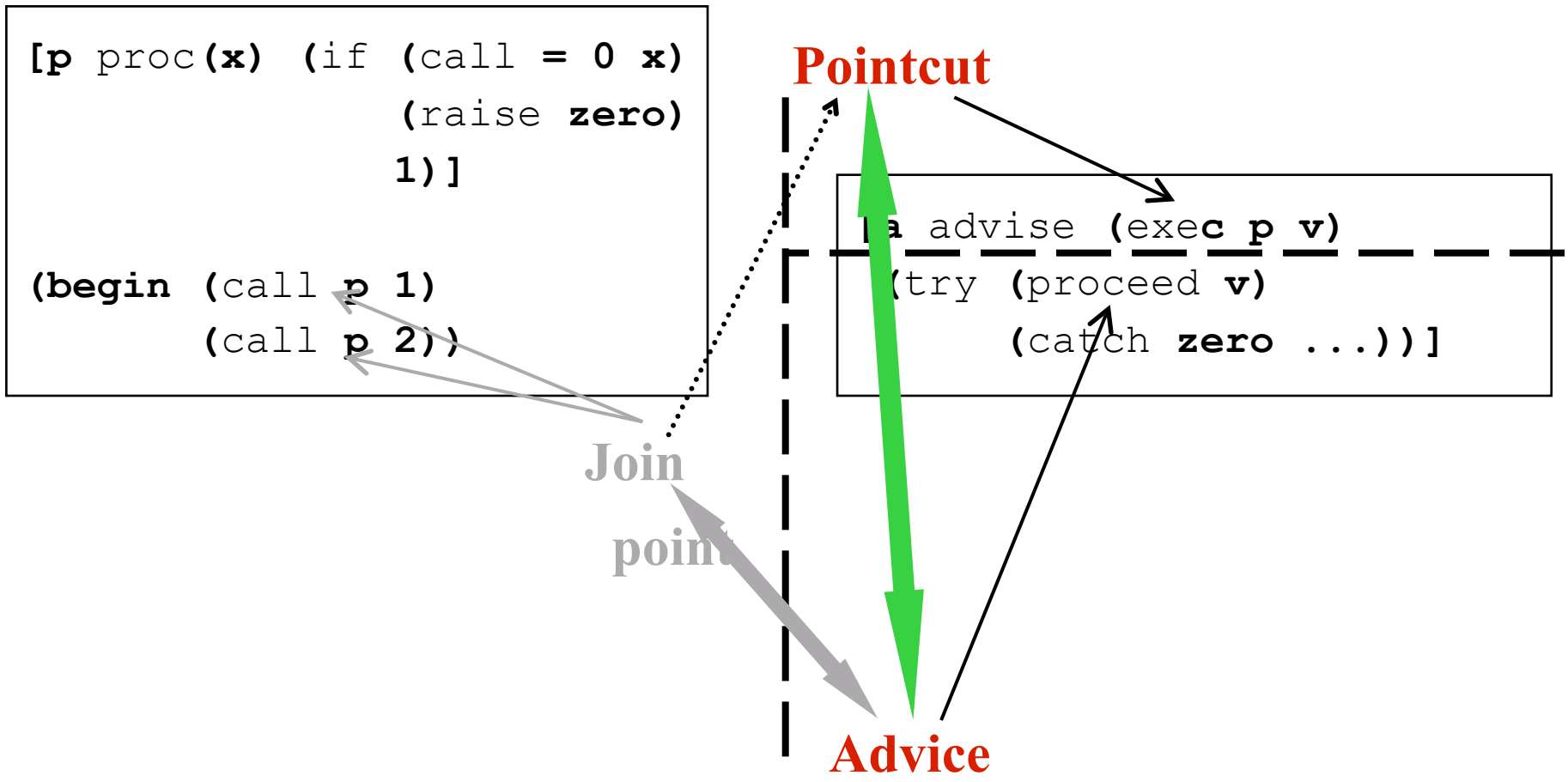
Two Interacting Abstractions: *Join point* and *Advice*



