Structural Information Flow: A Fresh Look at Types for Non-Interference

Hemant Gouni (with Frank Pfenning & Jonathan Aldrich)

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Information Flow Tracks *Dependencies*

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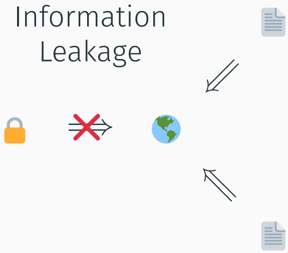
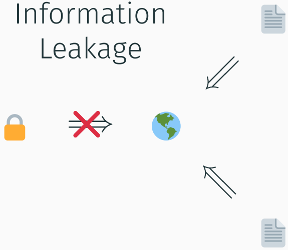
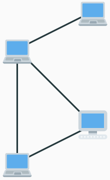


Information Flow Tracks *Dependencies*

Information
Leakage





Concurrent
+
Distributed
Systems

Information Flow Tracks *Dependencies*

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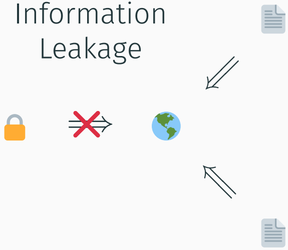
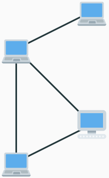


Program Slicing



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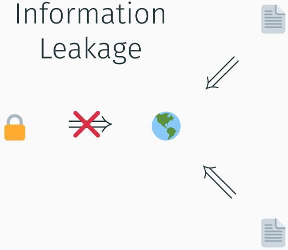

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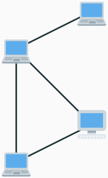

Program Slicing

Build Systems

Information Flow Tracks *Dependencies*

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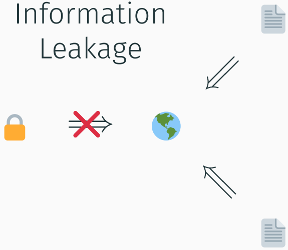

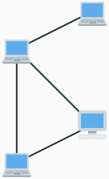

Concurrent
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Program Slicing

Build Systems

Incremental Computation

Information Flow Tracks *Dependencies*

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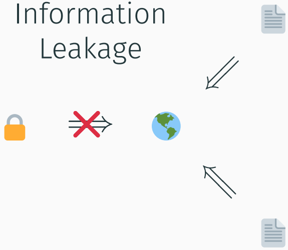

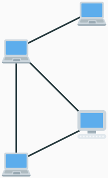

Concurrent + Distributed Systems

Program Slicing

Build Systems

Incremental Computation

Controlling Opaque Definitions

Information Flow Tracks *Dependencies*

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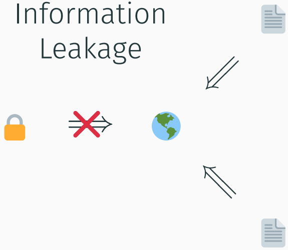

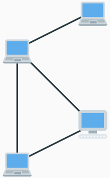

Concurrent + Distributed Systems

Program Slicing

Build Systems

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Lineage Tracking in CAD

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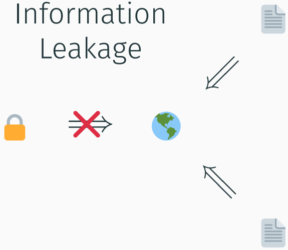

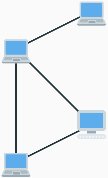

Concurrent + Distributed Systems

Program Slicing

Build Systems

Incremental Computation

Controlling Opaque Definitions

Lineage Tracking in CAD

...and **much** more!!

How to Reinvent Our Approach From Scratch 🧑‍🍳

A Familiar Friend: Parametric Polymorphism

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val id : α -> α

val snd : α -> β -> α

val map : (α -> β) -> list α -> list β
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`val map : (`α `->` β`) -> list` α `-> list` β

What about `incr : int -> int`?

A Familiar Friend: Parametric Polymorphism

val id : α -> α

val snd : α -> β -> α

val map : (α -> β) -> list α -> list β

What about `incr : int -> int`?

Insight 1

Separate **data abstraction** from **information flow**.

Relaxing Parametricity

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Idea: Tag types with *dependency variables* α

Result: `incr : ` α `int -> ` α `int`

What about `add : ` α `int -> ` β `int -> ` $\boxed{?}$ `int`?

Insight 1

Separate **data abstraction** from **information flow.**

Idea: Tag types with *dependency variables* α

Result: `incr : `α` int -> `α` int`

What about **`add`** ` : `α` int -> `β` int -> `$\boxed{?}$` int`?

Relaxing Parametricity

Insight 1

Separate **data abstraction** from **information flow.**

Idea: Tag types with *dependency variables* α

Result: `incr :` α `int ->` α `int`

What about **add** `:` α `int ->` β `int ->` ? `int`?

