Taming Aspects

Éric Tanter
University of Chile

Aspects?

What are Aspects?

Modular implementation of **crosscutting** concerns

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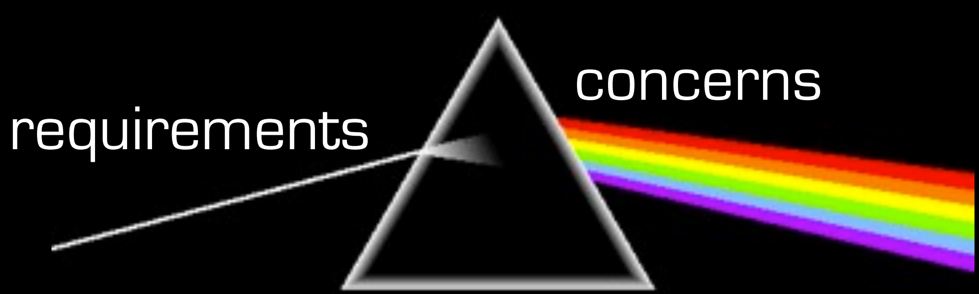
Monitoring
Security
Coordination
...



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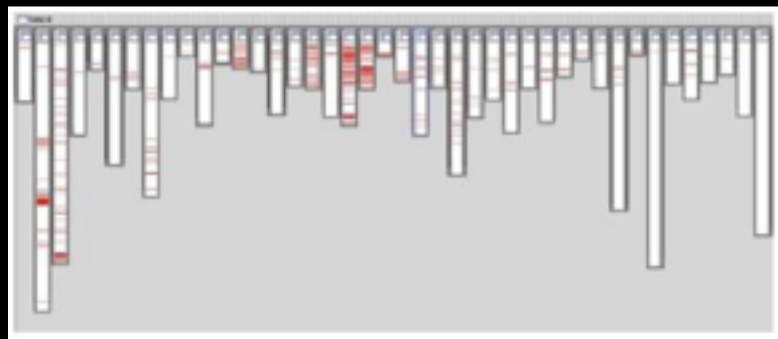

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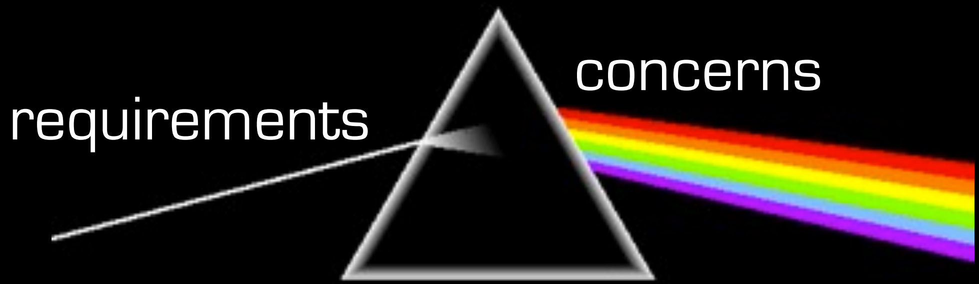

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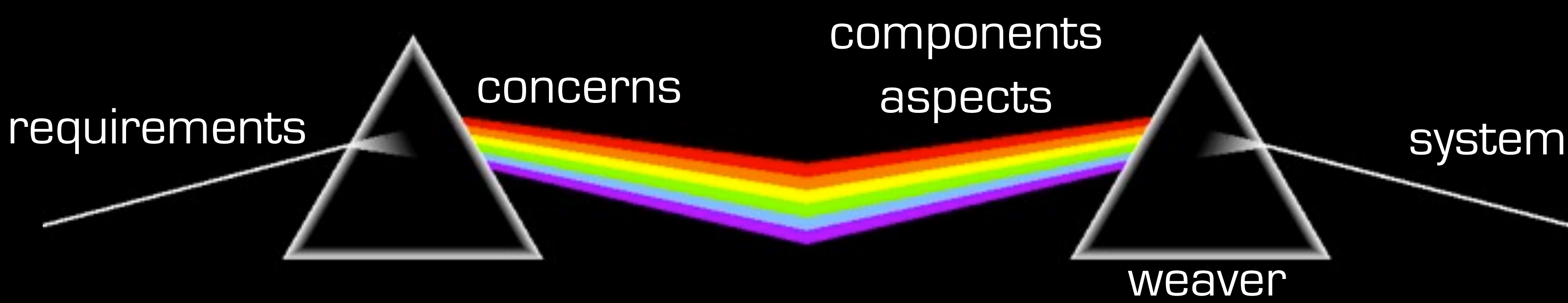

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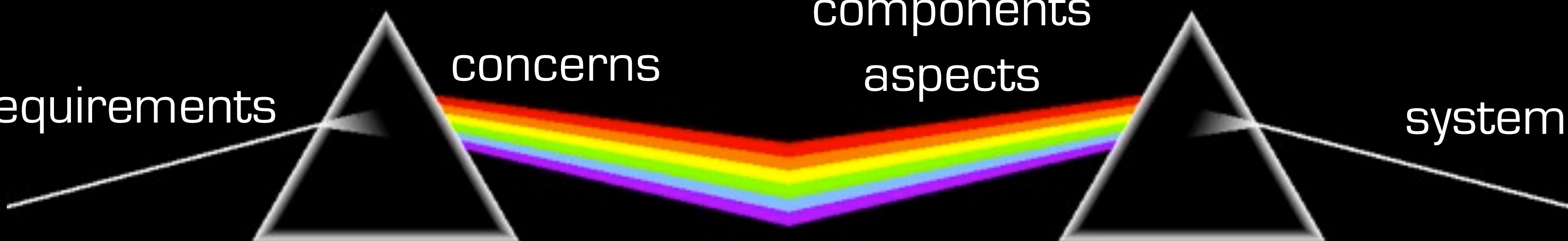

one **goal**, different **mechanisms**

Pointcut / Advice

A novel programming language mechanism

- interesting in its own right!

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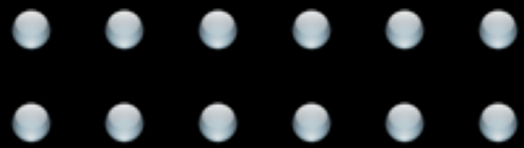

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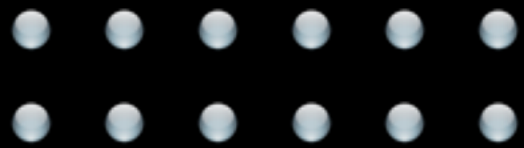

join points

pointcut

advice

"glorification" of the observer pattern

Quantification

join points

pointcut

advice

Quantification

join points

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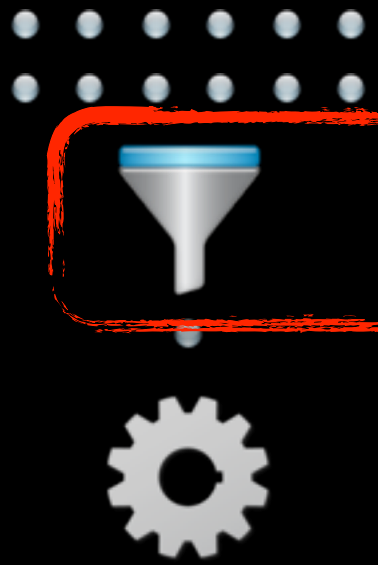
Quantification



join points

pointcut

```
execution(* Shape+.set*(..))
```

advice

Quantification


```
execution(* Shape+.set*(..))
&& this(s)
```

Quantification


```
pointcut change(Shape s):
   execution(* Shape+.set*(..))
   && this(s)
```

Quantification


```
pointcut change(Shape s):
   execution(* Shape+.set*(..))
   && this(s)
```

```
after(Shape s): change(s){
  // update observers
}
```

a join point

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computation
inside!

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computation inside!

“around” advice can ignore it

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“around” advice can ignore it
or proceed

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“around” advice can ignore it
or proceed
and proceed…

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this is more than 1-way notifications

Why is this exciting?

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pointcut/advice is effective for handling crosscutting

- behavioral reflection for mere mortals
- more declarative, esp. wrt **quantification** (pointcuts)
- more amenable to analysis (or so it seems)

still not there yet

- lots of open challenges

State of the Practice

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changing arguments/return	encryption, comfort zone, ...
arbitrary side effects	almost all aspects!

BUT...

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void around(): call(int Fib.calc(int)){
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   return -1;
}
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Break semantics!

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void around(Person p): execution(void *()) && this(p){
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ClassCastException!

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Aspect

Orientation

ASPECT

ORIENTATION

ASPECT

??

ORIENTATION

ASPECT ORIENTATION

ASPECT

ORIENTATION

TAMING

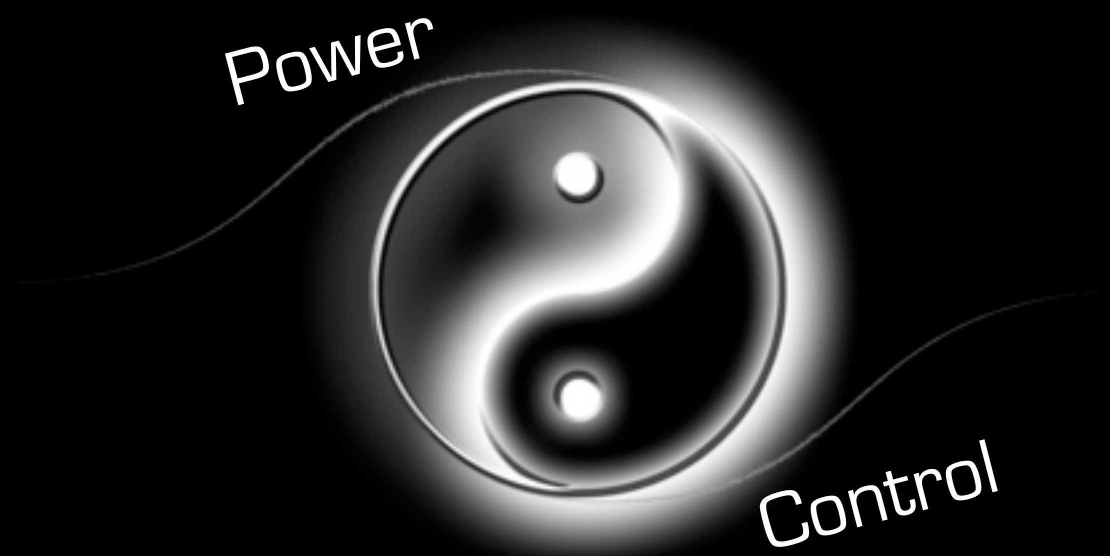
ASPECT

ORIENTATION

TAMING

ASPECT

ORIENTATION



Scoping

Interfaces

Types

Effects

Scoping

Interfaces

Types

Effects

Dynamic

Static

Scoping

Interfaces

Types

Effects

Scoping

Can we restrict quantification to well-defined boundaries?

What abstractions are meaningful?

Interfaces

Types

Effects

Global Quantification

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Global visibility of join points exacerbates many issues

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- etc.

Mitigating the Issue

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Explicit announcement of join points

- explicit join points [Hoffman, 2012]
- quantified typed events [Rajan, 2008]
- closure join points [Bodden, 2011]
- open applications
- etc.

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Expressive pointcuts

- rich pointcuts for robust patterns [Gybels, 2003], [Ostermann, 2005]
- application-specific pointcuts [Brichau, 2008]
- annotations [Kiczales, 2005]
- etc.

Scoped Quantification

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Global quantification

- just as bad as global mutable variables!

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Different scoping disciplines for identifiers

- lexical scope
- dynamic scope
- thread-local
- per object, class, module

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- dynamic scope
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All have been explored for aspects as well

- CaesarJ, AspectScheme, Eos, AspectJ...

Scoped Quantification: Advanced Models

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Scoping strategies [Tanter, 2008/2009/2010a]

- killer app: access control [Toledo, 2011/ 2012/2013]

Execution levels [Tanter, 2010b]

Membranes [Tanter, 2012] [Figueroa, 2013]

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Execution Levels

Composing Dynamic Analyses

joint work with
Walter Binder & co

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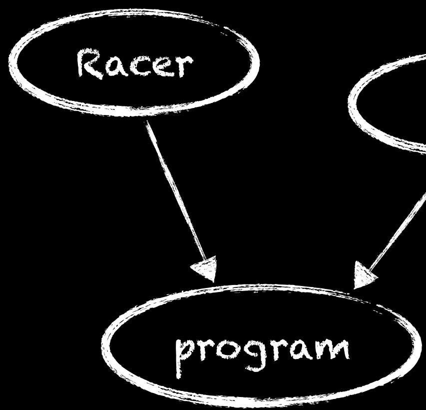

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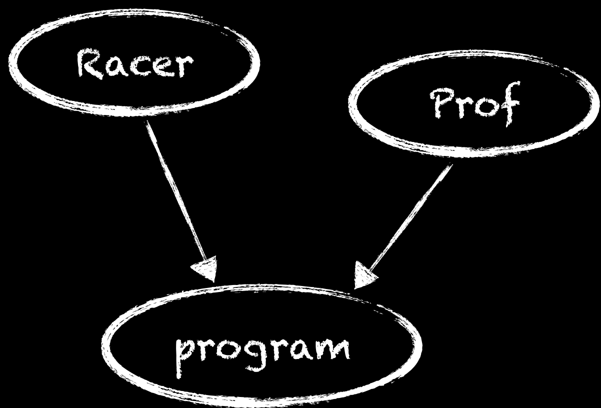

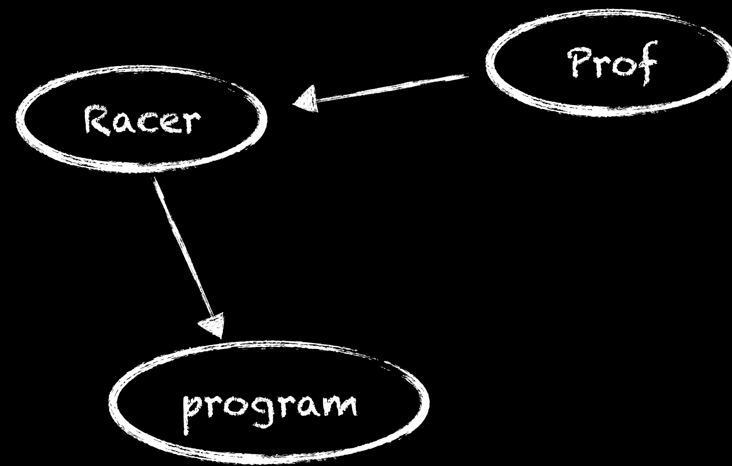

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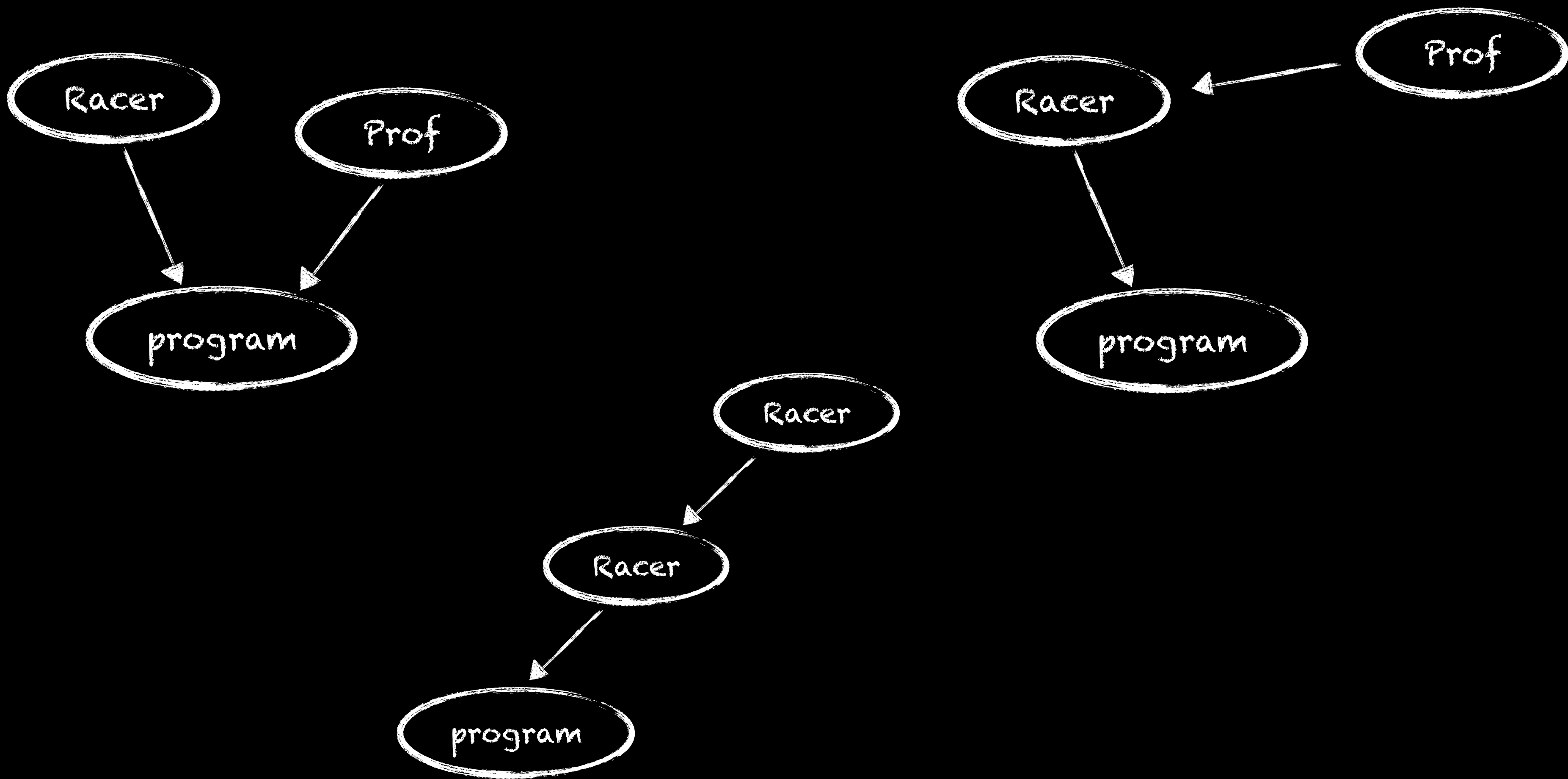

