All Your IFCException Are Belong To Us

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(joint work with Michael Greenberg, Ben Karel, Benjamin Pierce, Greg Morrisett, and more)

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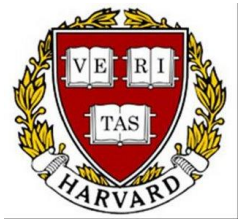
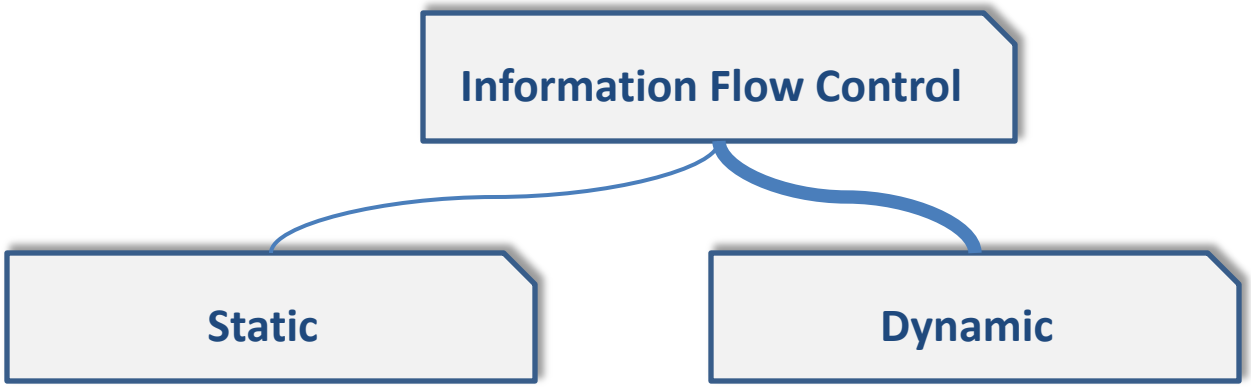
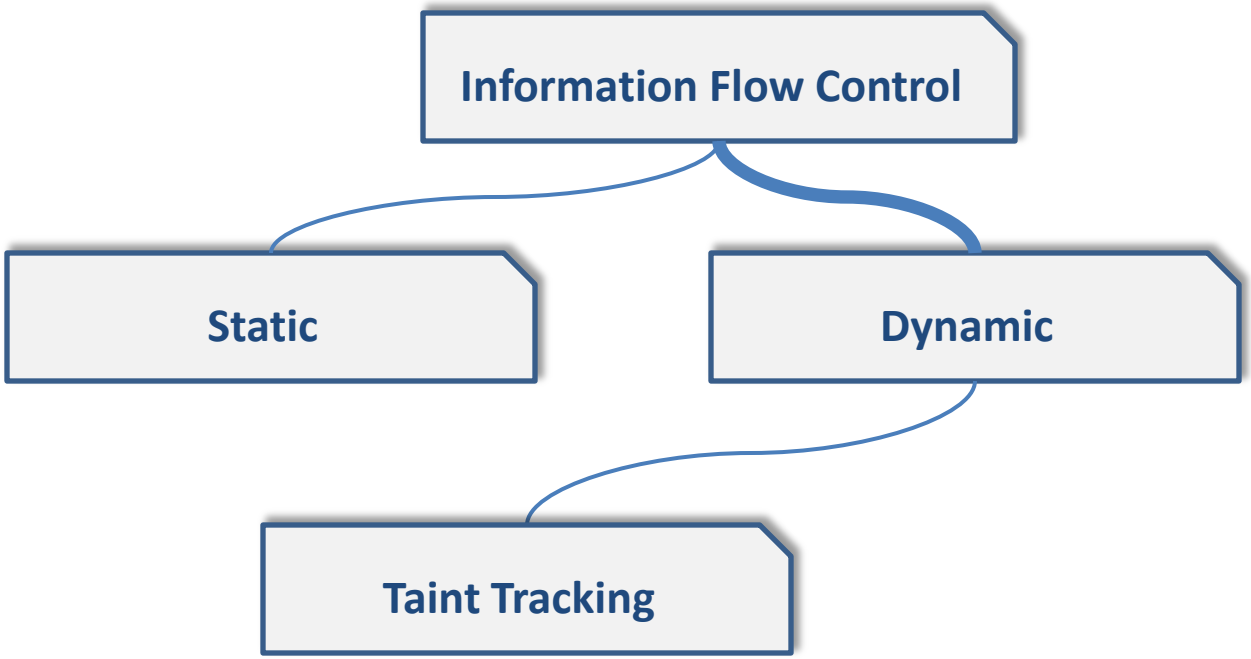