Third Abstraction: *Pointcut*



Interaction Between Pointcut and Advice

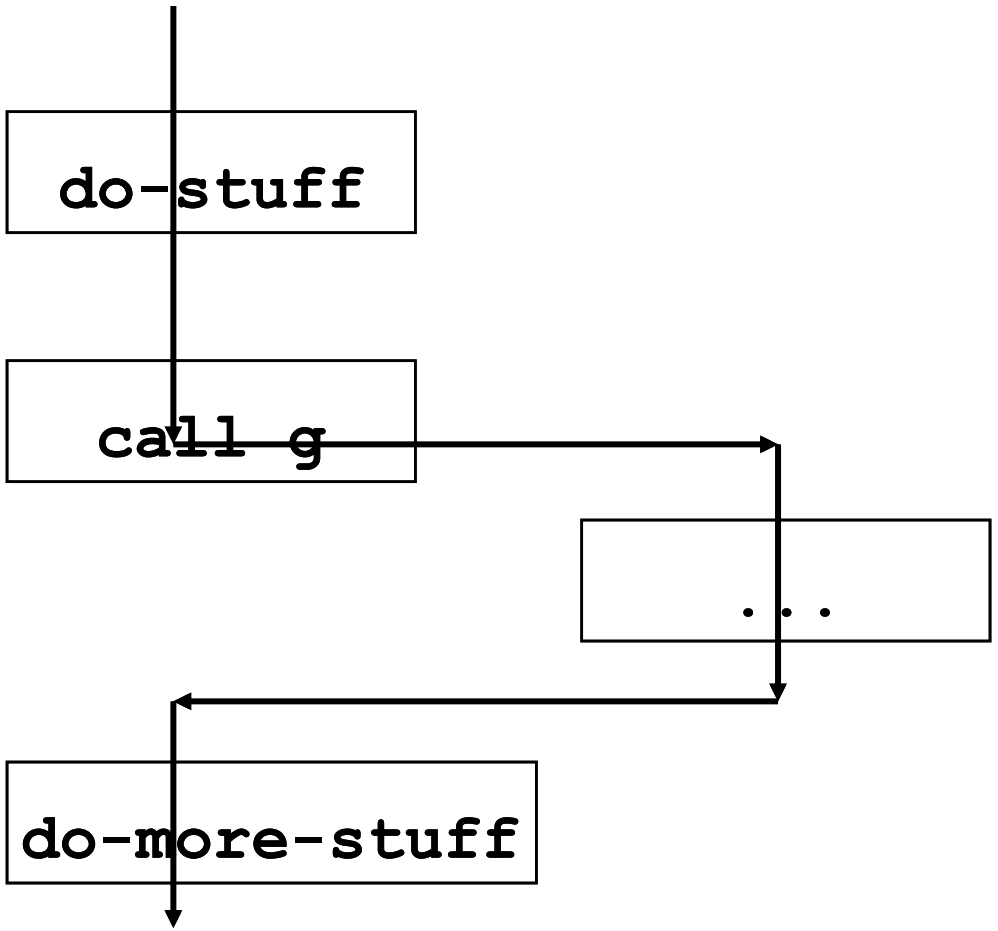


Idea

- A model of
  - dynamic join points,
  - pointcuts,
  - and advice,

  based on a continuation-passing style interpreter,
- provides a fundamental account of these AOP mechanisms.