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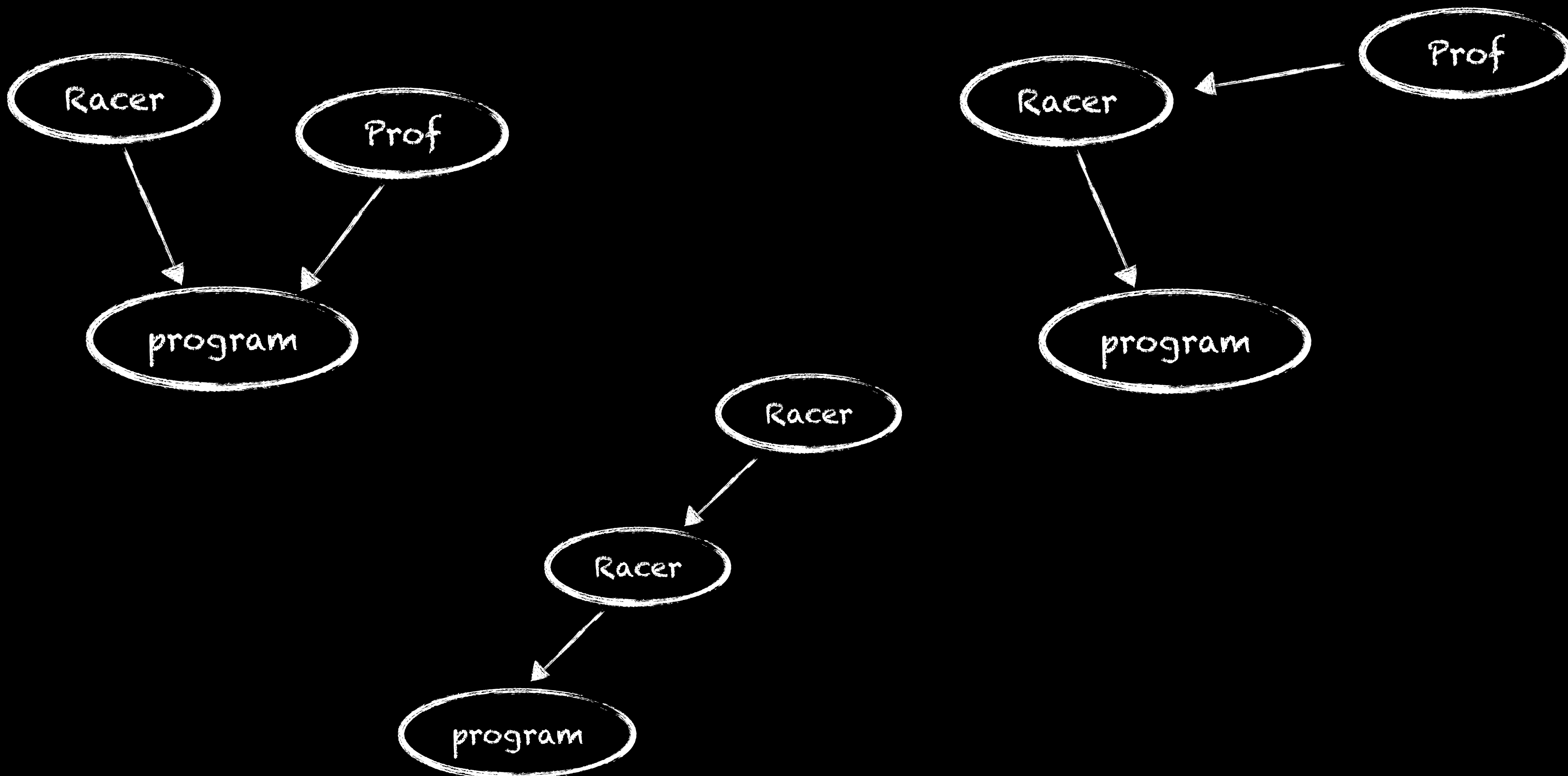
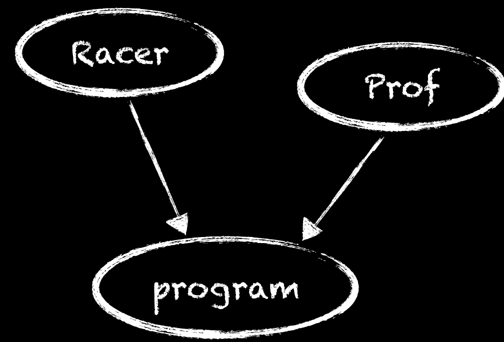


NONE CAN BE IMPLEMENTED! (until now...)

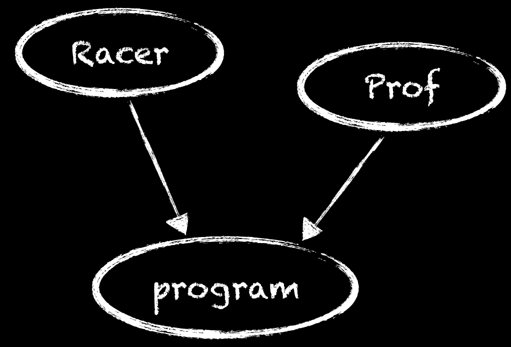
Why?



Why?

Each aspect alters the observation of others

- Racer creates objects
- Prof accesses fields



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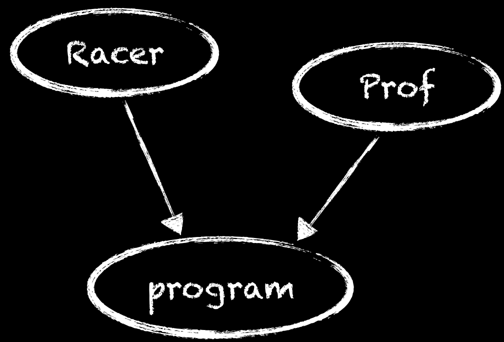

Each aspect potentially sees itself

- infinite regression

Execution levels

[Tanter, 2010b]

Structure computation in levels

- aspects stand at specific levels
- observe computation below

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level 0

Execution levels

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Execution levels

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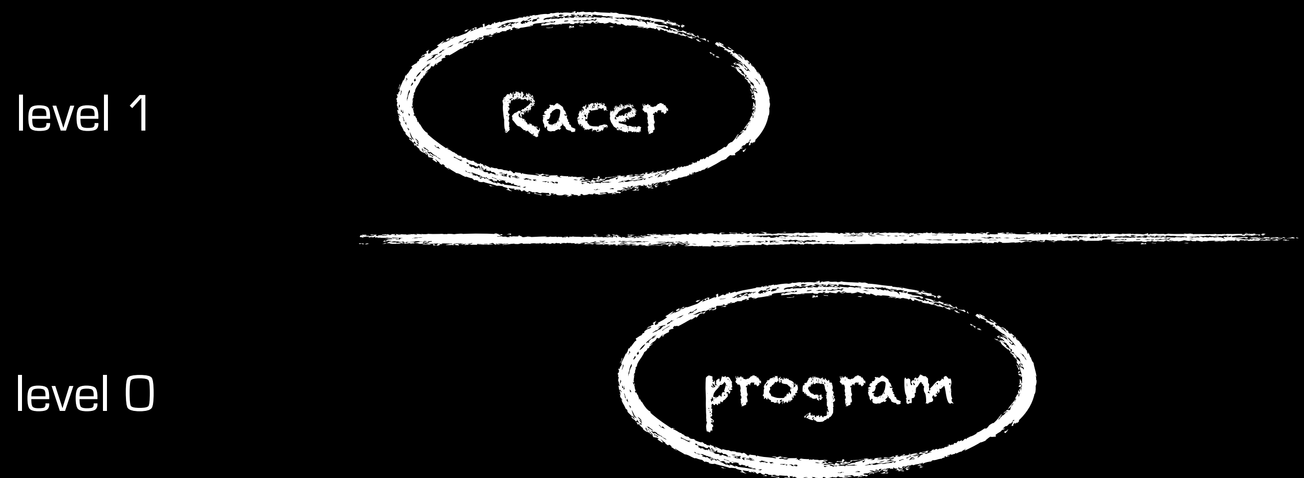

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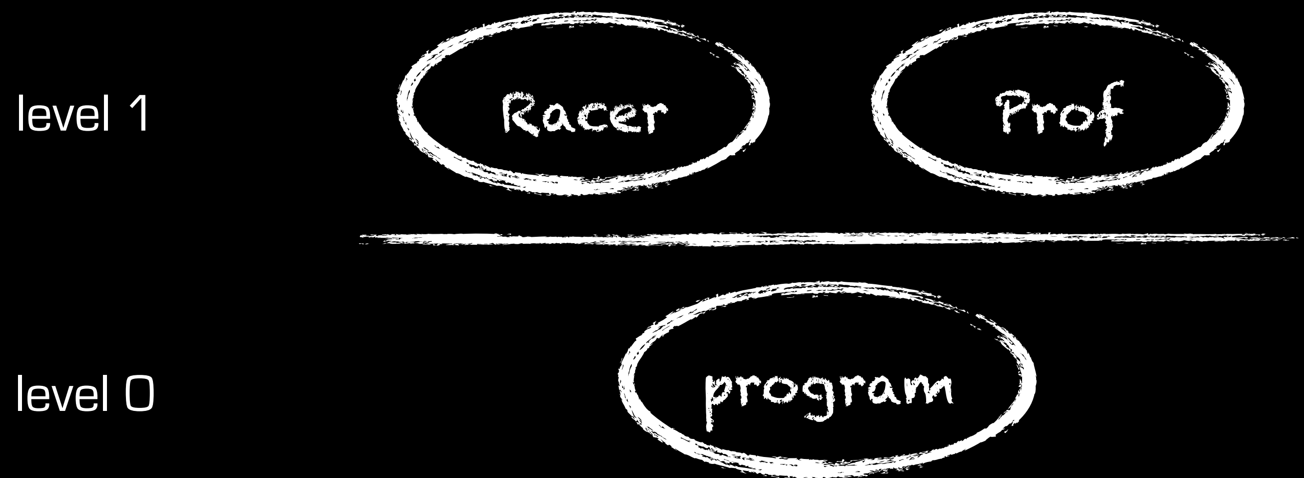

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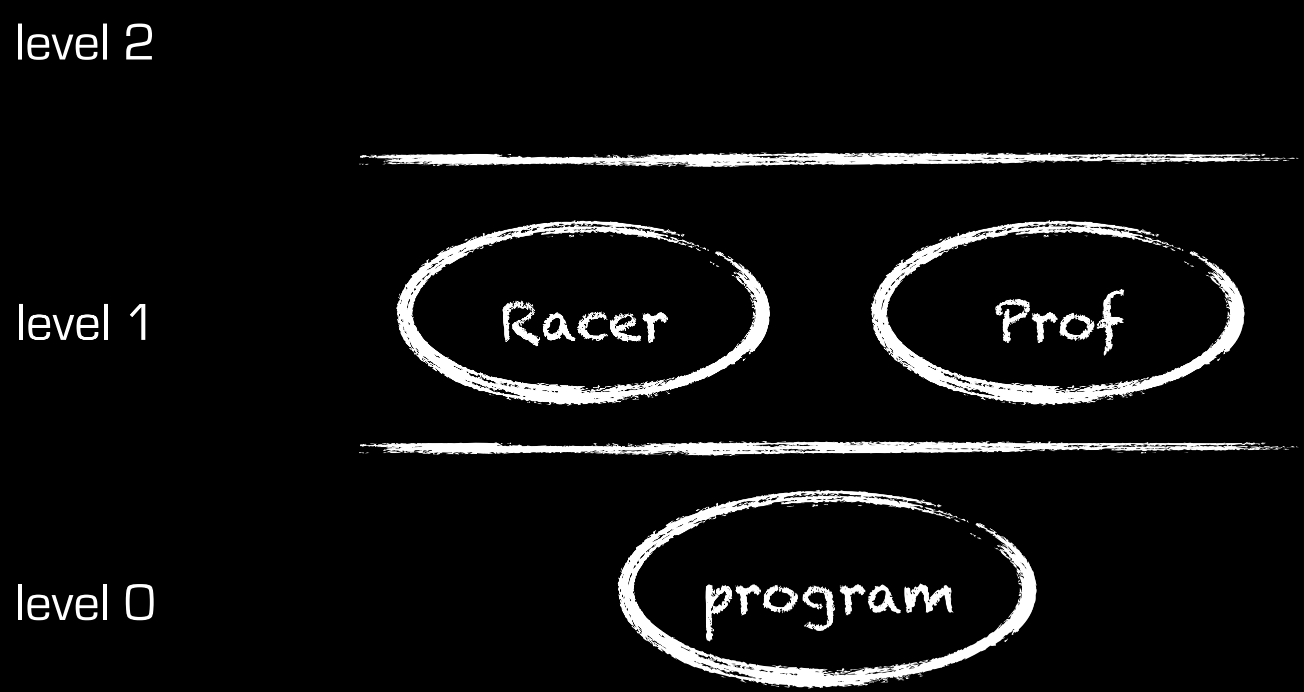

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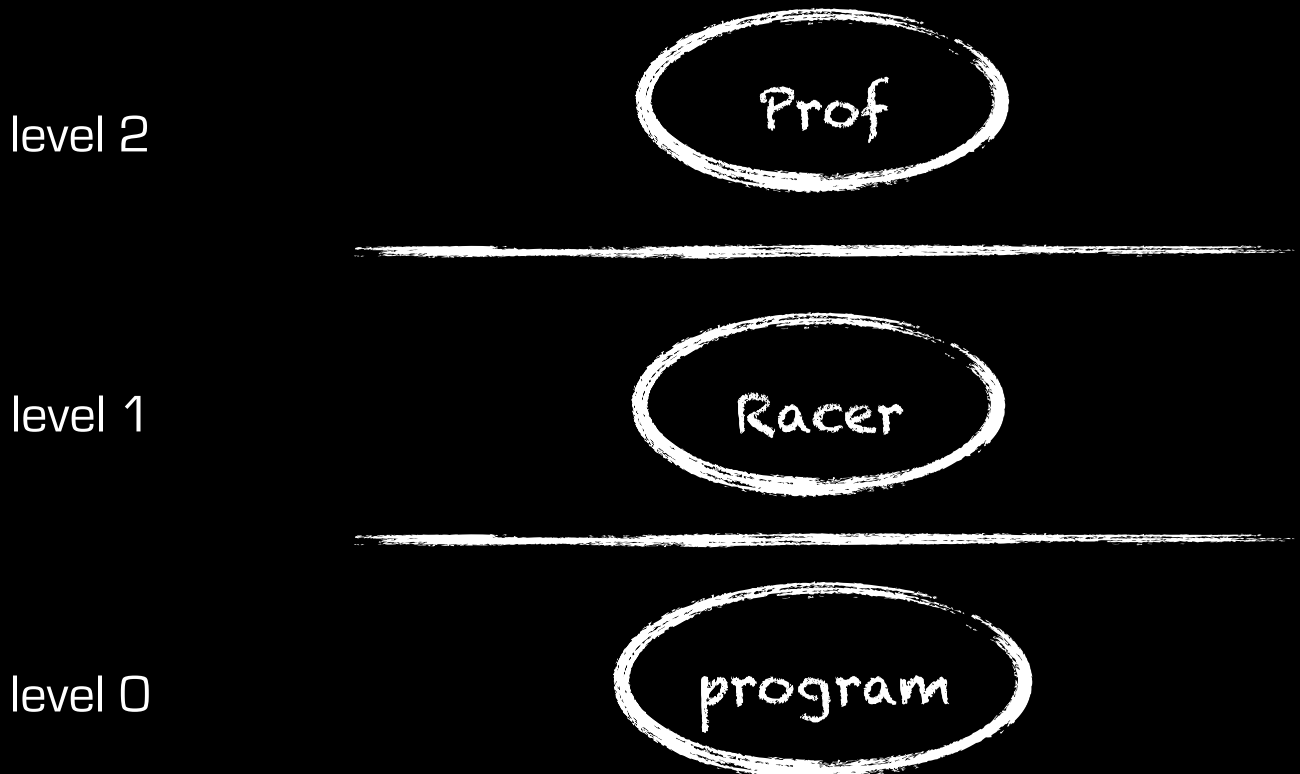

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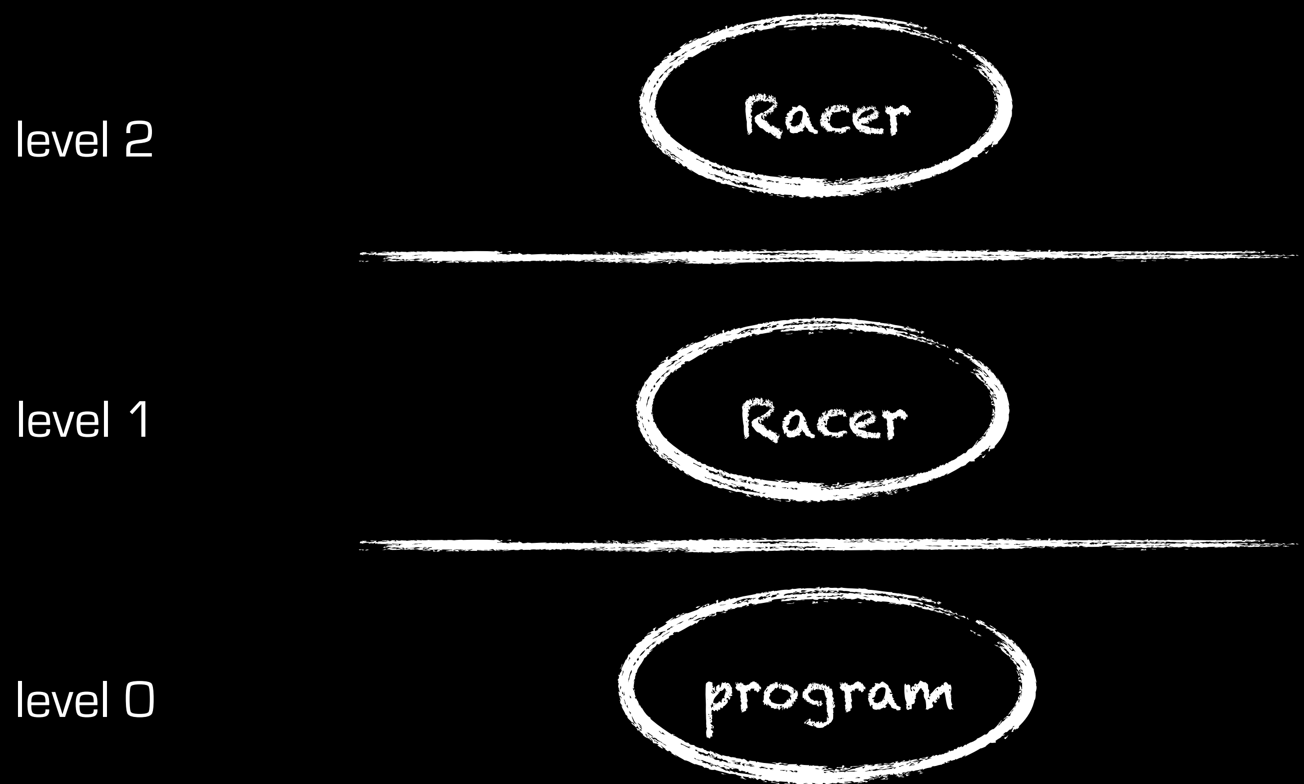

Levels: Theory and Practice

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Strong guarantee: aspect loops are avoided

joint work with

Nicolas Tabareau

Ismael Figueroa

Levels: Theory and Practice

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Can be implemented efficiently [Tanter, 2010c; Moret, 2011]

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Philippe Moret, Danilo Ansaloni

Levels: Theory and Practice

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Ad-hoc checks in practice

- 1/3 of all aspects in the "AspectJ in Action" book
- 18% of all pointcuts in corpus of ≈500 aspects
- all aspects work out-of-the-box with default level semantics

Topological Scoping

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Execution levels

- give structure to computation
- use this structure to define scoping
- come with some properties (eg. no loop)