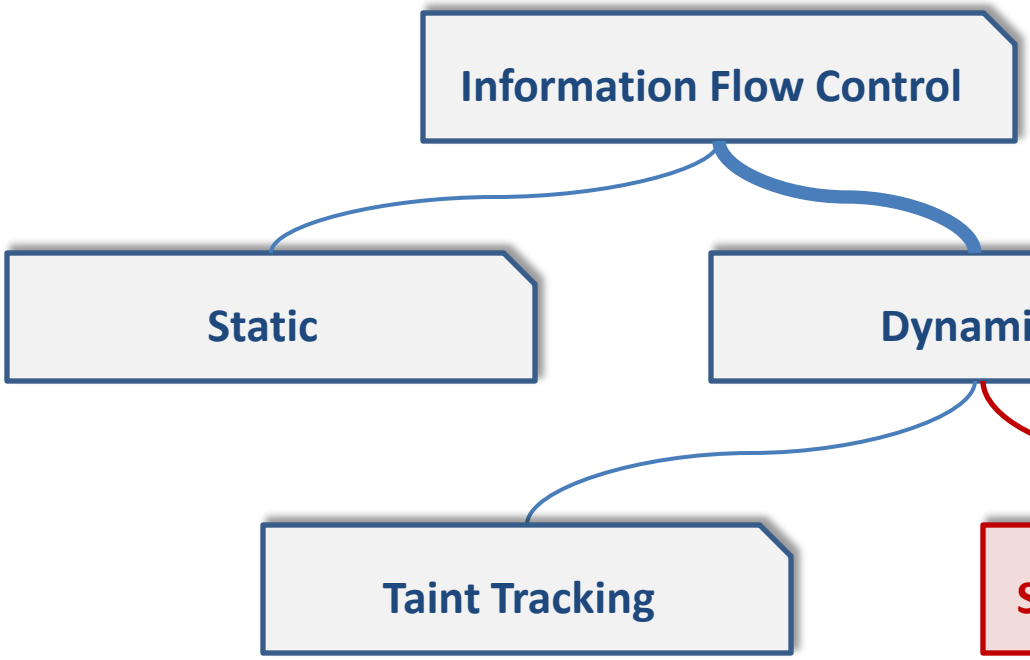
[Fenton, 1974]

[Denning, 1977]
type systems
& program analysis
Jif, FlowCaml, ...



[Fenton, 1974]

only explicit flows
Perl Taint mode, ...

