Typing Illegal Information Flows as Program Effects

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Problem

How can we?

- Reason about illegal programs:
  - Order illegal programs
- Express arbitrary relaxations of an information flow policy

Problem

How can we?

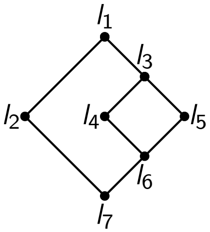
- Reason about illegal programs:
  - Order illegal programs
- Express arbitrary relaxations of an information flow policy

Approach

- Establish a base lattice $\Rightarrow$ strictest information flow policy
- Model illegal flows as kernels over the base lattice
- Assign to each program the strictest kernel that captures all its illegal flows

Flow Kernels

Original Lattice



Kernels are computed iteratively

$$\upharpoonright_{\mathbf{k}} [\mathbf{l_1}, \mathbf{l_2}](l) = \begin{cases} \mathbf{k}(l \sqcap \mathbf{l_2}) & \text{if } l \preccurlyeq \mathbf{l_1} \\ \mathbf{k}(l) & \text{otherwise} \end{cases}$$

- **k:** original kernel
- $(\mathbf{l_1}, \mathbf{l_2})$**:** new flow

Flow Kernels

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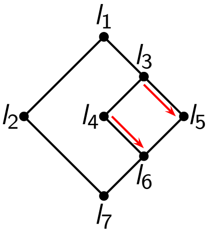
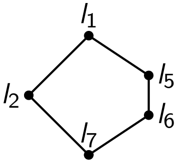


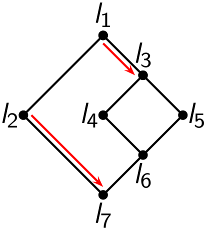
Illegal Flow: $l_3 \rightarrow l_5$



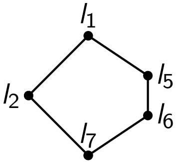
$l_3 \rightarrow l_5$

Flow Kernels

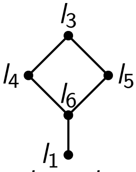
Original Lattice



Illegal Flow: $l_1 \to l_3$



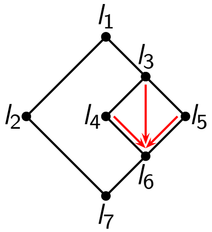
$l_3 \to l_5$



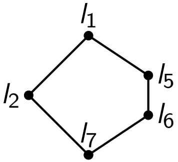
$l_1 \to l_3$

Flow Kernels

Original Lattice



Illegal Flow: $l_3 \rightarrow l_6$



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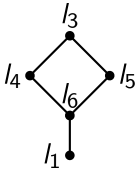

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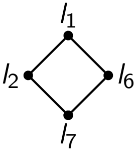
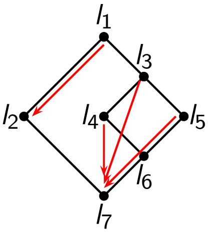


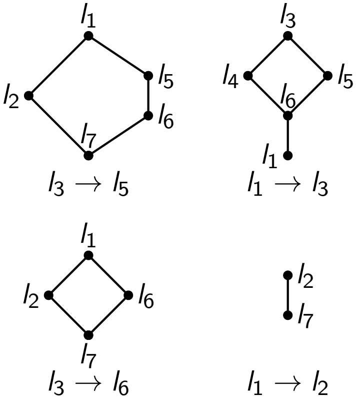
$l_3 \rightarrow l_6$

Flow Kernels

Original Lattice



Illegal Flow: $l_1 \rightarrow l_2$



Language

Syntax

- **Expressions:** λ-Calculus + Reference Creation + Thread creation

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Model

- **Model:** $\langle P, S \rangle \rightarrow \langle P', S' \rangle$
- P: **initial** pool of expressions
- S: **initial** memory

Language

Syntax

- **Expressions:** λ-Calculus + Reference Creation + Thread creation

Model

- **Model:** $\langle P, S\rangle \rightarrow \langle P', S'\rangle$
- P': **final** pool of expressions
- S': **final** memory

Property

$(\mathcal{L}, \Sigma, k, \Gamma, l)$-bissimulation

A binary relation between programs that behave in the same way according to an observer at level l.

$\approx^{\mathcal{L},\Sigma,k}_{\Gamma,l}$

The largest $(\mathcal{L}, \Sigma, k, \Gamma, l)$-bissimulation.

$(\mathcal{L}, \Sigma, k, \Gamma)$-Noninterference

A pool of expressions P satisfies Noninterference with respect to a setting $(\mathcal{L}, \Sigma, k)$ and a typing environment Γ if it satisfies $P \approx^{\mathcal{L},\Sigma,k}_{\Gamma,l} P$ for all security levels l.