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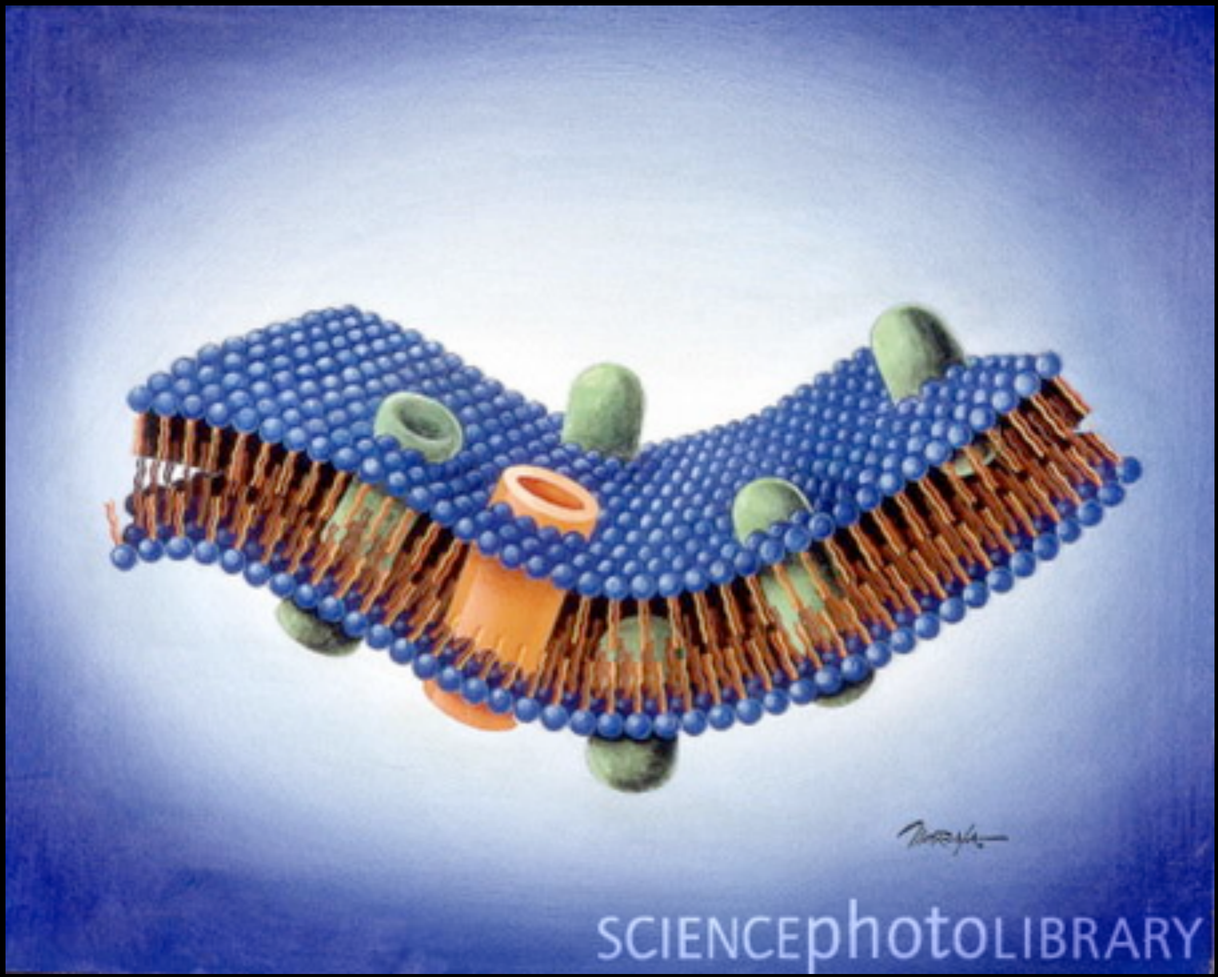
Membranes for AOP

joint work with
Nicolas Tabareau
Rémi Douence
Ismael Figueroa

GIVING STRUCTURE TO COMPUTATION

Programmable membranes [Boudol, 2004; Schmitt, 2004]

- inspired by membranes in biology



Membranes for AOP

[Tanter, 2012]

Why not use membranes for AOP?

- gives rise to flexible topological scoping
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X

Y

Membranes for AOP

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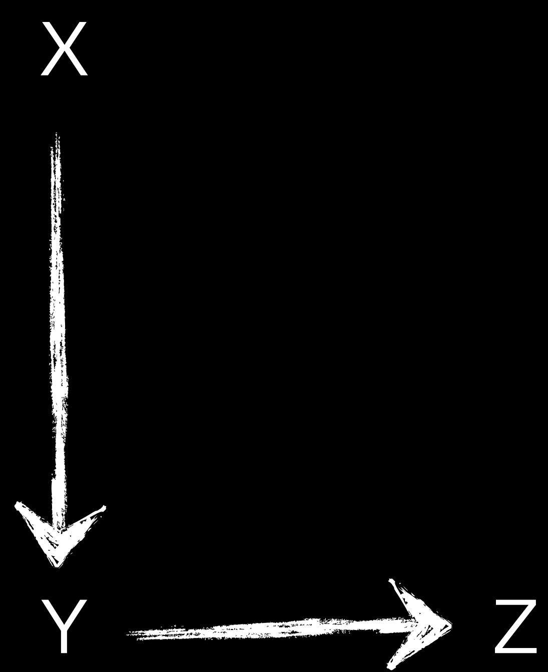

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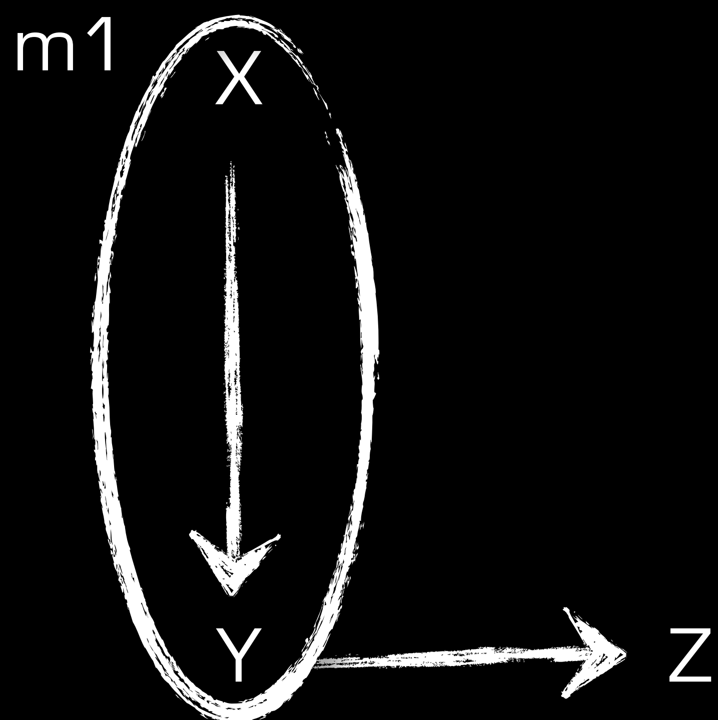

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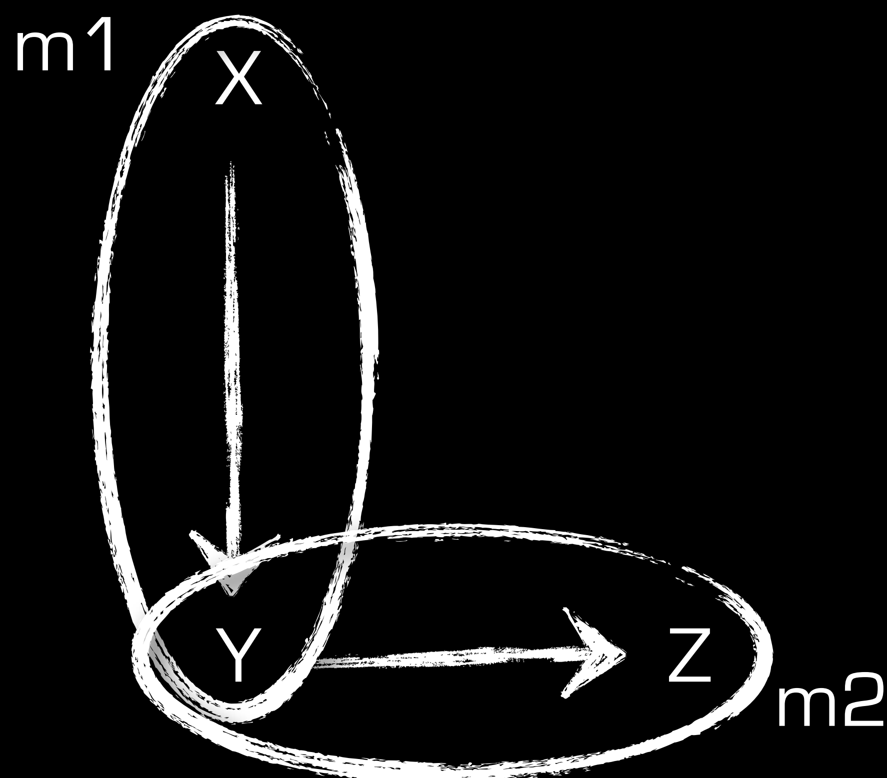

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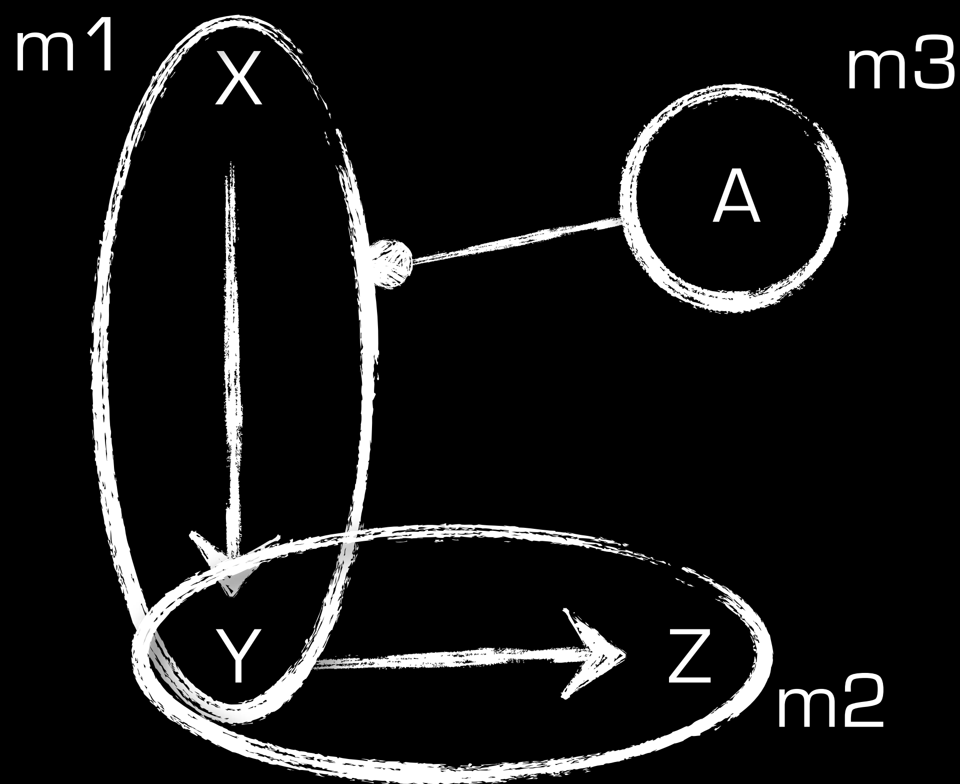

Wednesday, April 17, 13

Topological Scoping with Membranes

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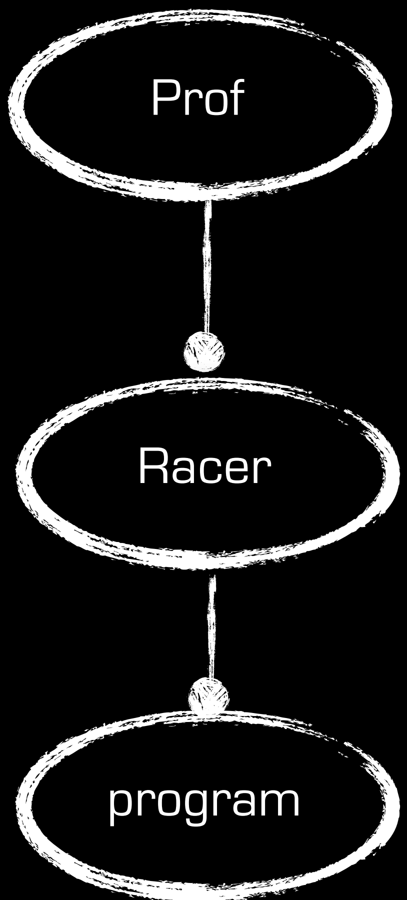
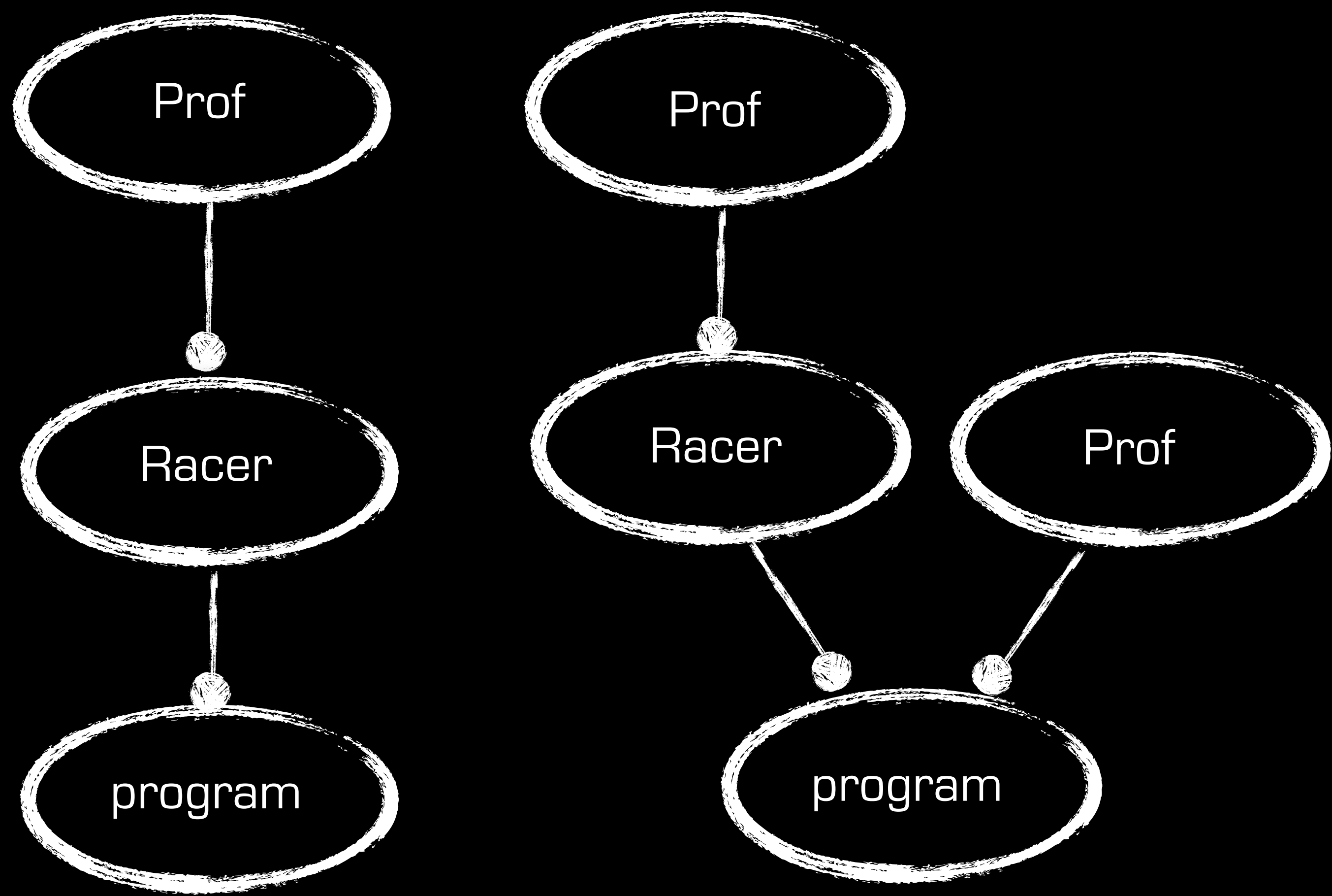


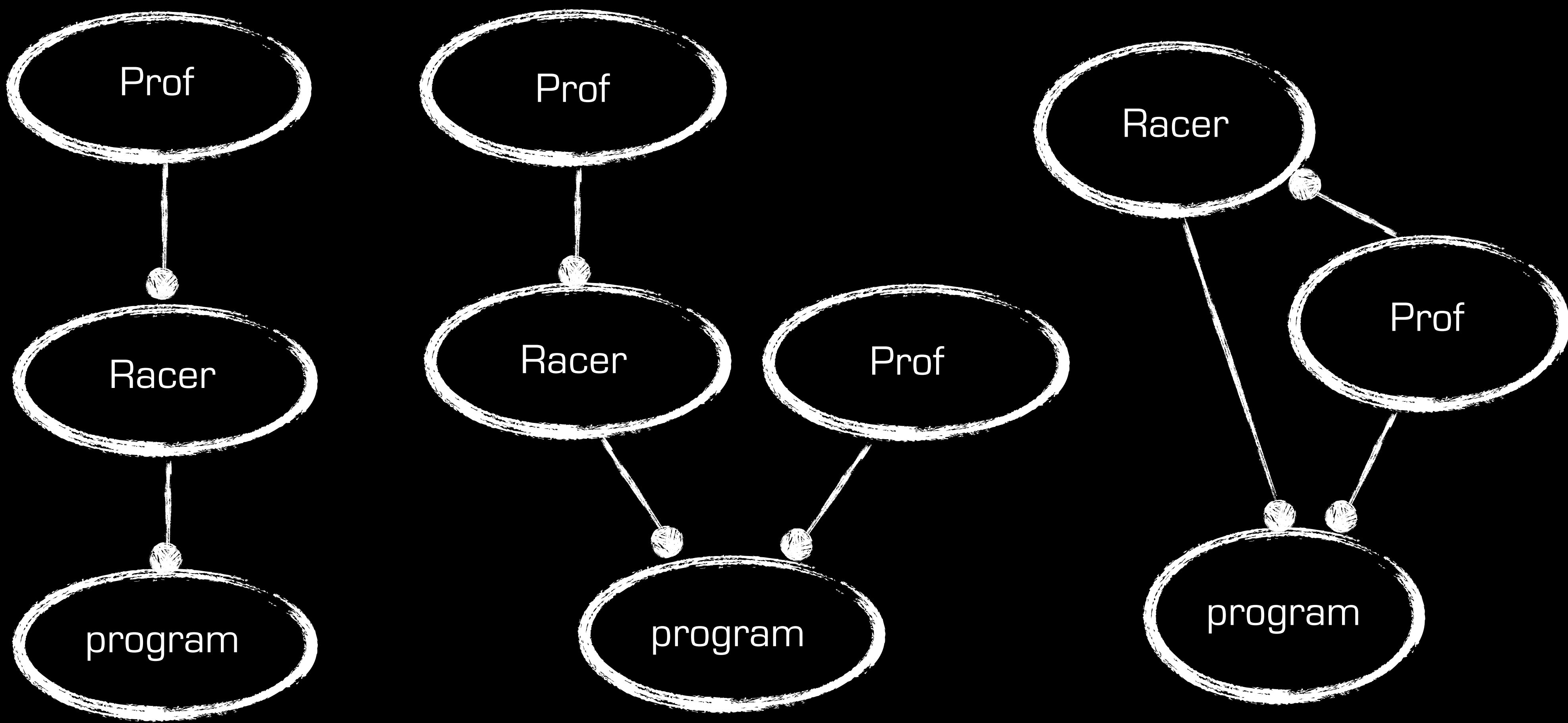
execution levels

Topological Scoping with Membranes



execution levels tree

Topological Scoping with Membranes



execution levels tree DAG

Membranes: Theory and Practice

[Figueroa, 2013]

Membranes: Theory and Practice

Wide design space

- how to create, deploy and configure membranes?
- can membranes crosscut? organized hierarchically?
- what guarantees are expected? tradeoff?
- MAScheme, AO Haskell [Figueroa, 2013]

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Exploit programmability

- ensure safety properties
- what language is useful to program membranes?
- Kell calculus

Scoping

Interfaces

Types

Effects

Scoping

Interfaces

Types

Effects

Can we reconcile quantification with modular reasoning?