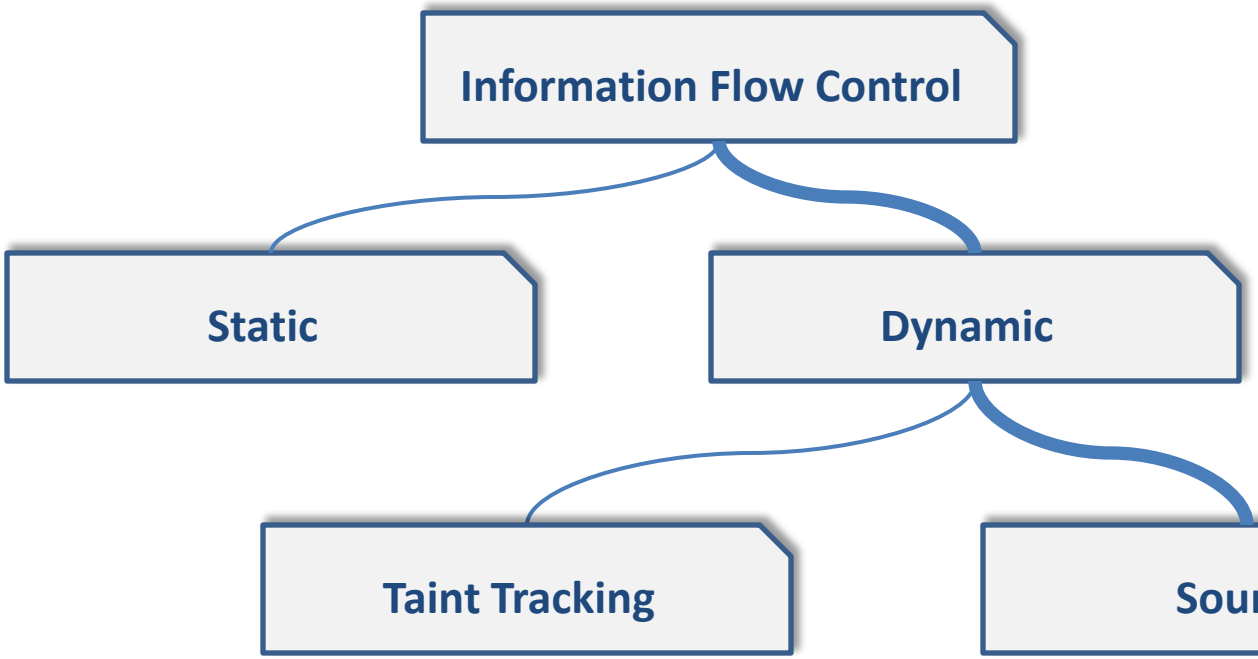


[Fenton, 1974]

[Schneider, 2000]

only explicit flows
Perl Taint mode, ...