Insight 2

Track **sets of dependencies** in types.

Generalizing to Dependency Sets

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Result: `add : [`α`] int -> [`β`] int -> [`$\alpha\ \beta$`] int`

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Track **sets of dependencies** in types.

Idea: Generalize each α to a *dependency set* $[\alpha]$

Result: `add : [`α`] int -> [`β`] int -> [`$\alpha\ \beta$`] int`

Let's work a more interesting example of information flow!

A Password Checker

```
let pass : [pwd] string = "katya"

let check : [α] string -> [α pwd] bool =
    fun attempt -> attempt == pass
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The conventional solution to this issue is *declassification*...

```
let pass : [pwd] string = "katya"

let check : [α] string -> [α ~~pwd~~] bool =
     fun attempt -> declassify(attempt == pass)
```

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A Password Checker

`let pass : [pwd] string = "katya"`

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Our checker is too conservative!

The conventional solution to this issue is *declassification*...

...which *subverts* the type system.

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> *[Non-interference] is too strict to be usable in realistic programs.*
>
> — *Wikipedia (Information Flow)*

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> *Noninterference is over-restrictive for programs with intentional information release (average salary, information purchase and password checking programs are flatly rejected by noninterference).*
>
> *— Sabelfeld and Sands 07*

Non-interference says dependency tracking must be faithful; declassification opposes it.

We resolve this conflict: the tools we've already introduced suffice for realistic programs.

Declassification for Free 💸

Step 0: Wishful Thinking 💭

```
signature PasswordChecker = sig






end
```

```
open PasswordChecker as pc
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signature PasswordChecker = sig
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    pass : [pwd] string


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open PasswordChecker as pc

let _ : [pwd] string = pc.pass ++ "arren"
```

Step 0: Wishful Thinking 💭

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signature PasswordChecker = sig
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     pass : [pwd] string
     check : [α] string -> [α] bool

end
```

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open PasswordChecker as pc

let _ : [pwd] string = pc.pass ++ "arren"
let _ : [ ] bool = pc.check "nemmerle"
```

Step 0: Wishful Thinking 💭

```
signature PasswordChecker = sig
    dependency pwd

    pass : [pwd] string
    check : [α] string -> [α] bool
    encrypt : [pwd α] string -> [α] string
end
```

```
open PasswordChecker as pc

let _ : [pwd] string = pc.pass ++ "arren"
let _ : [ ] bool = pc.check "nemmerle"
let _ : [ ] string = pc.encrypt pc.pass
```

Step 1: Expose Lurking Quantifiers 🥸

```
id  :        α -> α

map :        (α -> β) -> list α -> list β

add :        [α] int -> [β] int -> [α β] int
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Insight 3

Construct `exists` α from `forall` α + higher-order functions

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Insight 3

Construct `exists` α from `forall` α + higher-order functions

Existentials are better known as *modules* or *classes*!*

*(roughly)

Step 2: Dependency Abstraction 🤯

```
signature Queue = sig
  type t

  enqueue : int -> t -> t
  dequeue : t -> t * int
end

structure naive_queue : Queue = struct
  type t = List int

  enqueue x q = Cons(x, q)
  dequeue q = match q with ...
end
```

Step 2: Dependency Abstraction 🤯

```
signature Queue = sig
  type t  <-- Existentially Quantified!

  enqueue : int -> t -> t
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client view

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Step 2: Dependency Abstraction 🤯

implementation view

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signature Queue = sig
  type t = List int

  enqueue : int -> List int -> List int
  dequeue : List int -> List int * int
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structure naive_queue : Queue = struct
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```

Step 3: Our New Password Checker 🎉

```
signature PasswordChecker = sig
    dependency pwd

    pass : [pwd] string
    check : [α] string -> [α] bool

    encrypt : [pwd α] string -> [α] string

end
```

Step 3: Our New Password Checker 🎉

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        = fun str -> gpg str
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Extra: Dependency Elision

incr : [α] int -> [α] int

add : [α] int -> [β] int -> [α β] int

Extra: Dependency Elision

```
incr : int -> int

add : [α] int -> [β] int -> [α β] int
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Extra: Dependency Elision

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Extra: Dependency Elision

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```

---

map : (α -> β) -> list α -> list β

fold : β -> (α -> β -> β) -> list α -> β

filter : (α -> [β] bool) -> list α -> [β] list α

Extra: Dependency Elision

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incr : int -> int

add : int -> int -> int
```

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map : (α -> β) -> list α -> list β

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filter : (α -> [β] bool) -> list α -> [β] list α

Full explanation + more goodies in the paper!

Takeaway: Full-strength non-interference and practical programming are perfectly aligned.

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