What kind of static interfaces allow independent development?

Issues with Pointcut/Advice

class A

class B

class C

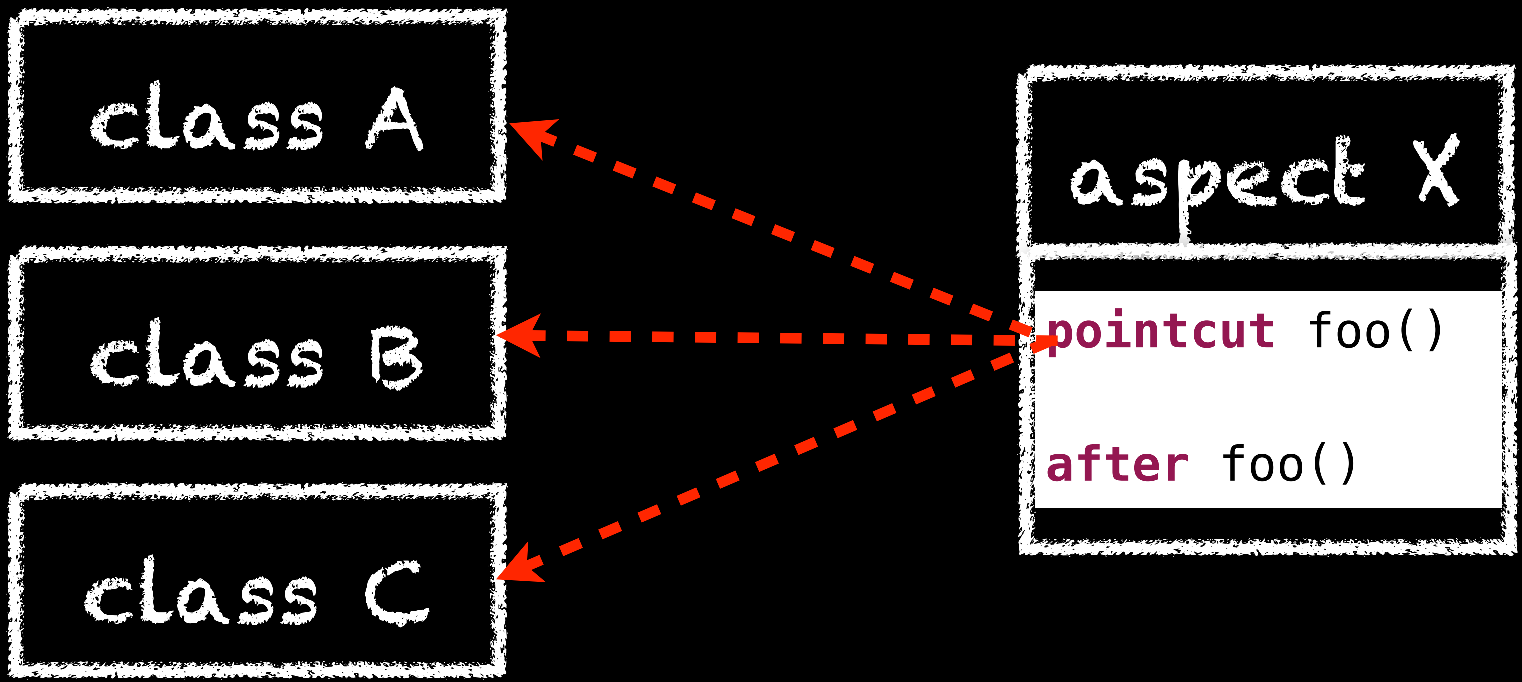
aspect X

```
pointcut foo()

after foo()
```

Issues with Pointcut/Advice

fragile dependencies



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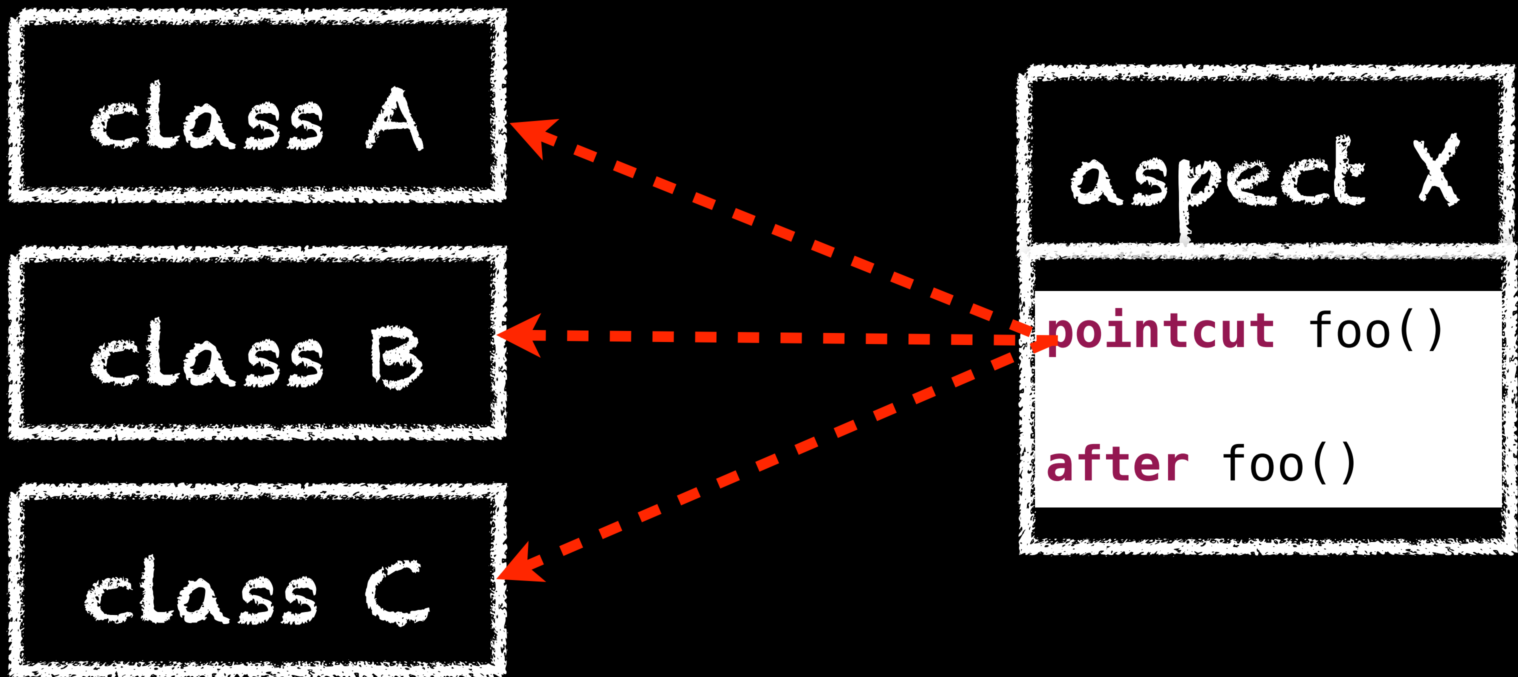

oblivious

⇒ no idea what is relied upon

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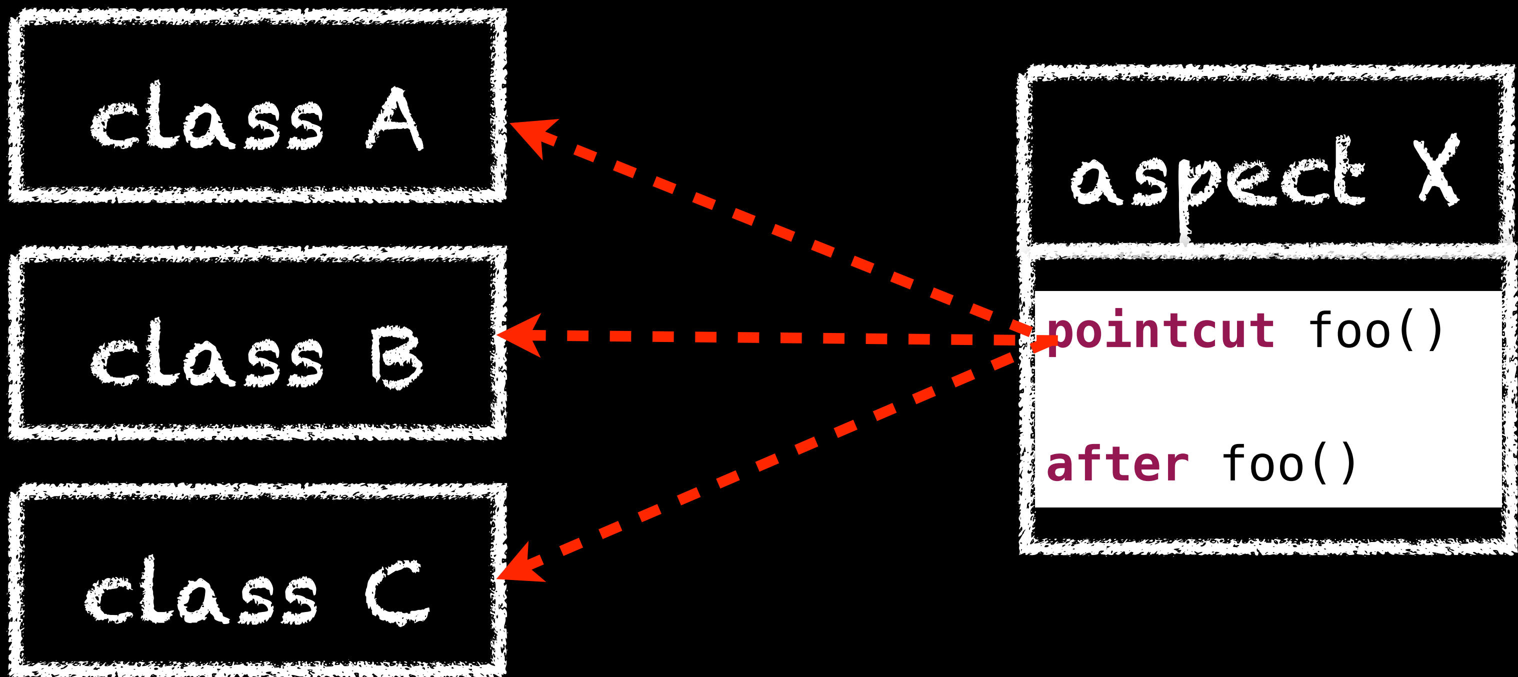

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modular reasoning?

independent development?

Modular Reasoning?

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Kiczales & Mezini [2005]

- fundamental issue is the crosscutting nature
- AOP makes the crosscutting concern explicit

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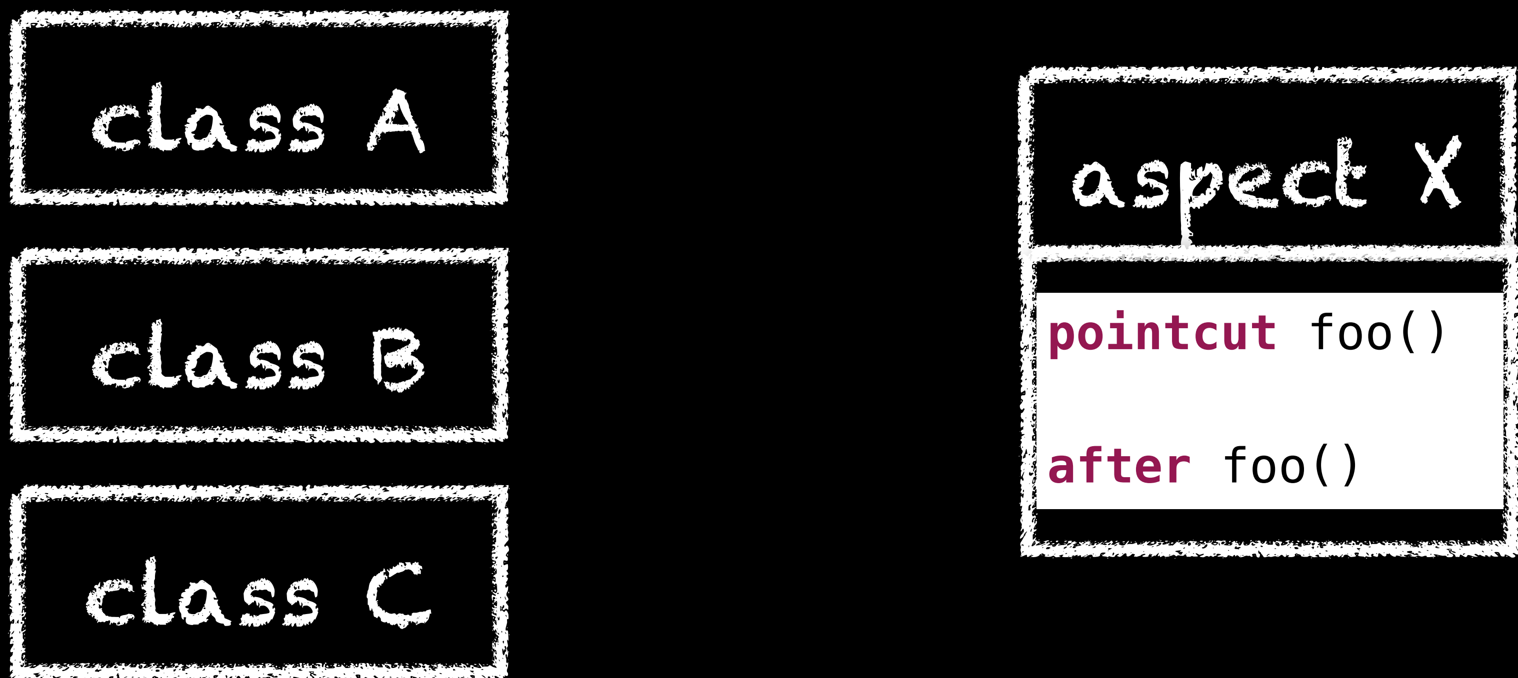

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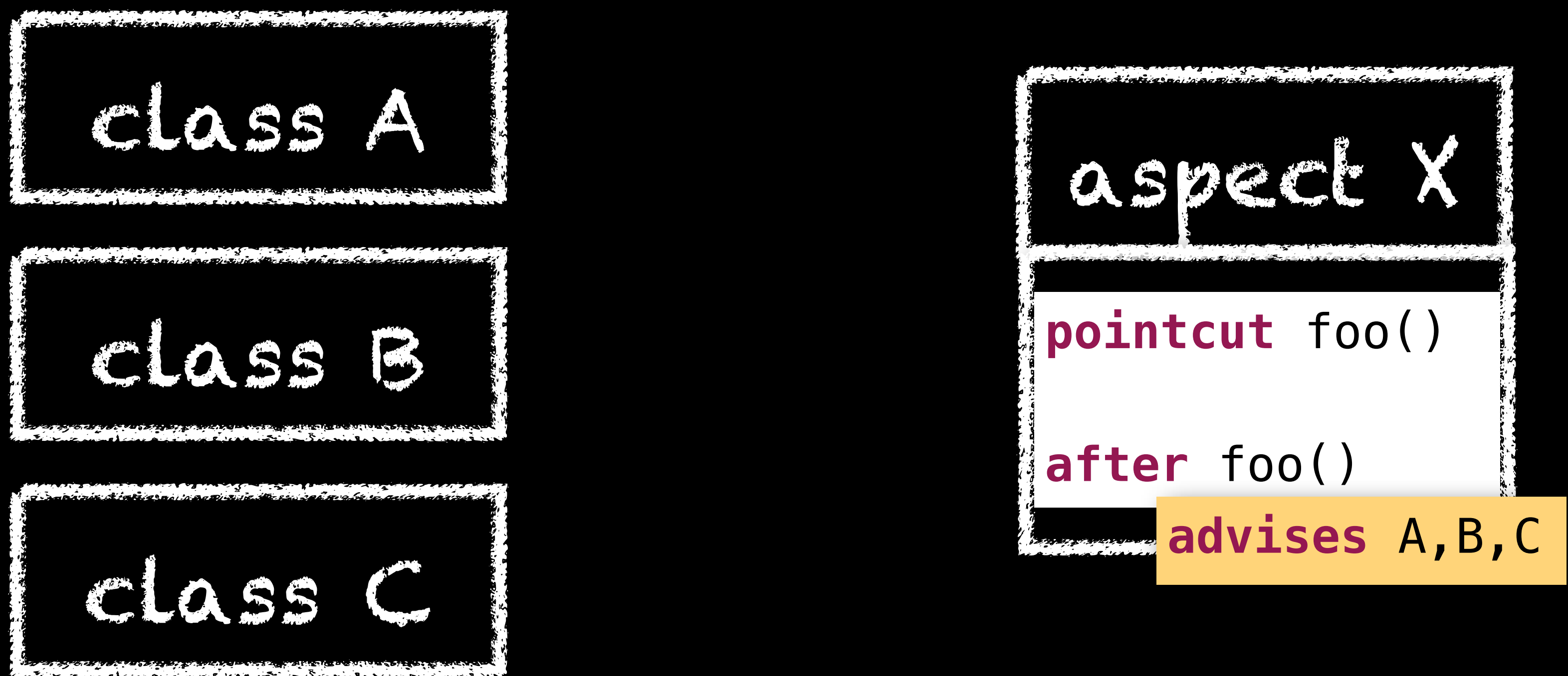