non-interference not a trace property
can't be **precisely** enforced by EM

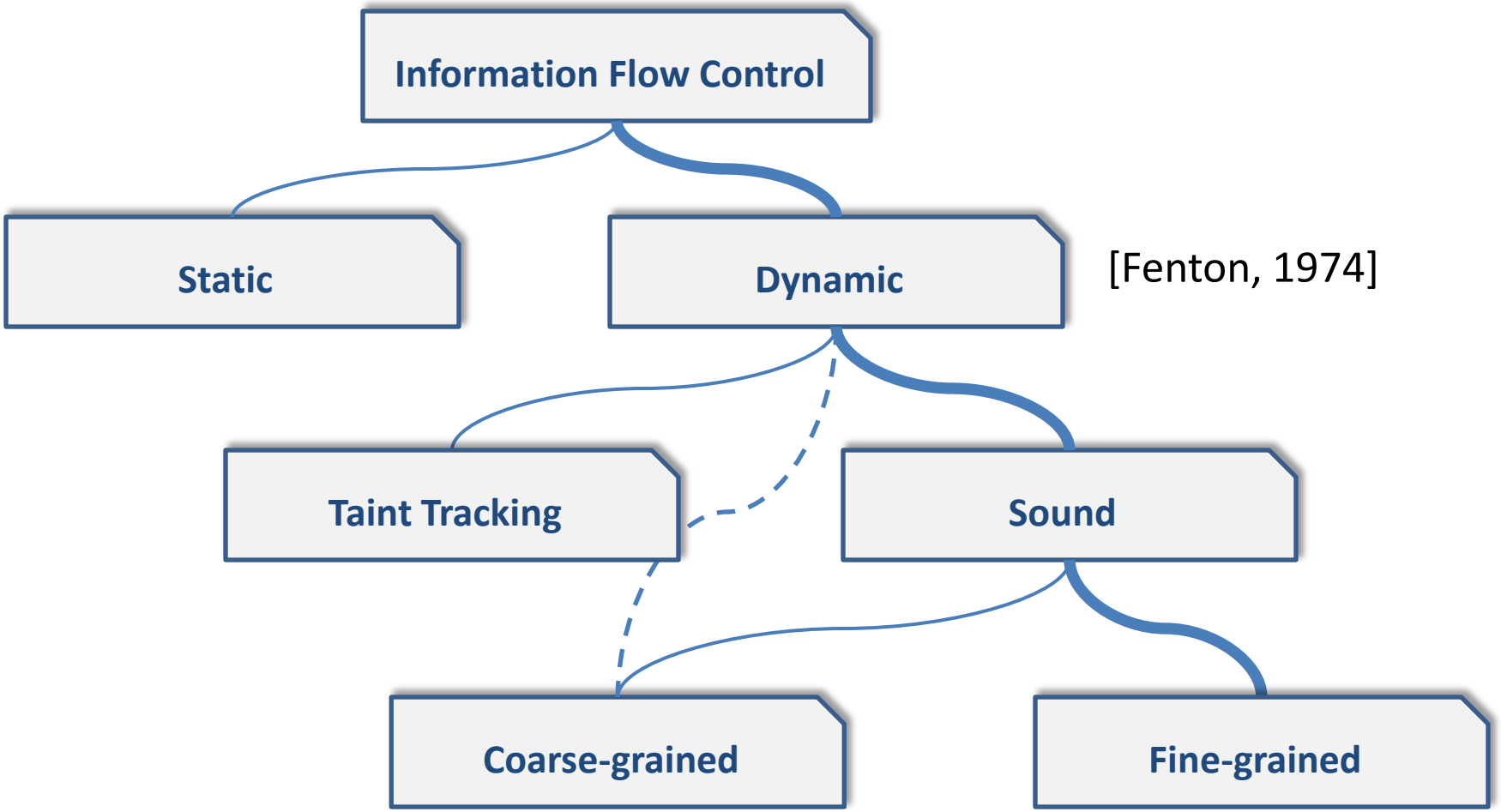


[Fenton, 1974]

enforce stronger property (incomplete)
changing language semantics allowed
also prevents implicit flows
non-interference proofs

[Krohn & Tromer, 2009]

[Sabelfeld & Russo, 2009]
[Austin & Flanagan, 2009]



[Fenton, 1974]

[Krohn & Tromer, 2009]

OSes: Asbestos (2005), Flume, HiStar

[Sabelfeld & Russo, 2009]
[Austin & Flanagan, 2009]

JavaScript

Preventing implicit flows

- ```
  let lref = ref low false in
  if h then
    lref := true;
  lref := false
  ```
  pc=high
  bad flow -> halt program
  false alarm (program non-interferent)