Without Continuations

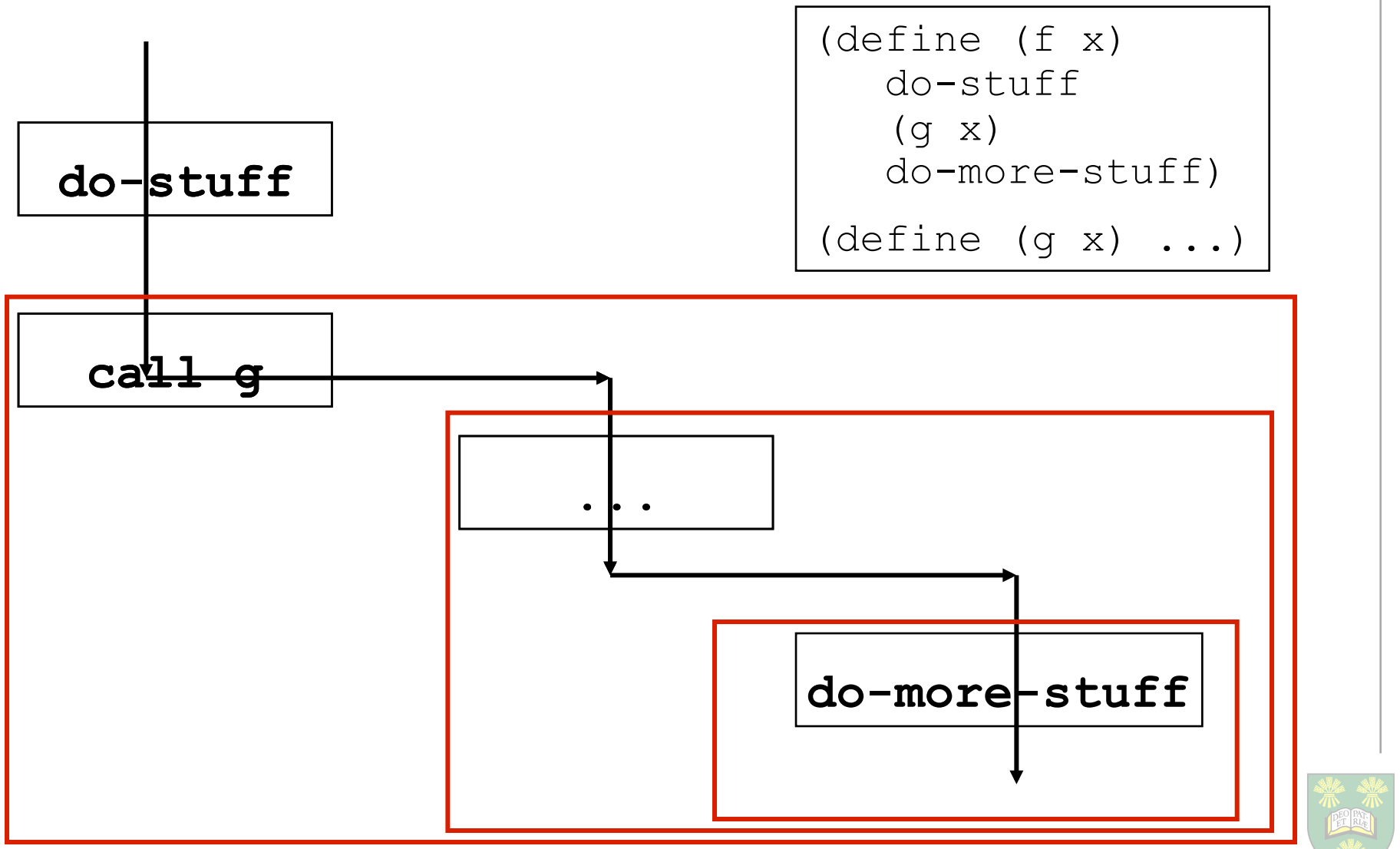



```
(define (f x)
   do-stuff
   (g x)
   do-more-stuff)

(define (g x) ...)
```

Continuations

[Strachey'67, Landin'68,...]



Model Development

- Begin with big-step semantics
  - definition of values, expressions
  - semantic definition of **`eval`**

introduces auxiliary continuations

- Apply CPS transformation
  - yields continuations (as lambdas)
  - generates definition of **`apply`**

yields frame structures

- Defunctionalize
  - yields identifiable frames in continuation structure

Defunctionalization [Reynolds '98, Ager+ '03]

- Procedures have structure
  - identifiers (argument names)
  - environment
  - expression (machine code)

- Continuations as escape procedures
  - have simple list/tree structure
    - fixed identifiers (next-continuation, argument)
    - predetermined environment
    - given semantics involving one operation

PROC Language

- Functions
  - 1st order, 2nd class
- Globals
- Standard syntax elements
  - If
  - Application
  - Primitives

Continuation Frames

Auxiliary

- facilitate eval regime
  - eager vs lazy

- **`testF -- if`**
- **`randF -- args`**
- **`konsF -- args`**
- **`rhsF -- set`**

Non-auxiliary

- Carry essential semantics of language

- **`getF`**
- **`setF`**
- **`callF`**
- **`execF`**

Insight … Principle

Insight: frames align with dynamic join points

Dynamic Join Point		
Value Consumed		Frame Information
(loc i_{global})	▶	(getF)
(loc i_{global})	▶	(setF val)
(val*)	▶	(callF i_{proc})
(proc i_{proc})	▶	(execF val*)

Principle:

A dynamic join point is modeled as a state in the interpreter where values are applied to non-auxiliary continuation frames.

Pointcuts -- identify frames

- **`callC`**
  - convert a procedure name to a procedure value
    - NB: accepts an internal value: an identifier
  - then continue to execF
- **`execC`**
  - accept arguments and execute procedure
- **`getC`**
  - accept global location and provide its value
- **`setC`**
  - accept global location and update its value

Pointcuts - combinators

- `and`
- `or`
- `not`

`Matching`

- Take a pointcut, value and frame
- Capture
  - necessary context values
- Yields function to replace frame and value

  - Bind in a user-parameterized *reflective monad*
    - *Mendhekar and Friedman*

```
(define (match-pc c v f)
   ;:(pcut × val × frm) → match
   (cond ;…other cases omitted
      [(and (callC? c) (callF? f)
            (eq? (callC-pid c) (callF-id f)))
         (make-match (callC-ids c)
                     v
                     (lambda (nv)
                       (values nv f)))]
      [(and (execC? c) (execF? f)
            (eq? (lookup-proc (execC-pid c)) v))
         (make-match (execC-ids c)
                     (execF-args f)
                     (lambda (nv)
                       (values v (make-execF nv))))))]
```