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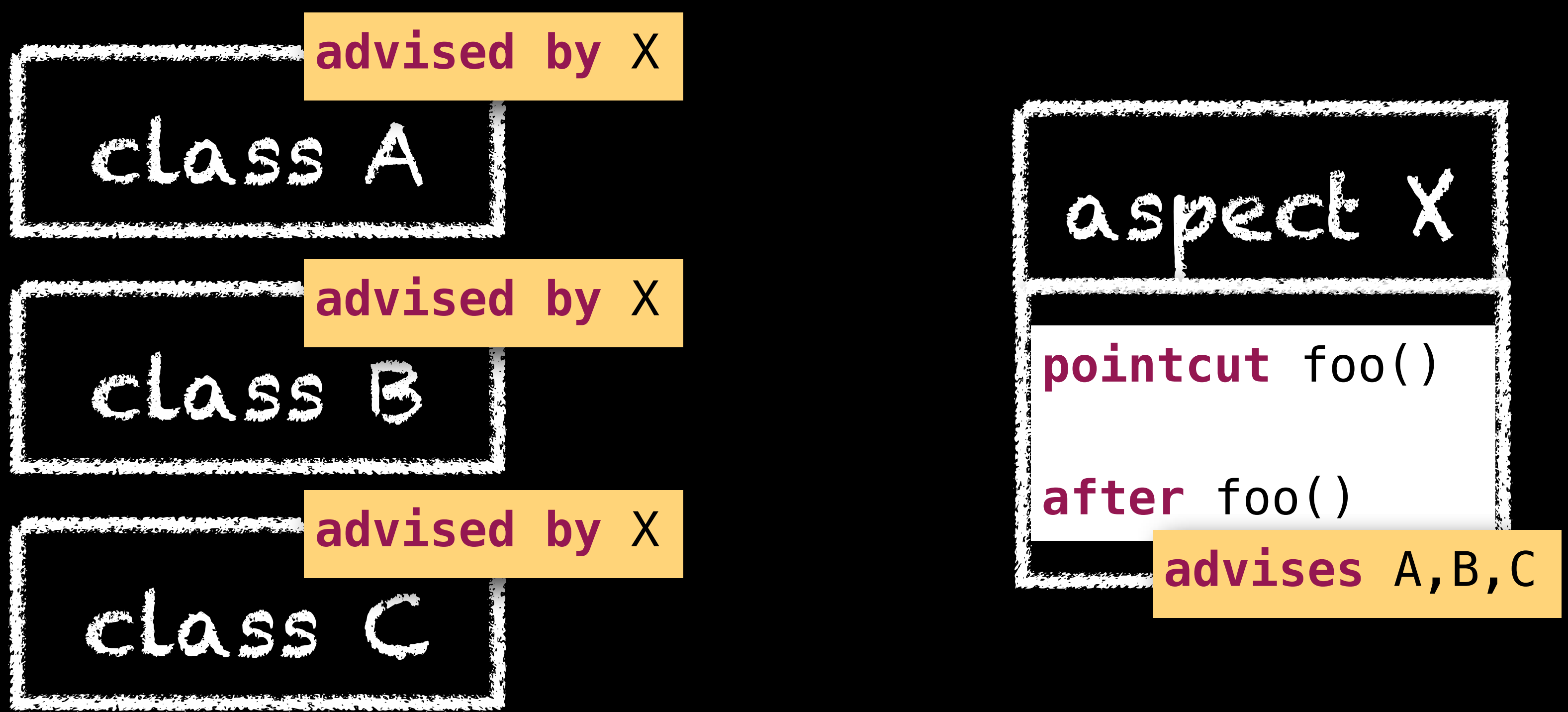

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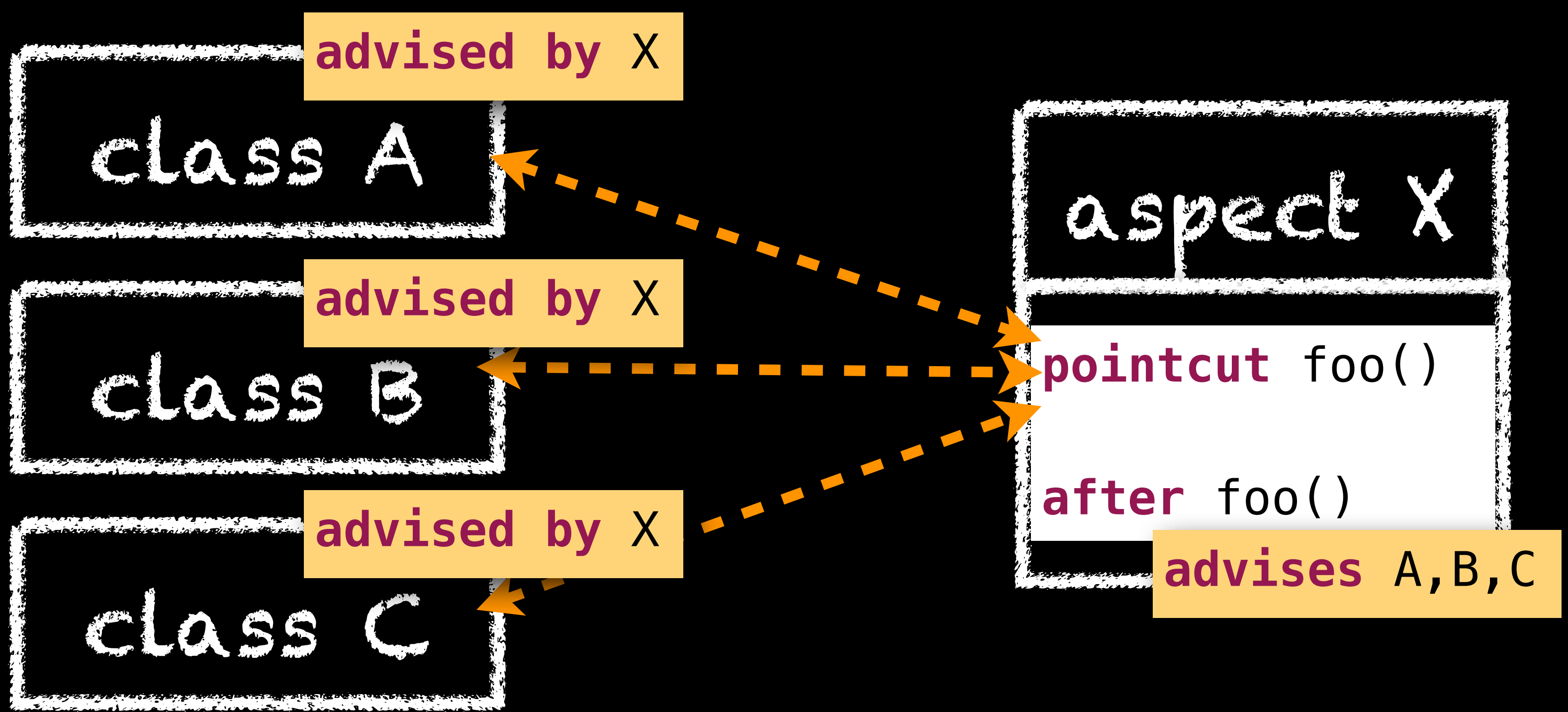

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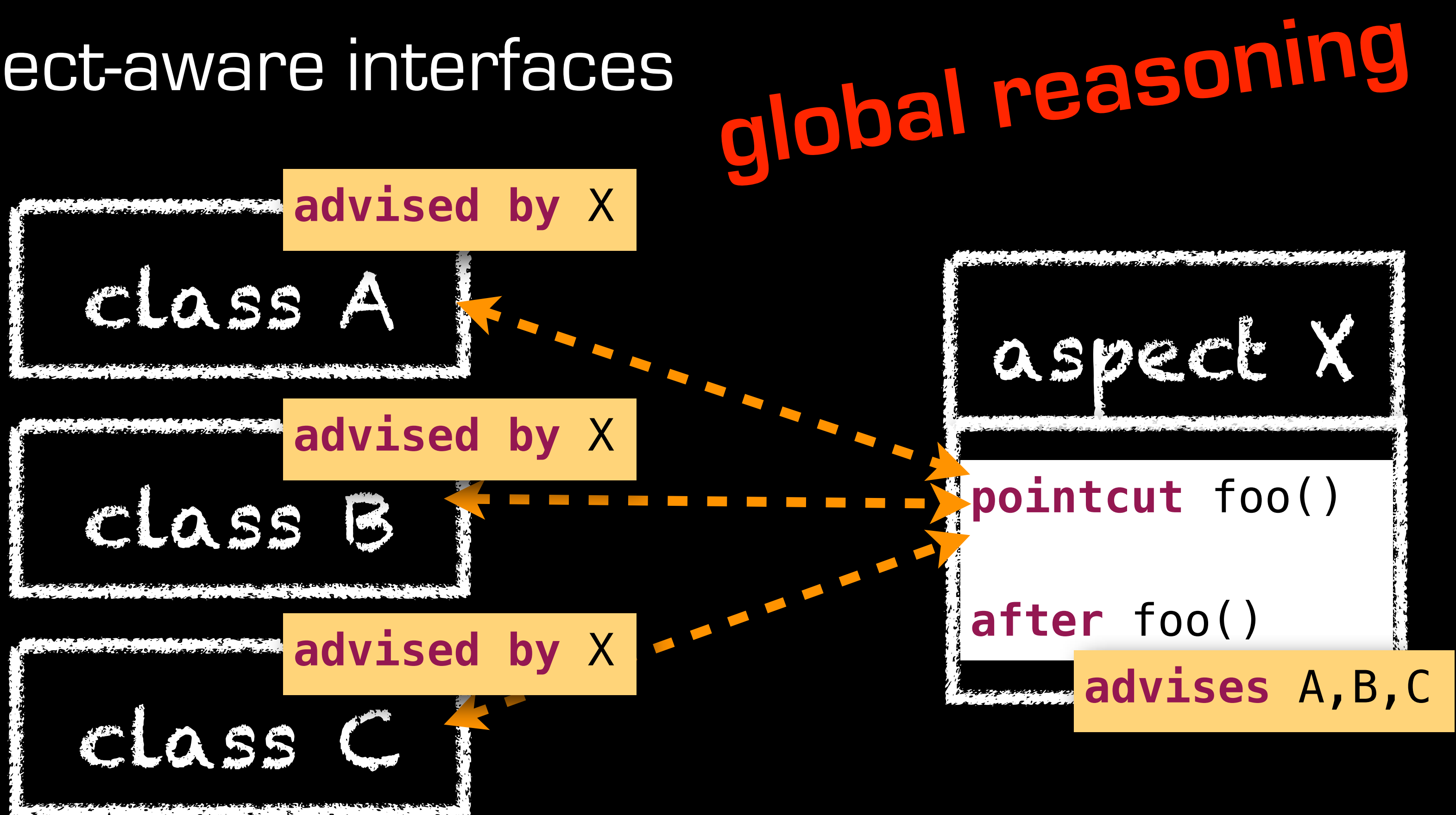

explicit dependencies

Recovering Modular Reasoning

Putting pointcuts in interfaces [Gudmundson, 2001]

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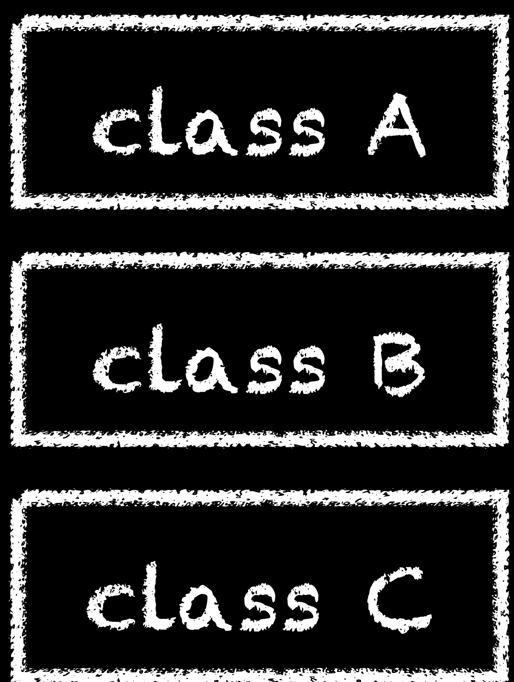

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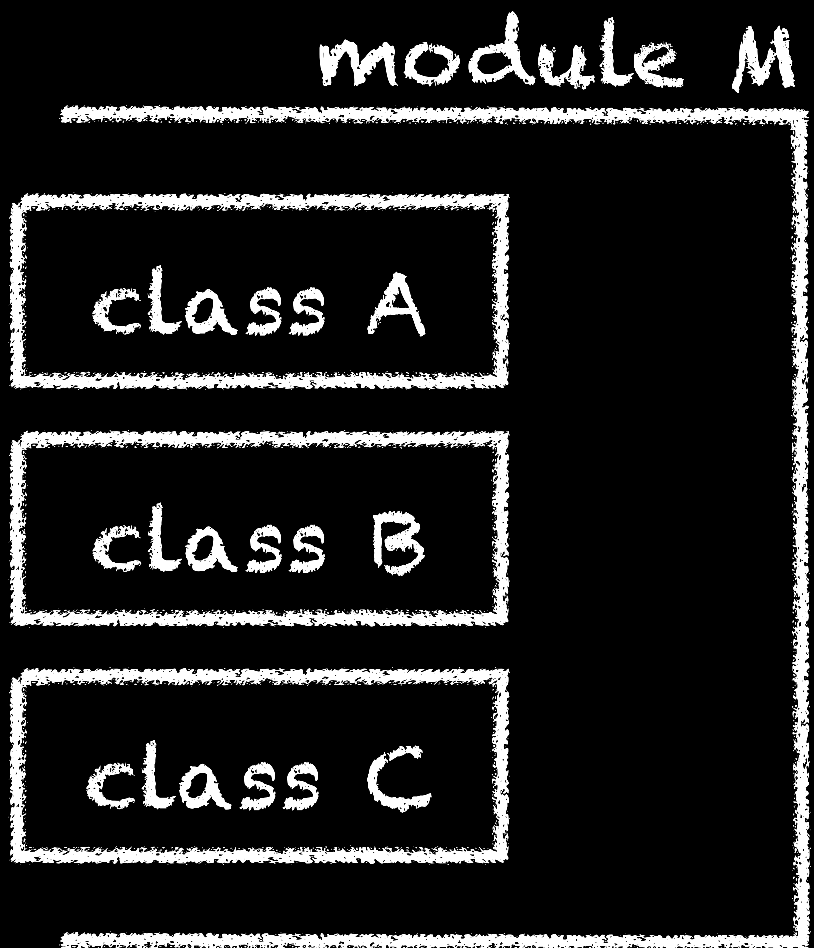

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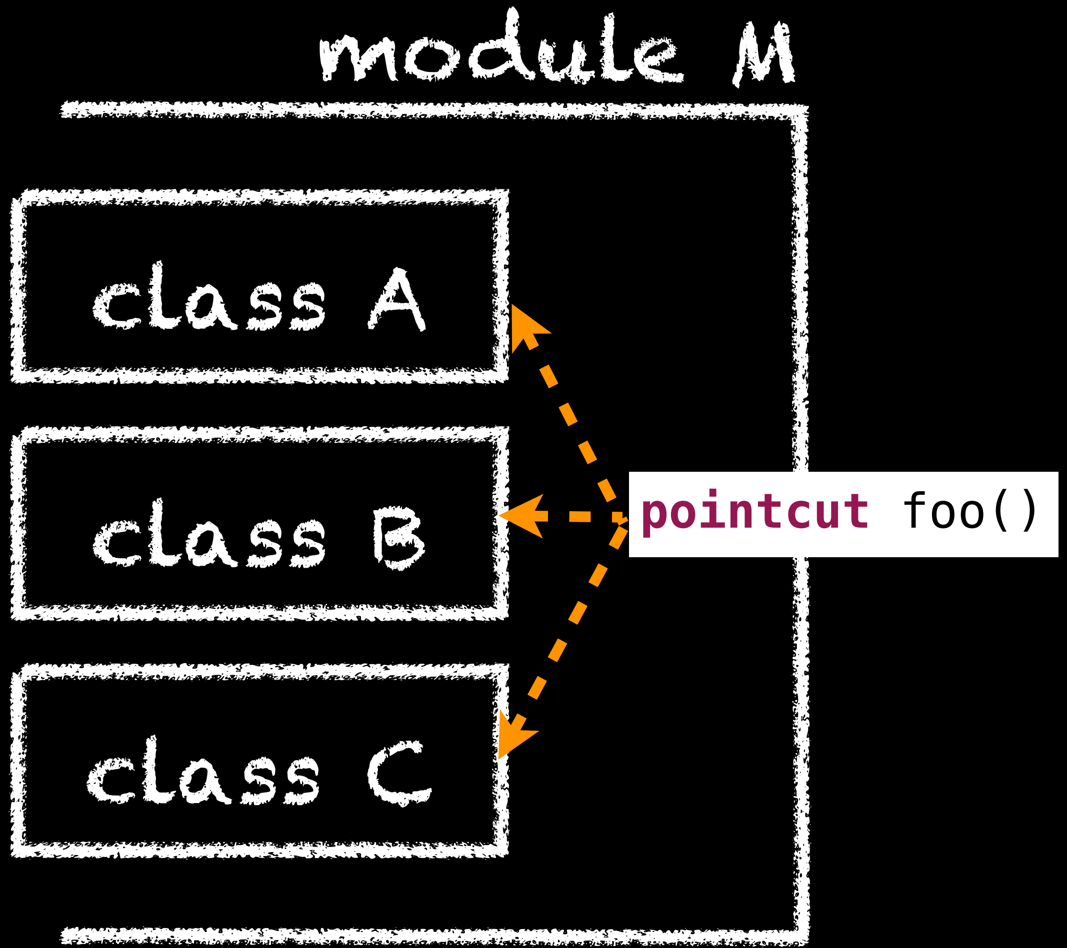