- even purely functional code can leak via control flow:
  - `if h then true else false`
  - semantics of conditional:
    - **if** true@high **then** true **else** false => true@high
  ```

Breeze

- **sound fine-grained dynamic IFC**
- **label-based discretionary access control**
  - clearance helps prevent covert channels
- **functional core** (λ) + state(!) + concurrency (π)
  - from Pict/CML towards something more Erlang-ish
- **dynamically typed**
  - directly reflects capabilities of CRASH/SAFE HW
  - dynamically-checked first-class **contracts**

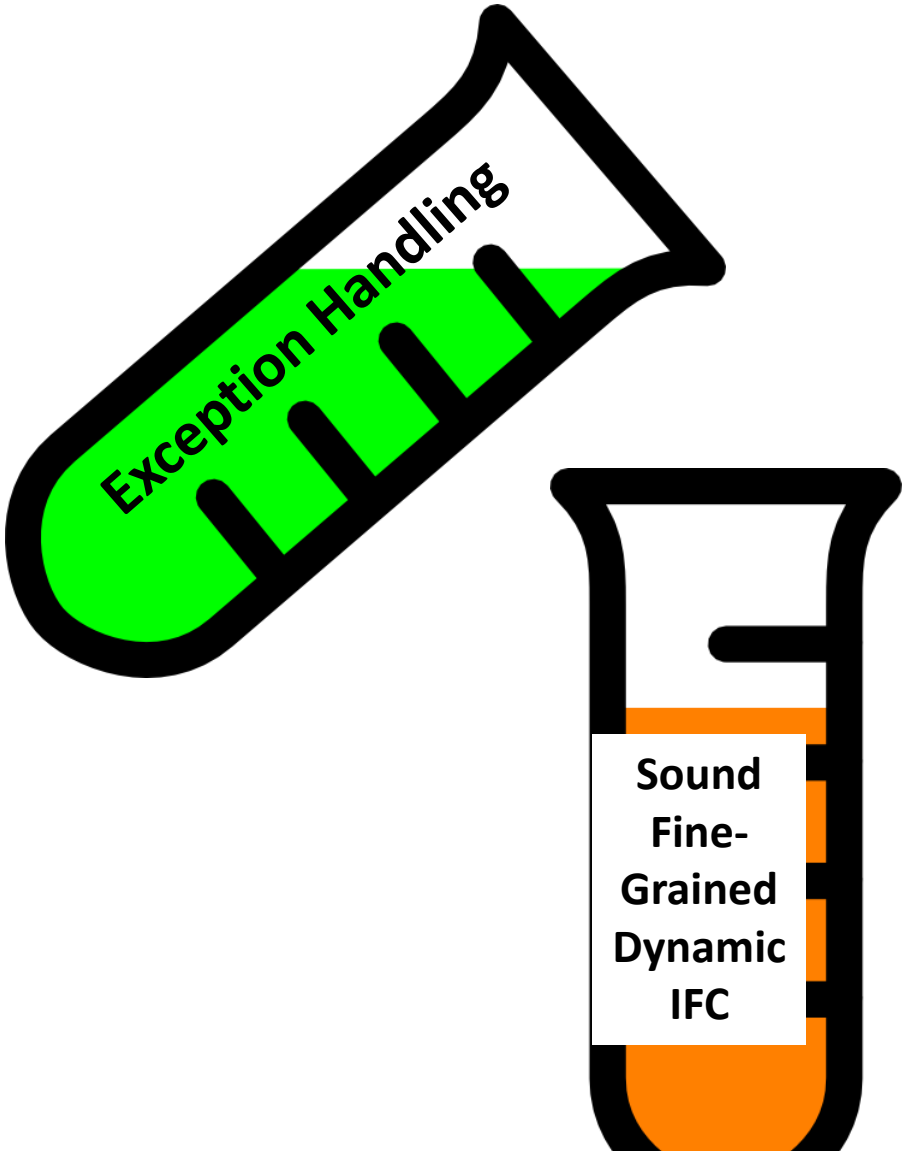
Exception handling

- we wanted all Breeze errors to be **recoverable**
  - **including IFC violations! (IFCException)**
- however, existing work* assumes errors are **fatal**
  - makes some things easier ... at the expense of others

+secrecy +integrity –availability

*There are 2 very recent (partial) exceptions:
[Stefan et al., 2012] and [Hedin & Sabelfeld, 2012]

But there is a problem



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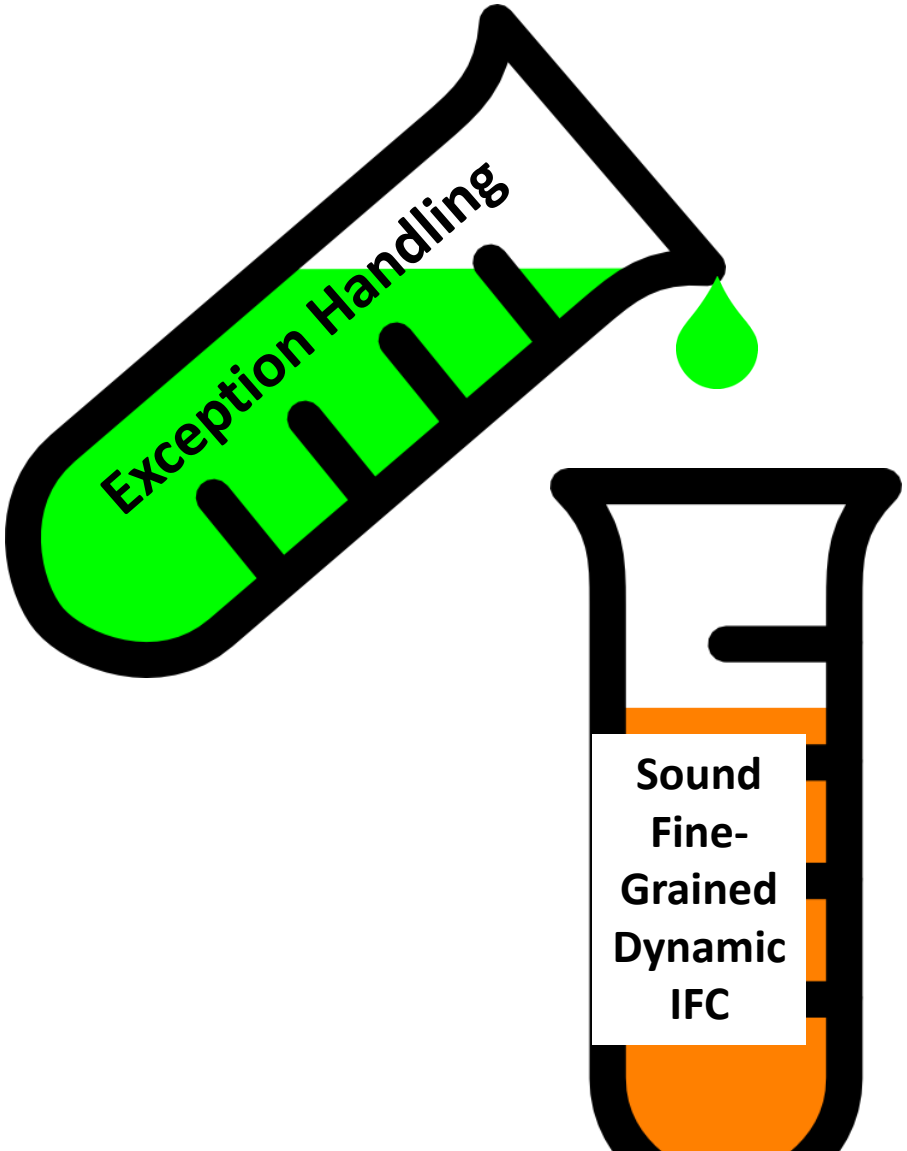
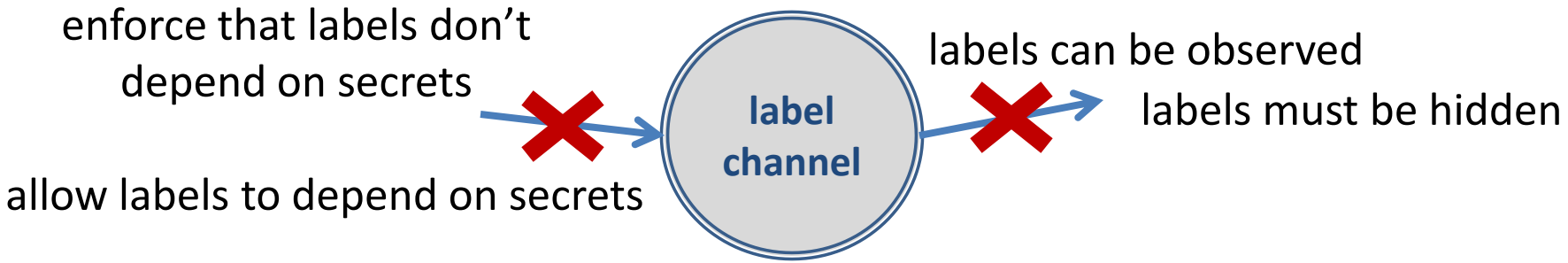


But there is a problem **… in fact two!**

Labels are information channels

- well-known fact:
  - changing labels are themselves information channels
- get soundness by preventing secrets from leaking either ***into*** or ***out of*** label channel



Problem #1: IFC exceptions reveal information about labels

- secret bit: h@high