Wrinkle: `cflowbelow` pointcut

- identifies join points based on control-flow context
- tail-call optimization discards context
- recovering context
  1) keep all of it
  2) preserve needed structure [CC'03]
     - dynamically threaded stack data structure
     - **or** state effect

`cflowabove` pointcut

- Adds to ability to bound the context search from above
- **`within`**
  - Exclude subordinate procedure calls
- **`enclosingexecution`**
  - Stop at the next higher calling scope
- Not strictly necessary, but expressive

Weaving is dispatch

```
(define (((adv-step advs) f k) v)
 ;:adv* → (frm × cont) → !val
   (let loop ([advs advs])
     (cond [(null? advs) ((base-step f k) v)]
           [(match-pc (caar advs) v f) =>
              (lambda (m)
                (eval (cdar advs)
                      (extend-env `(%proceed
                                    %advs .
                                    ,(match-ids m))
                                  `(,(match-prcd m)
                                    ,(cdr advs) .
                                    ,(match-vals m))
                                  empty-env)
                      k))]
           [else (loop (cdr advs))])))
```

Model Accounts for Observation

- Our account requires a new join point
  - We needed a new continuation frame
    - **`advF`**
- Arises naturally in the model
  - Rather than adding (without explanation)
    - AspectJ
    - And others

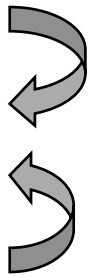
Fundamental Construction

- continuations arise naturally in big-step to small -step translation
- frames arise mechanically in defunctionalization of continuations

- no new language construct required
  - no continuation marks [Dutchyn, Tucker, Krishnamurthi]
  - no context labels [Dantas, Walker, Washburn, Weirich]
  - no rewrite points [Aßmann, Ludwig]
  - no awkward thunks [Wand, Kiczales, Dutchyn]
  - no predicate dispatch [Orleans]

Dynamic Semantic Model

Abstraction	Model Element	Interaction
join point	frame activation	dispatch
advice	behaviour specification	dispatch table
pointcut	frame identifier	



- Distills other descriptions to essentials
  - continuation marks
  - context labels
  - thunks
- Key insight: dynamic join points, pointcuts and advice
  - provide mechanism to **modularize** and **specialize** control structure

Elegant, Evocative Model

- based on a fundamental language construct
- pointcuts align well with existing AOP languages
  - adds `cflowabove` for simpler coding
  - explains provinence of `adviceexecution`
- clarifies relationship of DJP and reflection
- framework for understanding that dynamic aspects modularize control structure

Future Directions

- Object - Aspect Duality
  - Dynamic aspects modularize control (and associated operations)
    - Just as object modularize data (and associated operations)

Frame Activation	Pointcut	AspectJ
$(field_{\text{location}}\ i) \blacktriangleright (getfield_{\text{frame}}\ o)$	getfield o.i	getfield o.i
$o \blacktriangleright (setfield_{\text{frame}}\ field_{\text{location}}\ i)$	setfield o i	setfield o.i
$v* \blacktriangleright (dispatch_{\text{frame}}\ o\ i)$	dispatch o.i(...)	call o.i(...)
$(method_{\text{location}}\ i) \blacktriangleright (exec_{\text{frame}}\ o\ v*)$	exec o.i(...)	exec o.i(...)
$v* \blacktriangleright (allocate_{\text{frame}}\ i)$	alloc i(...)	init i(...)
$(\text{class}\ i) \blacktriangleright (init_{\text{frame}}\ v*)$	init i(...)	preinitialize i(...)

Figure 51: Object-Oriented Dynamic Join Points

- Category theory?

Future Directions

- Reflective Monads
  - Within the continuation monad
    - identify and operate on the continuation and value
  - á la Mendhekar & Friedman and Filinski

  - Lost “chapter 3a” of my dissertation

Future Directions

- Typing Aspects -- *abstract control types*
  - Value typing (mundane PE) isn't enough
    - Must abstract the control restructuring too
  - Rinard et al., Katz et al., and others
- Second half of my dissertation
  - But, more sophisticated
    - Take polarized logic from Shan
    - And effect typing from many others

Future Directions

- Static Aspects
  - Introduce an account of phase separation
    - Elaboration vs. execution
  - Continuations in elaboration

    = static join points?

  - Masuhara and Kiczales (ECOOP 2003)

Discussion