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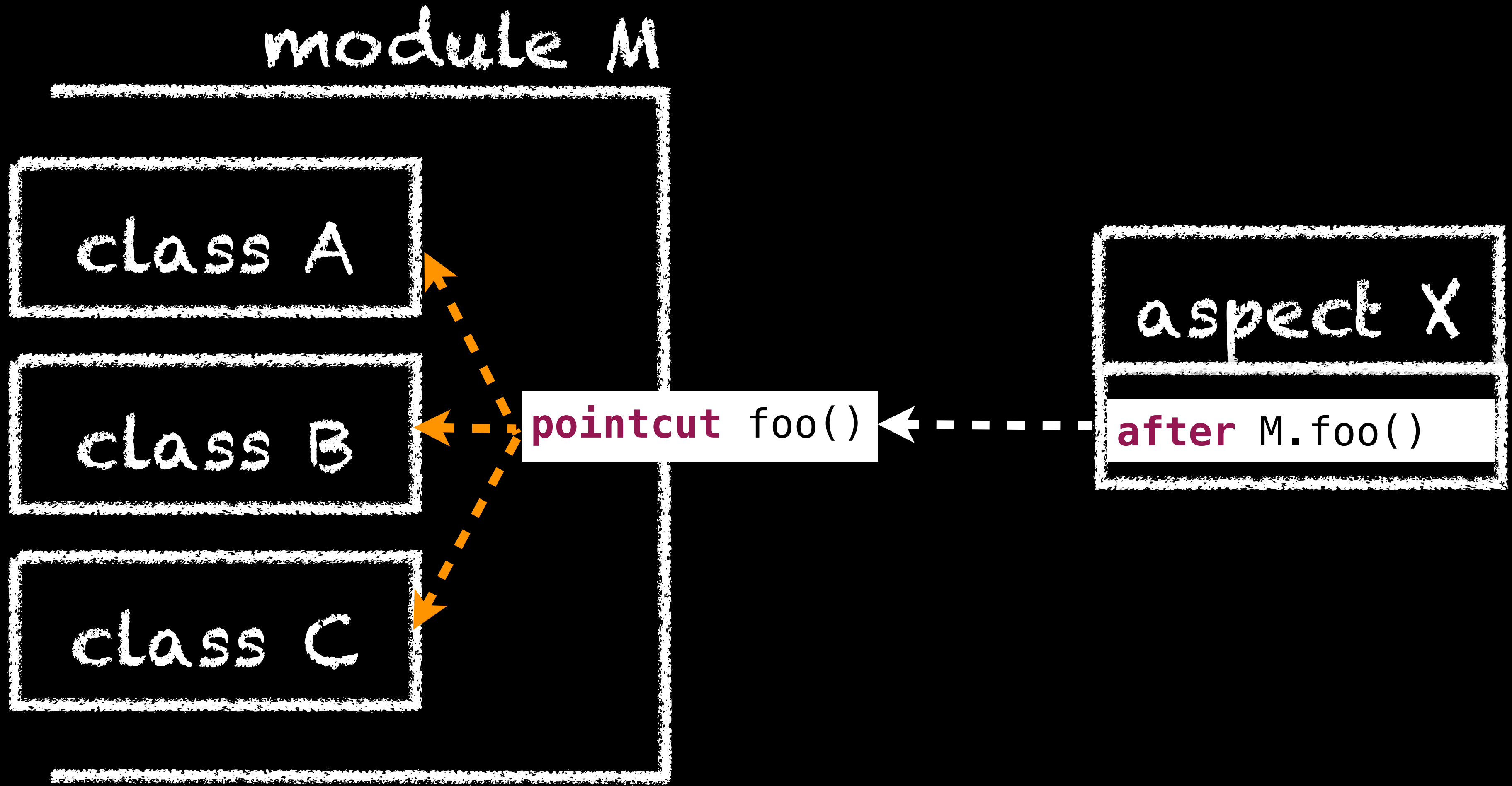
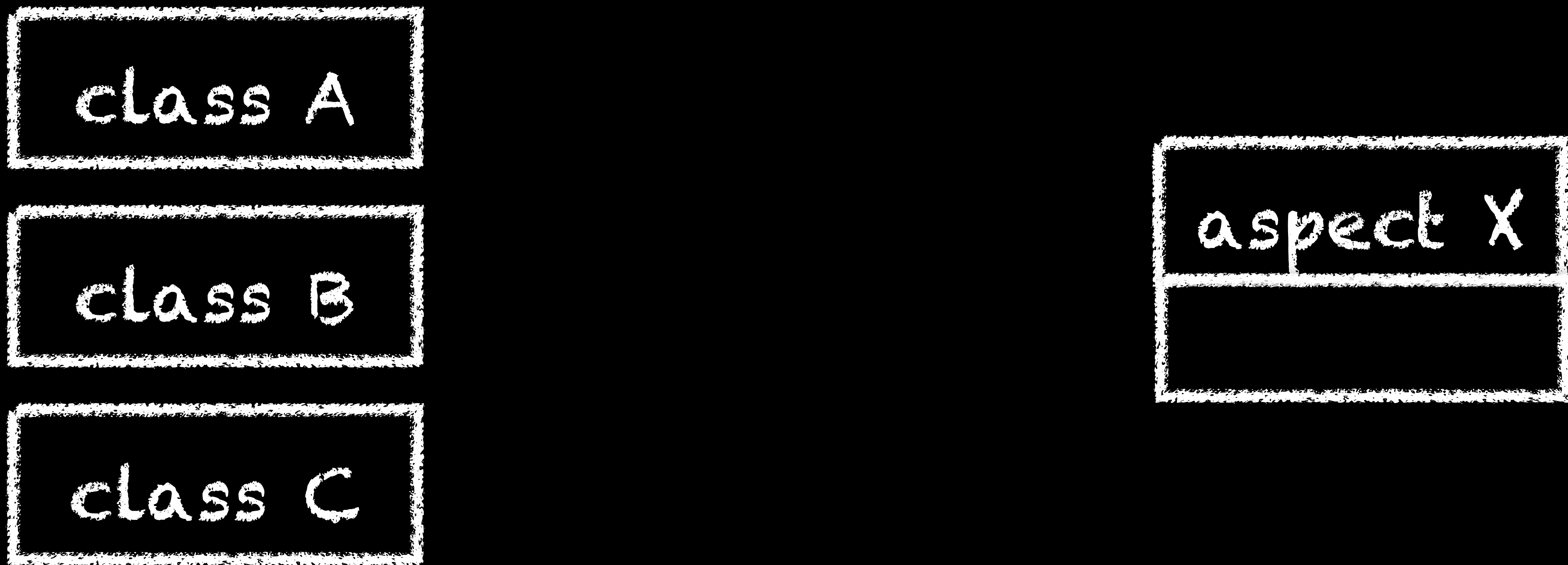


Join Point Types

[Steimann, 2010]



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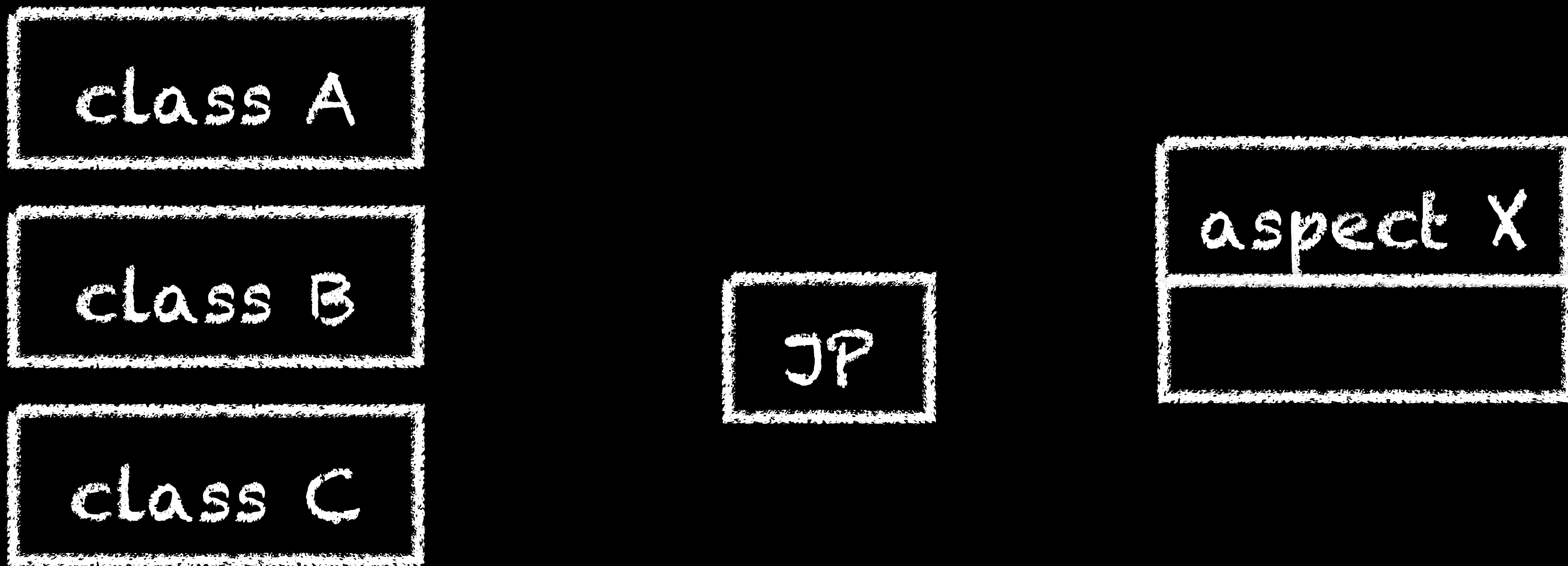

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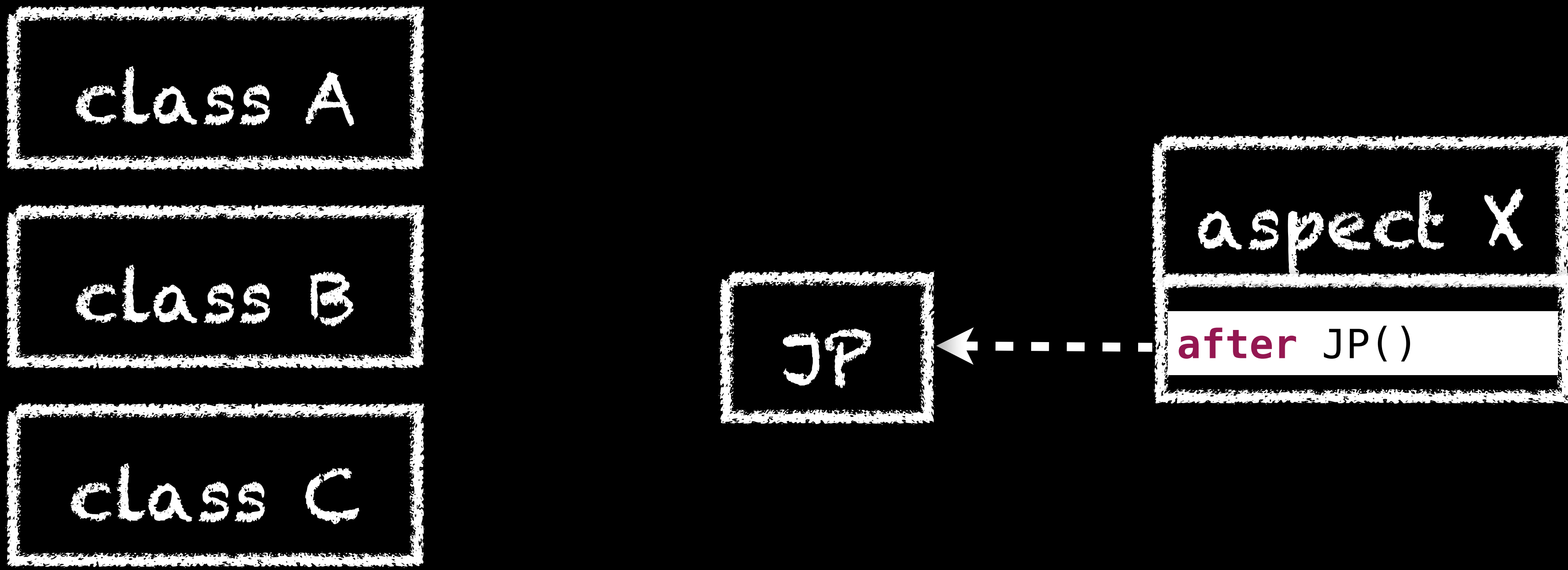

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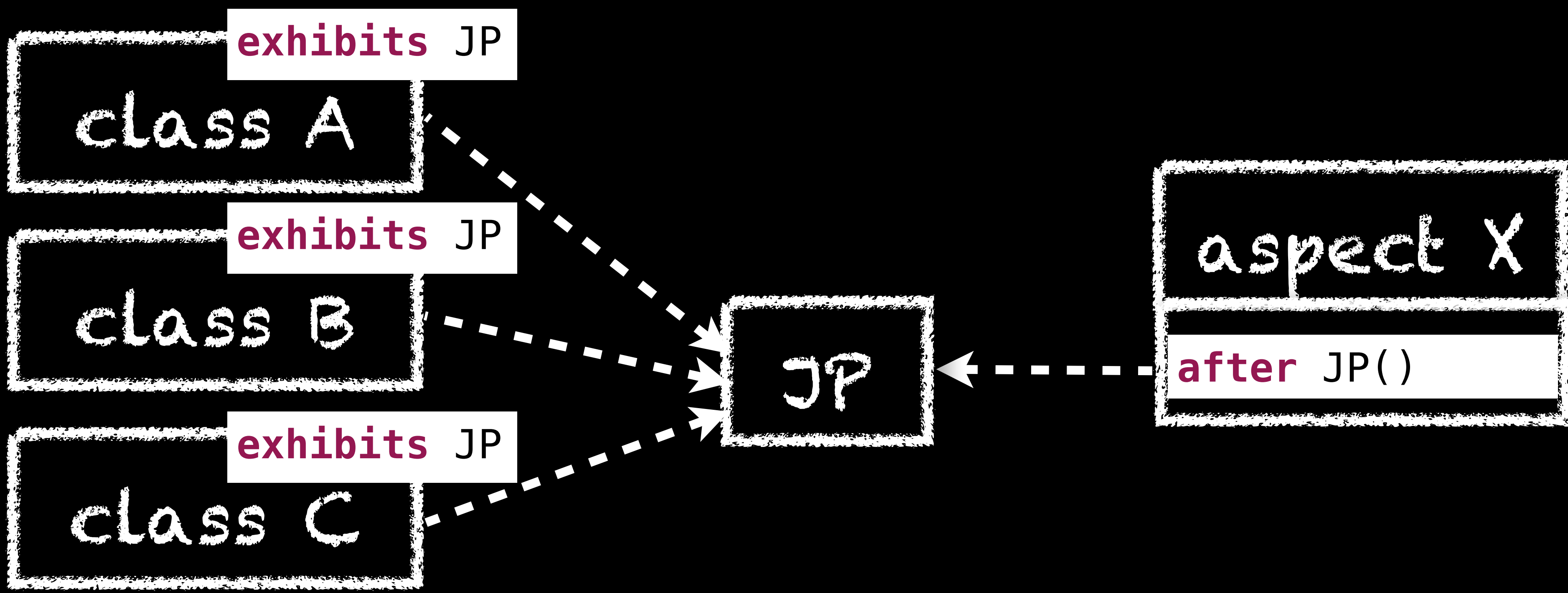

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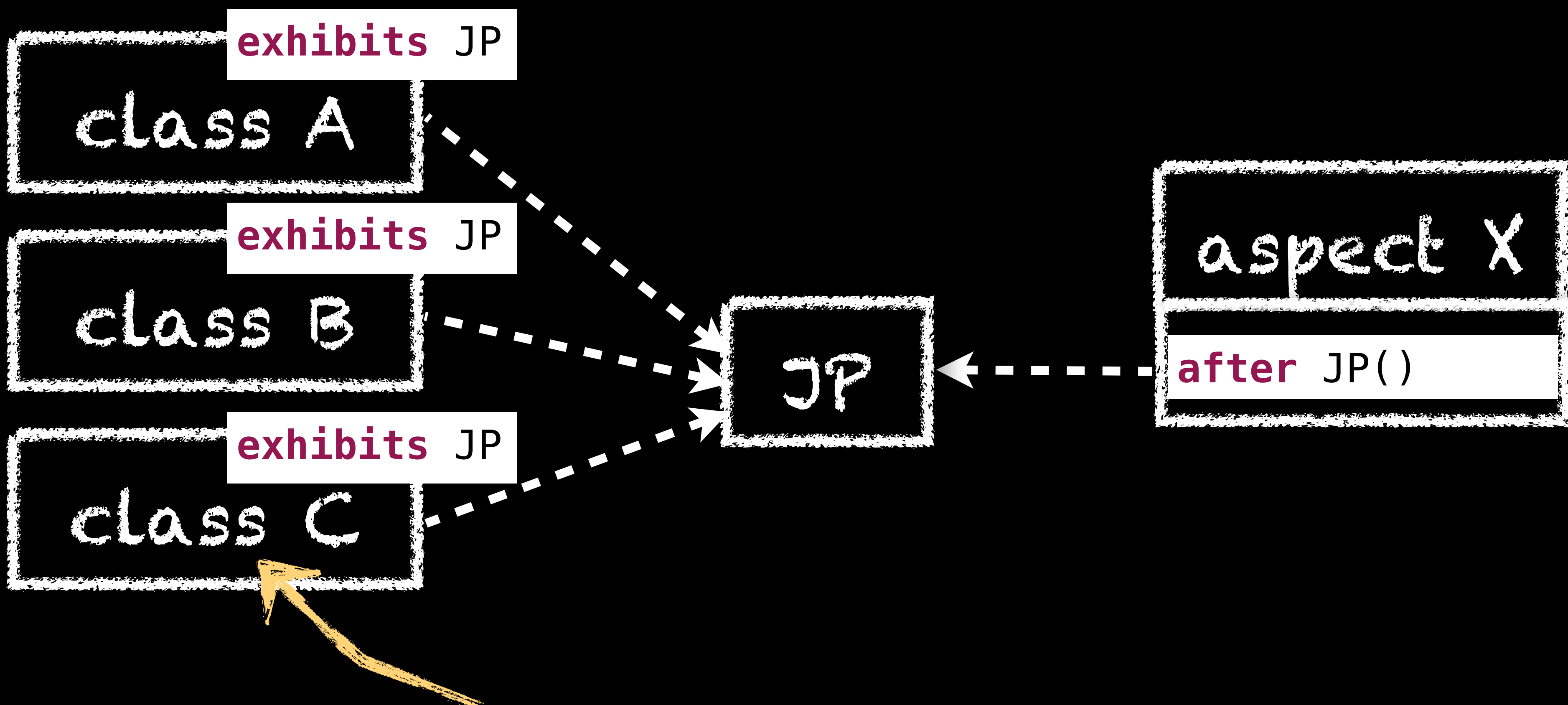

local quantification only!

```
class C exhibits JP {
  pointcut JP: execution(void setX(..)) || ...
  //...
}
```

Modularity Issues

```
joinpointtype CheckingOut {
  float price;
  Customer cus;
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```
interface IFoo {
  m(float p, String s);
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return type?

checked exceptions?

Modularity Issues

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joinpointtype CheckingOut {
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interface IFoo {
  ??? m(float p, String s) throws ???;
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return type?
checked exceptions?

not type safe

Join Point Interfaces

[Inostroza, 2011] [Bodden, TOSEM]

joint work with
Milton Inostroza
Eric Bodden

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"Join Point Types Revisited"

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- no fragile name dependencies

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- no fragile name dependencies
- expressive enough for safe modular type checking

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```
jpi void CheckingOut(float price, Customer cus) throws IOException
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"Join Point Types Revisited"

- no fragile name dependencies
- expressive enough for safe modular type checking

```
jpi void CheckingOut(float price, Customer cus) throws IOException
```

Fix other shortcomings

- join point polymorphism semantics (multiple dispatch)
- unsound use of variant typing (later)
- etc.

Quantification Issues

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Some aspects are inherently "wide"

- dynamic analyses, system-wide properties, etc.
- require a lot of exhibit clauses

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Case study

- port existing “Law Of Demeter” checking aspect

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	# exhibits
LawOfDemeter	130

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	# **exhibits**
LawOfDemeter	**130**

Cannot really ignore this kind of aspects!

Controlled Global Quantification

```
jpi JP(): execution(* *.*(..))
```

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white box

```
class A {
  //...
}
```

Controlled Global Quantification

```
jpi JP(): execution(* *.*(..))
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white box

```
class A {
  //...
}
```

black box

```
sealed class C {
  //...
}
```

Controlled Global Quantification

```
jpi JP(): execution(* *.*(..))
```

white box

```
class A {
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black box

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sealed class C {
  //...
}
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(can still expose other JPIs)

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white box

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class A {
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black box

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(can still expose other JPIs)

grey box

```
class B {
  exhibits JP(): global() && !execution(* secret(..));
  //...
}
```

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Perspectives

Perspectives

vs

Perspectives

Modular reasoning

vs

Perspectives

Modular reasoning	vs	Unanticipated extension points

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Resolving this tension is crucial

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- look back at work on Open Implementations [Kiczales, 1997]

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Modular reasoning vs Unanticipated extension points

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- look back at work on Open Implementations [Kiczales, 1997]
- exploit a taxonomy of aspects
  - quantification: narrow vs. wide
  - life cycle: development vs. production

Scoping

Interfaces

Types

Effects

Scoping

Interfaces

Types

Effects

Can we ensure that aspects do not break type soundness?

Interaction with other features?
(eg. polymorphism)

Typing Aspects

Safe pointcut/advice binding

- advice can replace computation
- should not introduce runtime type errors

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well-typed
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+

well-typed aspect (?)

→

well-typed
composed program
???

Subtype Polymorphism

Aspects and Subtyping

Principles

- body of advice must adhere to advice signature
- pointcut signature <: join point signatures
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```
void around(Person p): execution(void *()) && this(p){
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```
Person -> void
```

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`Person -> void`   `Person -> void`

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unsafe!
(AspectJ, Join Point Types)

Invariance in Practice

joint work with
Milton Inostroza
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A simple solution is to prohibit type variance

- first version of JPIs
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advices

	AspectJ	JPI
AJHotDraw	49	**77**
LawOfDemeter	6	**68**

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Generic JPIs

- type parameters [Jagadeesan, 2006]

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Beyond genericity: type ranges [De Fraine, 2008/2010]

- flexible type-safe replacement advice
- ... added complexity (no free lunch :/)

Parametric Polymorphism

joint work with

Ismael Figueroa

Nicolas Tabareau

A Typed Functional Embedding of First-Class Aspects

A Typed Functional Embedding of First-Class Aspects

join points represent function applications

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fib 10
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how to ensure the aspect is well-typed?