```
let href = ref high () in
.......
try
  href := (if h then ()@high
           else      ()@top );
  true
catch IFCException => false
```

low <: high <: top

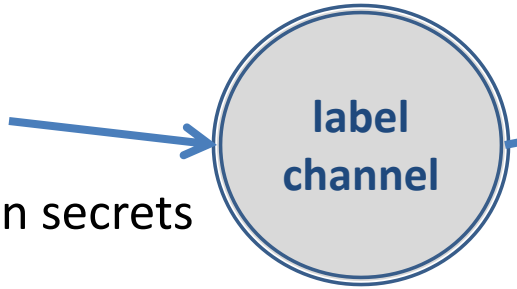
raise the pc on each assignment by the label of the written value?

encode h into label

if branch – assignment works

else branch – IFCException

IFC errors must be hidden too (not low observable) we don't want this restriction!

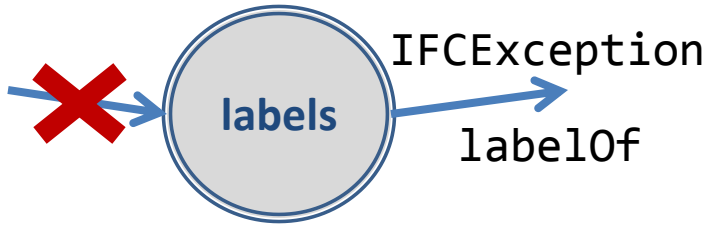


allow labels to depend on secrets

labels must be hidden

Solution to problem #1: brackets

- **prevent labels from depending on secrets so that labels are public**
- no longer automatically restore pc
  - `pc=low  if h then ()@high else ()@top  pc=high`
- instead, restore pc manually using **brackets**
  - choose label on result before branching on secrets
  - `pc=low  top[if h then ()@high else ()@top] => ()@top  pc=low`
  - brackets are not declassification!
  - sound even when annotation is incorrect (next slide)
  - bracket annotations can be dynamically computed (labelOf)



Problem #2: exceptions destroy control flow join points

- ending brackets have to be control flow join points
  - ```
    try
      let _ = high[if h then throw Ex] in
      false
    catch Ex => true
    ```
- brackets need to delay all exceptions!
  - `high[if true@high then throw Ex] => “(Inr Ex)@high”`
  - `high[if false@high then throw Ex] => “(Inl ())@high”`
- similarly for failed brackets
  - `high[()@top] => “(Inr EBracket)@high”`
    ```