(broken)

Matched Types

annotate PC with their **matched type**

```
data PC a b = PC (forall a’ b’. JP a’ b’ → Bool)
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(broken)

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```

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adv :: Advice Char Char
adv proceed c = proceed (toUpper c)
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✓ unifiable

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unifiable

```
id ‘a’
```

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✔ unifiable

```haskell
id ‘a’
```

✔

```haskell
id [True,False]
```

✘

```
data Aspect a b = Aspect (PC a b) (Advice a b)
```

```
pc :: PC a  a
pc = pcCall id
```

```
adv :: Advice Char Char
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```

unifiable

```
id ‘a’
```

```
id [True,False]
```

Problem: **unification is symmetric**

Well-typed Aspects

```
data Aspect a b c d = Aspect (PC a b) (Advice c d)
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Well-typed Aspects

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A multi-parameter type class defines a **relation** between types

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Composing Pointcuts

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primitive pointcut designators

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pcCall, pcType :: (a → b) → PC a b
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pcAnd :: PC a b → PC a b → PC a b
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pcNot :: PC a b → PC c d
```

```
pcOr  :: (LeastGen (a→b) (c→d) (e→f)) ⇒
         PC a b → PC c d → PC e f
```

```
pc1 :: PC Int Int
```

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```

rely on anti-unification

Advantages of the Approach

[Tabareau, 2013]

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Type soundness

- proof follows from correctness of LeastGen
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Compact implementation

- 1K vs. 15-25K for AspectML and AspectualCaml

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Monadic embedding as a Haskell library

Scoping

Interfaces

Types

Effects

Scoping

Interfaces

Types

Effects

Can we control what advice can do?
(proceed, args/return, side effects)

Beyond Types

Beyond Types

Type soundness does not tell much

- control effects through proceed?
- arbitrary effects?

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Type soundness does not tell much

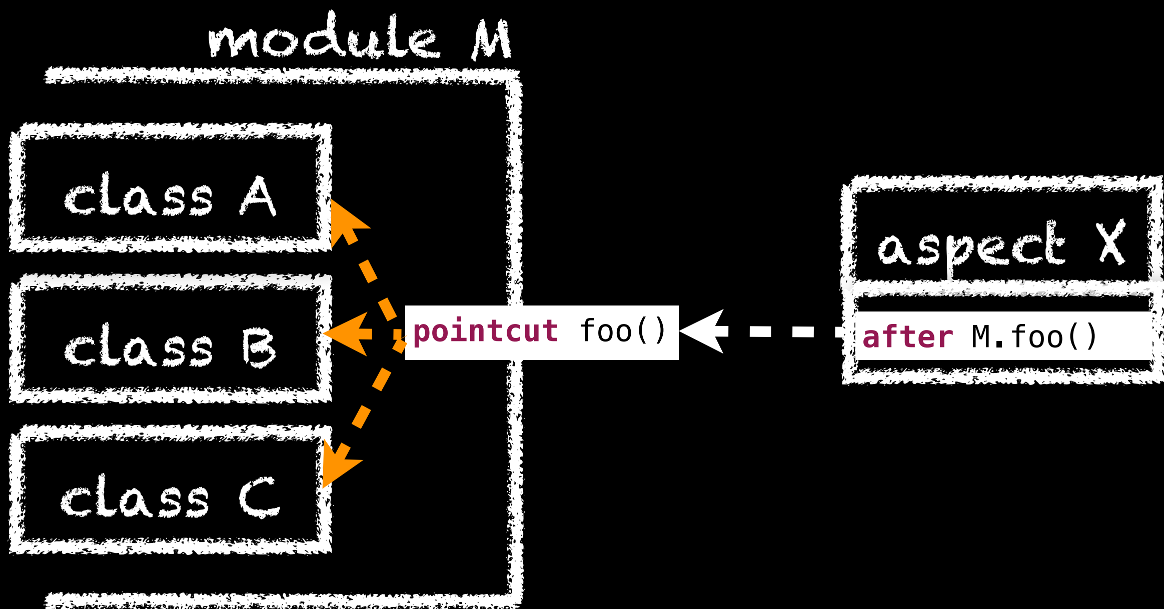
- control effects through proceed?
- arbitrary effects?

Expressive aspect specifications

- black-box behavioral contracts [Skotiniotis, 2004; Zhao, 2003]...
- control effects [Rinard, 2004]
- translucid contracts [Bagherzadeh, 2011]
- model checking [Katz, 2003; Krishnamurthi, 2004]...

Rich Types

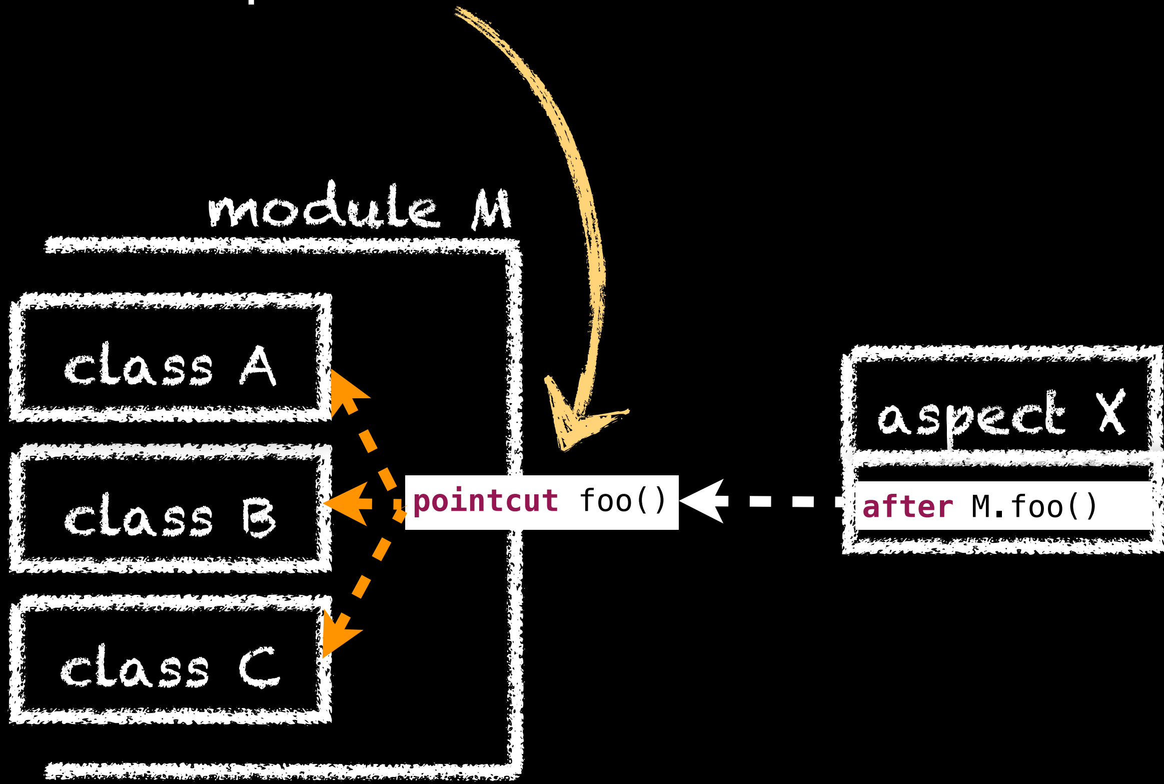
Rich Types



module M
class A
class B
class C
pointcut foo()
aspect X
after M.foo()

Rich Types

Can we enrich aspect interfaces with effect specs?



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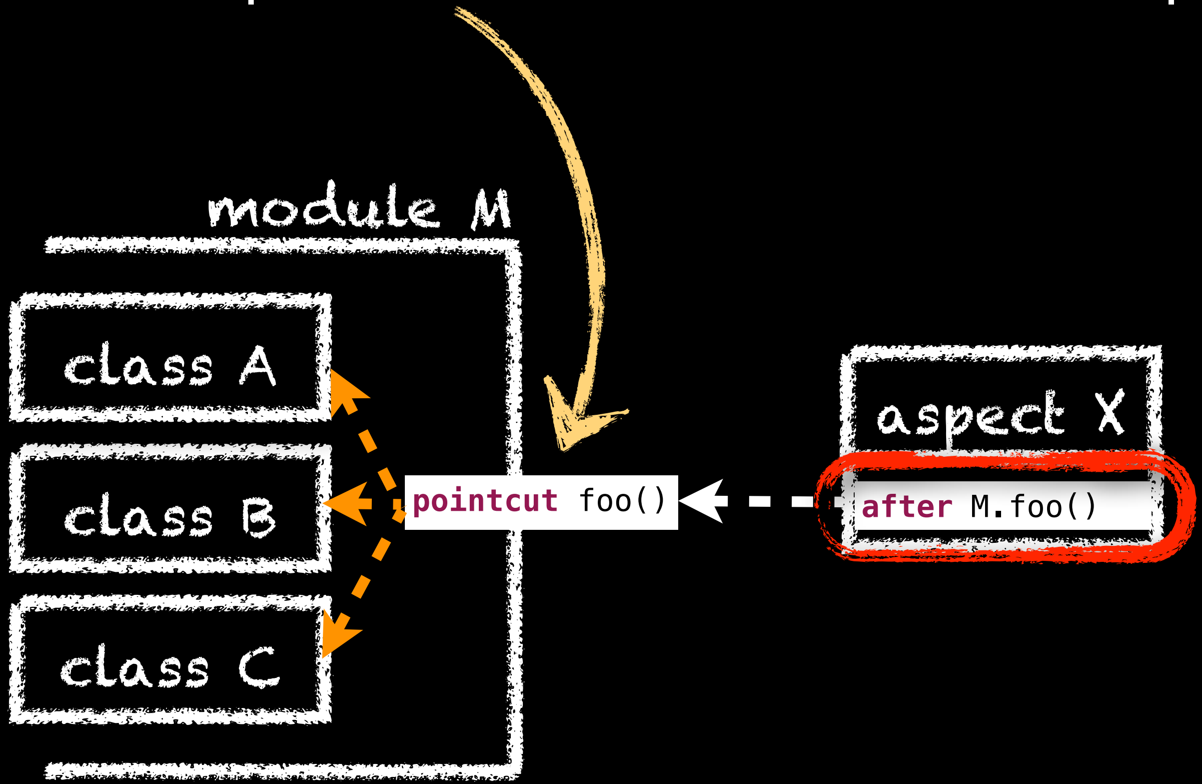

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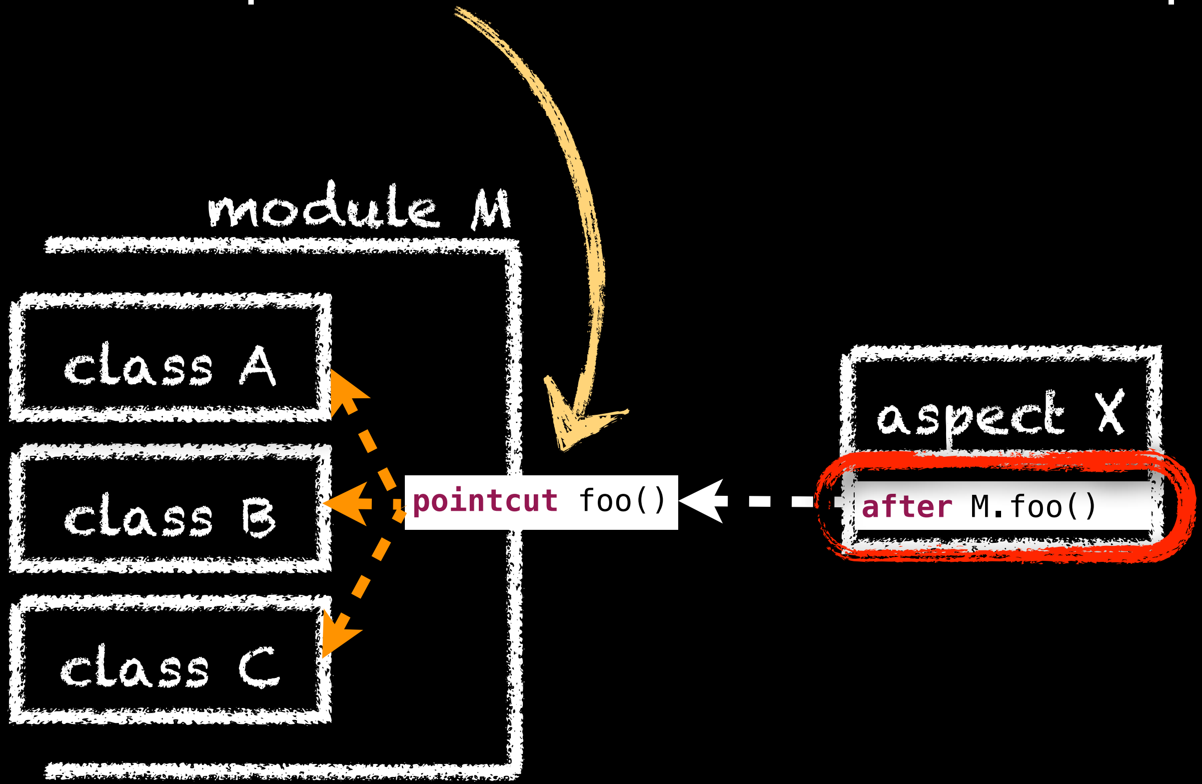

The Haskell type system deals with effects!

All You Need to Know About Monads (for this talk)

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Purity is the default

```
foo :: Int → Int
```

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Side effects reflected in types

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monads

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Several effects

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foo :: Int → App Int
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```
type App = ReaderT AppConf (StateT AppState IO)
```

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monad transformers

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Several effects

"effect stack"

```haskell
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IO

"effect stack"

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“effect stack”

Several effects

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Reader AppConf

State AppState

IO

“effect stack”

Several effects

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foo :: Int → App Int
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type App = ReaderT AppConf (StateT AppState IO)
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Reader AppConf
State AppState
IO

"effect stack"

```
foo :: (Monad m) ⇒ Int → m Int
```

All You Need to Know About Monads (for this talk)

Purity is the default

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Side effects reflected in types

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type App = ReaderT AppConf (StateT AppState IO)
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Reader AppConf
State AppState
IO

“effect stack”

```
foo :: (Monad m) ⇒ Int → m Int
```

(we’ll omit the constraints on monadic type variables)

Talking About Effects

joint work with
Ismael Figueroa
Nicolas Tabareau
[Tabareau, 2013]

Parametrize the model by the effect stack

```
data JP a b = JP (a → b) a
data PC a b = PC (forall a’ b’. JP a’ b’ → Bool)
type Advice a b = (a → b) → a → b
data Aspect a b c d =
  (LessGen (a→b) (c→d)) ⇒ Aspect (PC a b) (Advice c d)
```

Talking About Effects

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Parametrize the model by the effect stack

```
data JP m a b = JP (a → m b) a
data PC m a b = PC (forall a’ b’. m JP a’ b’ → m Bool)
type Advice m a b = (a → m b) → a → m b
data Aspect m a b c d =
  (LessGen (a→b) (c→d)) ⟹ Aspect (PC m a b) (Advice m c d)
```

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Parametrize the model by the effect stack

```
data JP m a b = JP (a → m b) a
data PC m a b = PC (forall a’ b’. m JP a’ b’ → m Bool)
type Advice m a b = (a → m b) → a → m b
data Aspect m a b c d =
  (LessGen (a→b) (c→d)) ⟹ Aspect (PC m a b) (Advice m c d)
```

Computation happens within the AOT monad transformer

```
newtype AOT m a = ...
```

(used to pass the aspect environment around)

Embedding Type Constraints in Pointcuts

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```
module Fib (fib, pcFib) where
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innerFib = ...
fib = ...
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```

```
pcFib :: PC m Int Int
pcFib = pcCall innerFib
```

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```

```
comb :: t → Advice m a b
```

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module Fib (fib, pcFib) where
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Embedding Type Constraints in Pointcuts

```
module Fib (fib, ppcFib) where
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innerFib = ...
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```

```
ppcFib :: ProtectedPC m Int Int t a b
ppcFib = protectPC pcFib comb
```

```
pcFib :: PC m Int Int
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```
myadvice :: t
myadvice = ...
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```
myaspect = aspect ppcFib myadvice
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```

```
comb :: t → Advice m a b
```

```
myaspect = aspect ppcFib myadvice
```

control effects & side effects

Control Flow Effects

[Rinard, 2004]

Control Flow Effects

[Rinard, 2004]	**definition**
combination	free
replacement	no proceed
augmentation	proceed once same arg/ret
narrowing	proceed at most once same arg/ret

Control Flow Effects

EffectiveAdvice
[Oliveira, 2010]

[Rinard, 2004]	definition	type
combination	free	`Advice m a b`
replacement	no proceed	
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Wednesday, April 17, 13

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memoization?

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memoization?

Enforcing Narrowing Advice

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type Narrow m a b c = (a → m Bool, Augment m a b c, Replace m a b)
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combinator that requires Narrow

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narrow :: Narrow m a b c → Advice m a b

narrow (pred, aug, rep) proceed x =
  do b <- pred x
     if b then replace rep proceed x
          else augment aug proceed x
```

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memoize = ...
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memoize = ...
```

```
crazy :: Advice ...
crazy = ...
```

Effect Interference

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Reason about interferences base/aspects [Oliveira, 2010]

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```
AOT m a
```

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```
AOT m a
```

Error d
Reader c
State b
IO

Effect Interference

Reason about interferences base/aspects [Oliveira, 2010]

`NIAOT t m a`

Error d

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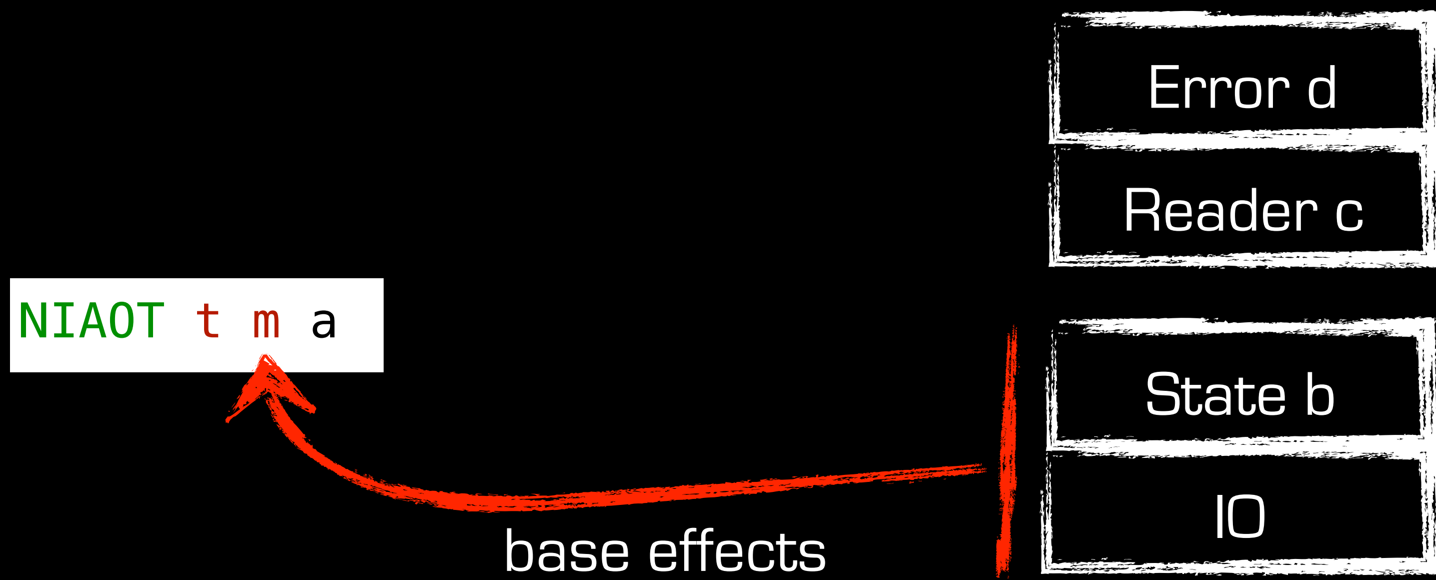
Effect Interference

Reason about interferences base/aspects [Oliveira, 2010]



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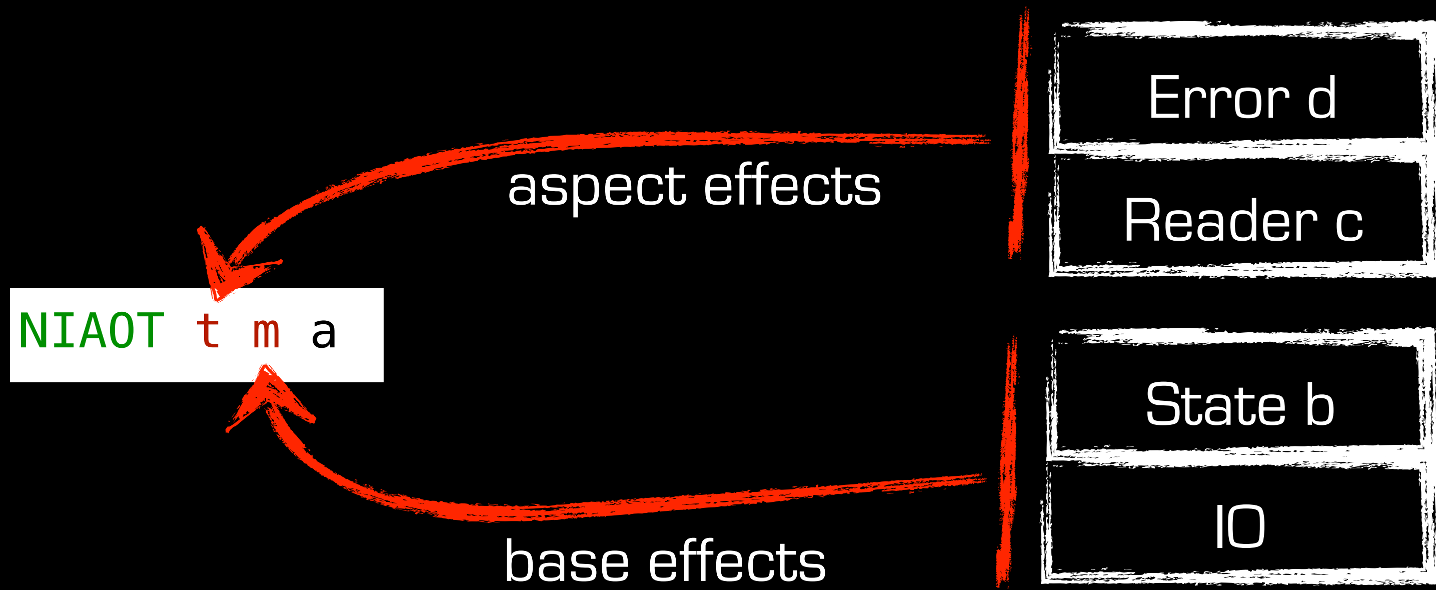

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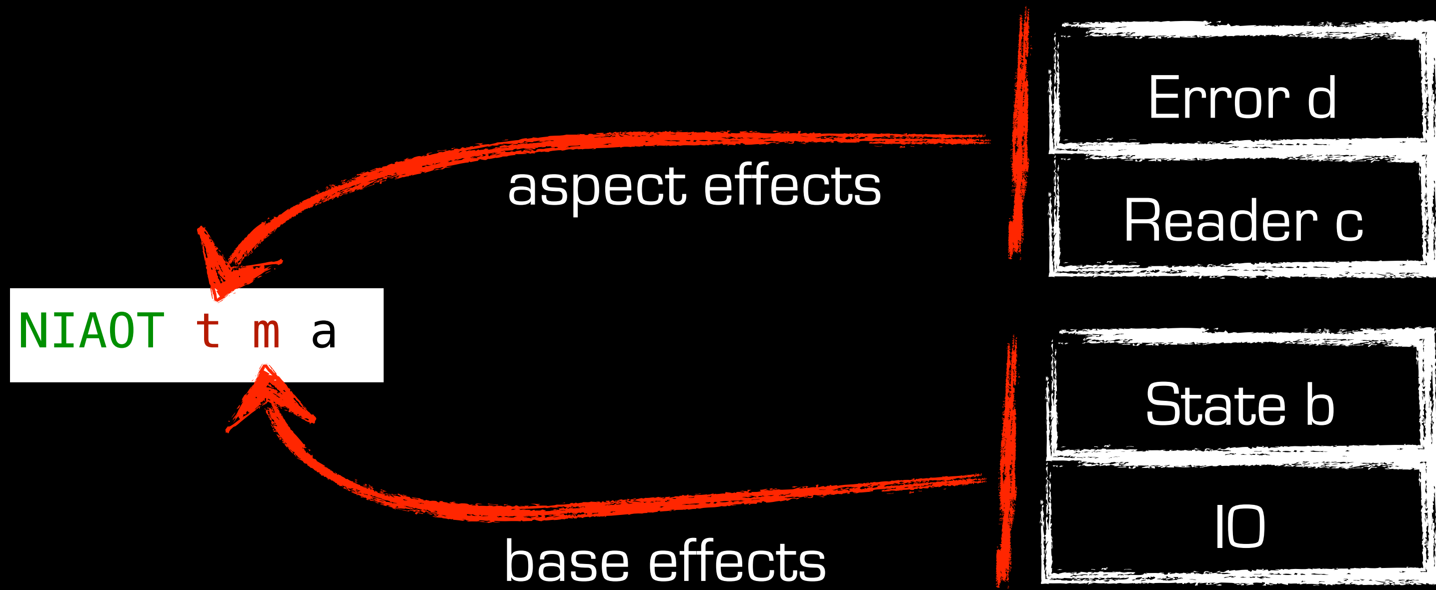


rely on parametricity to enforce non-interference

Effect Interference

Reason about interferences base/aspects [Oliveira, 2010]

`NIAOT t m a`

aspect effects

Error d

Reader c

base effects

State b

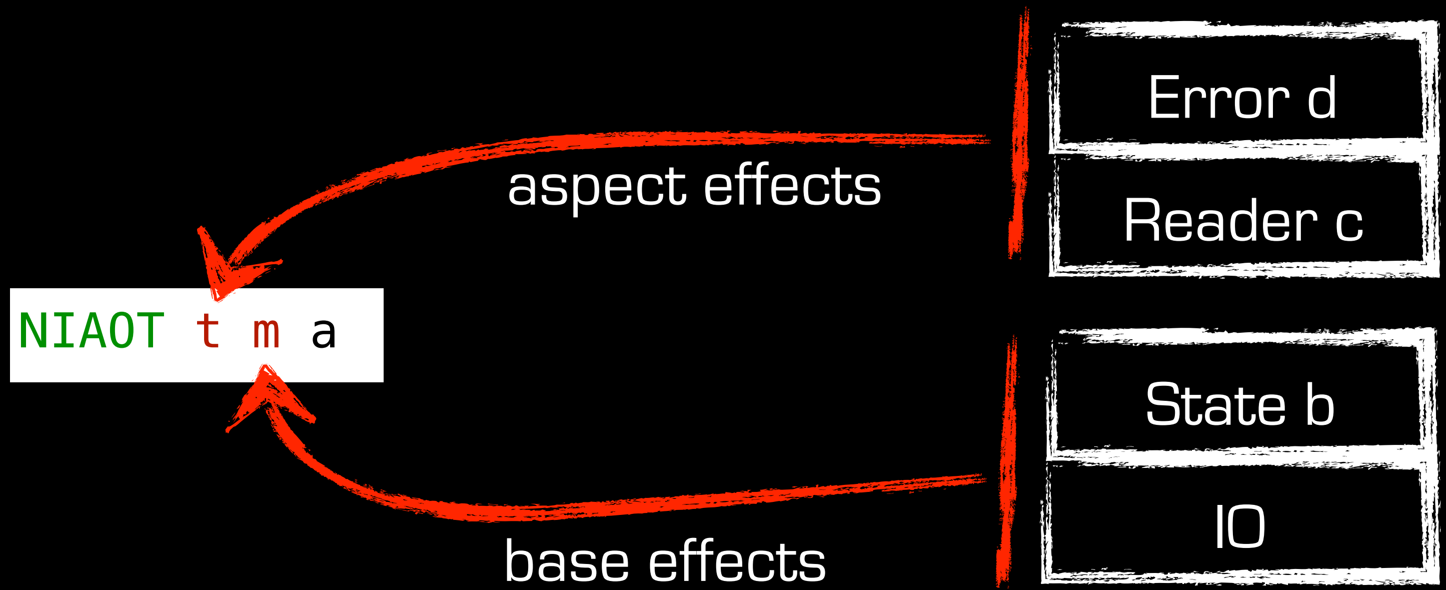
IO

rely on parametricity to enforce non-interference

```
type NIAdvice t a b = forall m. Advice (NIAOT t m) a b
```

Effect Interference

Reason about interferences base/aspects [Oliveira, 2010]



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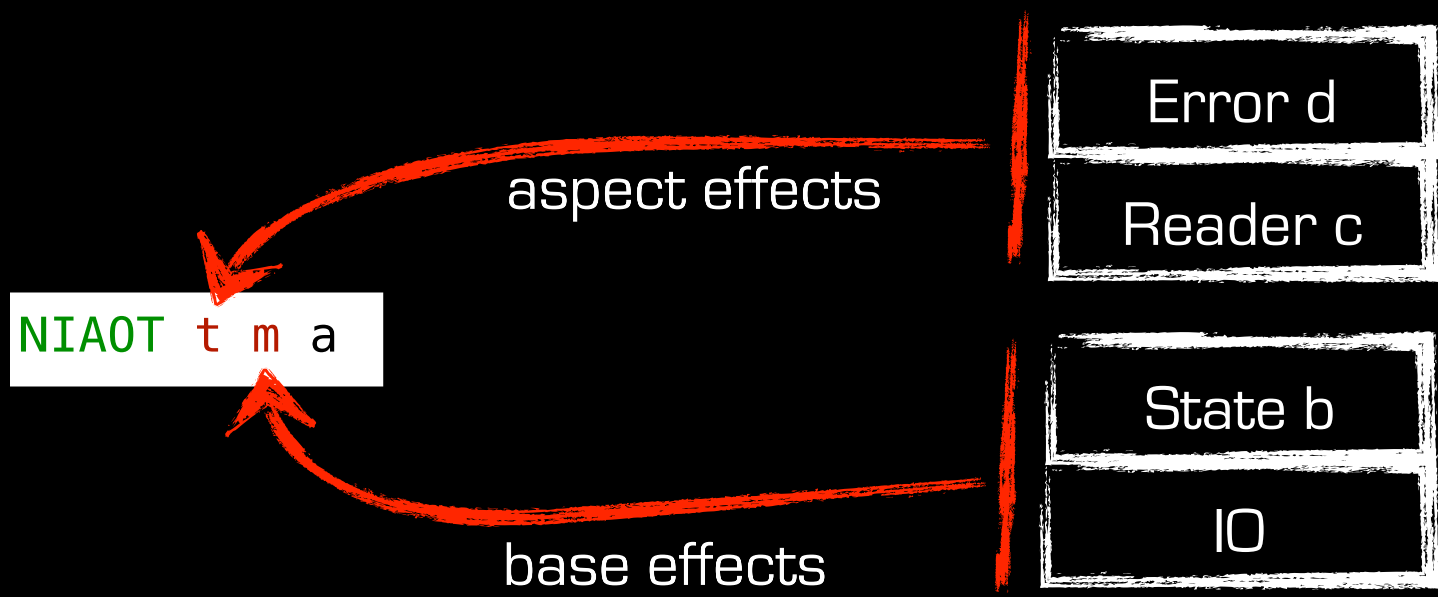


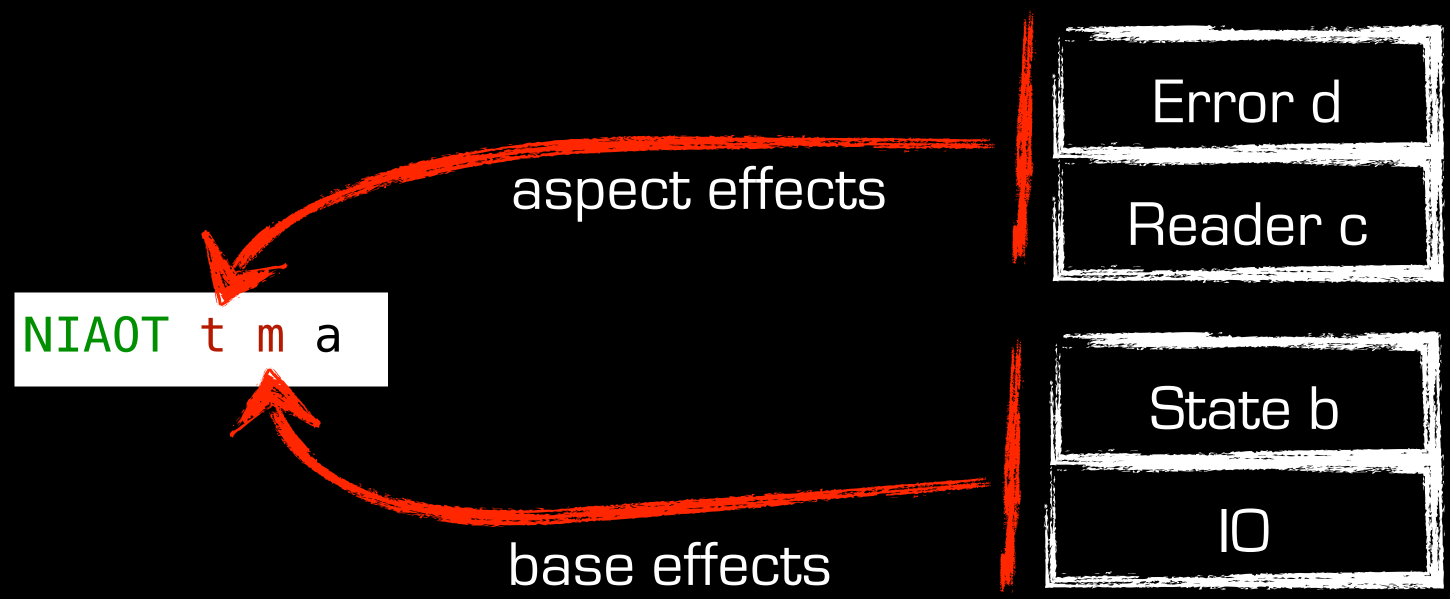
rely on parametricity to enforce non-interference

```
type NIAdvice t a b = forall m. Advice (NIAOT t m) a b

type NIPC t a b = forall m. PC (NIAOT t m) a b
```

Effect Interference

Reason about interferences base/aspects [Oliveira, 2010]



rely on parametricity to enforce non-interference

```
type NIAdvice t a b = forall m. Advice (NIAOT t m) a b

type NIPC t a b = forall m. PC (NIAOT t m) a b

type NIBase m a b = forall t. a -> NIAOT t m b
```

Enforcing Non-Interfering Advice

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type NIAdvice t a b = forall m. Advice (NIAOT t m) a b
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Enforcing Non-Interfering Advice

```
type NIAdvice t a b = forall m. Advice (NIAOT t m) a b
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combinator that requires NIAdvice

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Enforcing Non-Interfering Advice

```haskell
type NIAdvice t a b = forall m. Advice (NIAOT t m) a b
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combinator that requires NIAdvice

```haskell
niAdvice :: NIAdvice t a b -> Advice (NIAOT t m) a b
```

```haskell
module Fib (fib, ppcFib) where
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type NIAdvice t a b = forall m. Advice (NIAOT t m) a b
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memoize :: NIAdvice ...
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```

Perspectives

Perspectives

extend EffectiveAdvice to deal with **quantification**

Perspectives

extend EffectiveAdvice to deal with **quantification**

extend Open Modules to deal with **effects**

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Challenges

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- beyond the base/aspects distinction

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Challenges

- beyond the base/aspects distinction
- compose restrictions (eg. non-interfering + narrowing)
- type system challenges
  - higher-rank polymorphism
  - managing the monadic stack: views [Schrijvers, 2011]

Conclusions

Scoping

- balance flexibility / guarantees
- practical & efficient implementations
- new models

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Interfaces

- time to try them out for real
- need a gradual adoption path

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Interfaces

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- need a gradual adoption path

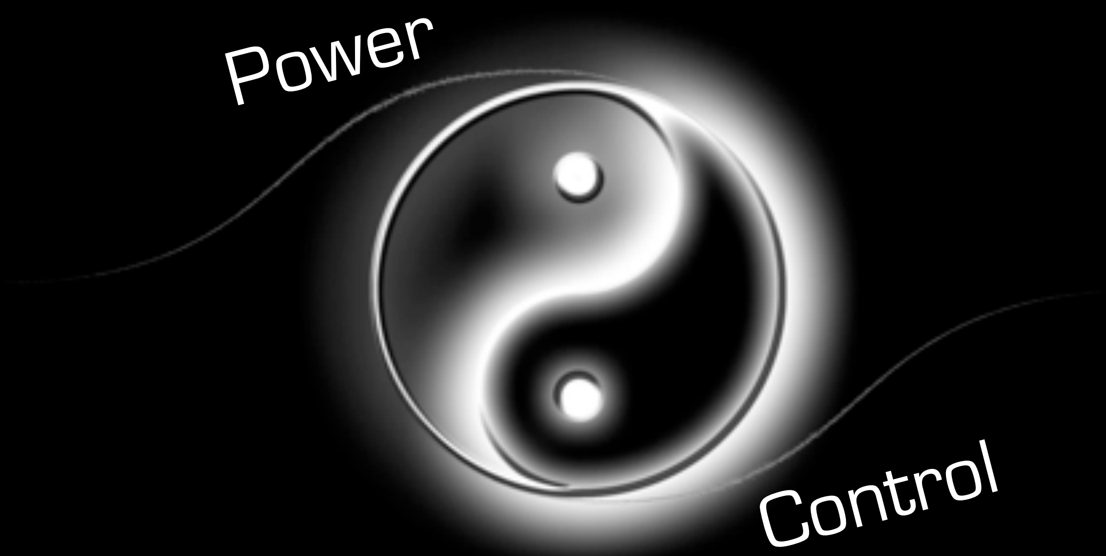
Typing

- Holy Grail: expressiveness vs. complexity

Effects

- exploit the (existing) type system or design specific analyses?
- lightweight & practical

TAMING
ASPECT
ORIENTATION



To be continued...

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