Solution #2: Delayed exceptions

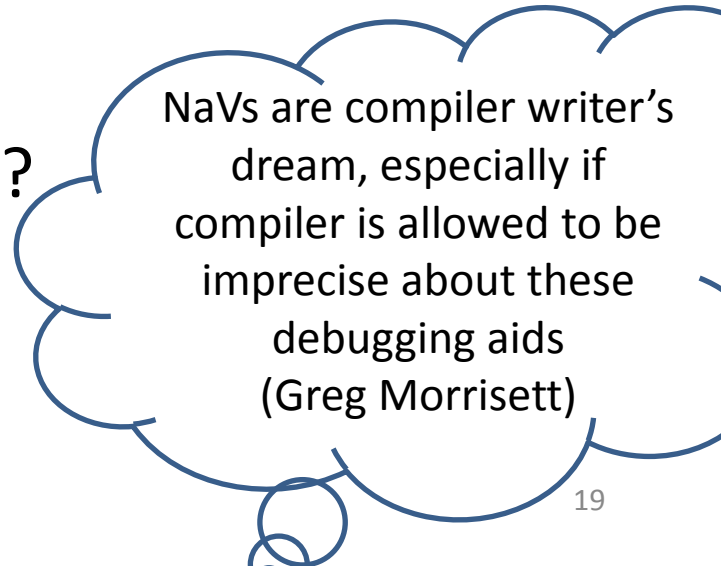
- **delayed exceptions unavoidable**
  - still have a choice how to propagate them
- we studied **two alternatives** for error handling:
  1. **mix active and delayed exceptions** ($\lambda^{[\,]}_{throw}$)

Solution #2: Delayed exceptions

- **delayed exceptions unavoidable**
  - still have a choice how to propagate them
- we studied **two alternatives** for error handling:
  1. **mix active and delayed exceptions** ($\lambda^{[]}_{throw}$)
  2. **only delayed exceptions** ($\lambda^{[]}_{NaV}$)
     - delayed exception = not-a-value (NaV)
     - NaVs are first-class replacement for values
     - NaVs propagated solely via data flow
     - NaVs are labeled and pervasive
     - more radical solution; implemented by Breeze

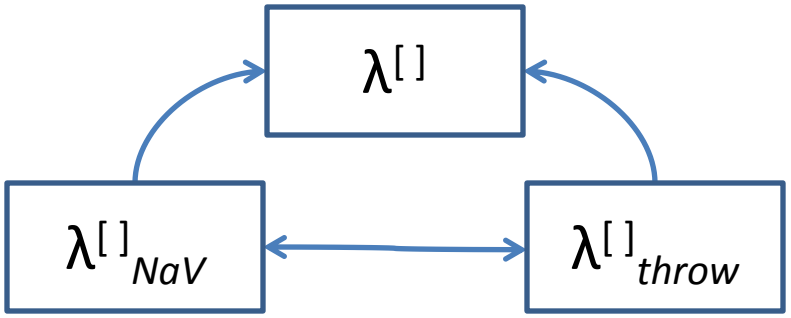
What's in a NaV?

- error message
  - `EDivisionByZero ("can't divide %1 by 0", 42)
- stack trace
  - pinpoints error **origin**
    (not the billion-dollar mistake)
- propagation trace
  - how did the error make it here?



Formal results

- proved termination-insensitive **non-interference** in Coq for $\lambda^{[]}$, $\lambda^{[]}_{NaV}$, and $\lambda^{[]}_{throw}$
  - for $\lambda^{[]}_{NaV}$ even with all debugging aids; **error-sensitive**
- **conjecture**: in our setting NaVs and catchable exceptions have equivalent expressive power
  - translations validated by QuickChecking code extracted from Coq (working on Coq proofs)



Conclusion

- reliable error handling *possible* even for sound fine-grained dynamic IFC systems
- we study two mechanisms ($\lambda^{[\,]}_{NaV}$ and $\lambda^{[\,]}_{throw}$)
  - **all errors recoverable**, even IFC violations
  - key ingredients:
    sound public labels (brackets) + **delayed exceptions**
  - quite radical design (not backwards compatible!)
- our practical experience with NaVs:
  - issues are surmountable
  - writing good error recovery code is still hard

THE END