Relaxing IF Settings

Original IF Setting

- **Lattice:** $\mathcal{L}$
- **Labeling:** Σ

Relaxing IF Settings

Original IF Setting

- **Lattice:** $\mathcal{L}$
- **Labeling:** Σ

$\xrightarrow{\mathbf{k}}$

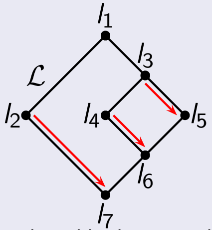
Relaxed IF Setting

- **Lattice:** $k(\mathcal{L})$
- **Labeling:** $k \circ \Sigma$

Relaxing IF Settings

Original IF Setting - Illegal

$$\Sigma = \left\{ \begin{array}{c} a \mapsto l_2, b \mapsto l_3 \\ c \mapsto l_5, d \mapsto l_7 \end{array} \right\}$$



$$((c_{l_5} := (!b_{l_3})); (d_{l_7} := (!a_{l_2})))$$

Relaxing IF Settings

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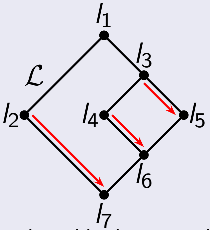
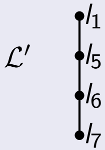


$$((c_{l_5} := (!b_{l_3})); (d_{l_7} := (!a_{l_2})))$$

Relaxed IF Setting - Legal

$$\Sigma' = \left\{ \begin{array}{c} a \mapsto l_7, b \mapsto l_5 \\ c \mapsto l_5, d \mapsto l_5 \end{array} \right\}$$



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Information Flow Analysis

Checking Type System

$$\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M : s, \tau$$

M is typable with **type** τ and **security effect** s in the **typing context** Γ with respect to the IF setting $\langle \mathcal{L}, \Sigma, k \rangle$.

Information Flow Analysis

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Security Effect - s

- $s.r$: reading effect
- $s.w$: writting effect
- $s.t$: testing effect

Information Flow Analysis

Checking Type System

$$\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M : s, \tau$$

Informative Type System

$$\Gamma \vdash_{\mathcal{L},\Sigma} M : \langle s, s_d \rangle, \tau$$

s_d is the **declassification effect** of M.

Information Flow Analysis

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- Γ: **a map from variables to security levels**

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- $\mathcal{L}$: **Lattice of security levels**

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- Γ: **a map from variables to security levels**
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- Σ: **a map from references to security levels**
- s: **security effect**

Information Flow Analysis

Checking Type System

$$\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M : s, \tau$$

- k: **parametrizing kernel**

Informative Type System

$$\Gamma \vdash_{\mathcal{L},\Sigma} M : \langle s, s_d \rangle, \tau$$

- s_d: **declassification effect**

- Γ: **a map from variables to security levels**
- $\mathcal{L}$: **lattice of security levels**
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Information Flow Analysis

Checking Type System - Assign Rule

$$\frac{\begin{array}{ll}\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M : s_1, \theta \text{ ref}_l & k(s_1.t) \sqsubseteq k(s_2.w) \\ \Gamma \vdash^{k}_{\mathcal{L},\Sigma} N : s_2, \theta & k(s_1.r), k(s_2.r) \sqsubseteq k(l)\end{array}}{\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M := N : s_1 \sqcup s_2 \sqcup s_l, \text{unit}}$$

Where: $s_l = \langle \bot, k(l), \bot \rangle$

Information Flow Analysis

Checking Type System - Assign Rule

$$\frac{\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M : s_1, \theta \text{ ref}_l \qquad k(s_1.t) \sqsubseteq k(s_2.w) \qquad \Gamma \vdash^{k}_{\mathcal{L},\Sigma} N : s_2, \theta \qquad k(s_1.r), k(s_2.r) \sqsubseteq k(l)}{\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M := N : s_1 \sqcup s_2 \sqcup s_l, \text{unit}}$$

Where: $s_l = \langle \bot, k(l), \bot \rangle$

Informative Type System - Assign Rule

$$\frac{\Gamma \vdash_{\mathcal{L},\Sigma} M : \langle s_1, s_1^d \rangle, \theta \text{ ref}_l \qquad \Gamma \vdash_{\mathcal{L},\Sigma} N : \langle s_2, s_2^d \rangle, \theta}{\Gamma \vdash_{\mathcal{L},\Sigma} M := N : \langle s, s_d \rangle, \text{unit}}$$

Where:

$s_d = s_1^d \curlyvee s_2^d \curlyvee \upharpoonright \{(s_1.t, s_2.w), (s_1.r, l), (s_2.r, l)\}$

$s = s_1 \sqcup s_2 \sqcup \langle \bot, l, \bot \rangle$

Information Flow Analysis

Soundness

$$\Gamma \vdash_{\mathcal{L},\Sigma} M : \langle s, s_d \rangle, \tau$$
$$\Downarrow$$
$$\Gamma \vdash^{s_d}_{\mathcal{L},\Sigma} M : s', \tau$$

Information Flow Analysis

Soundness

$$\Gamma \vdash_{\mathcal{L},\Sigma} M : \langle s, s_d \rangle, \tau$$
$$\Downarrow$$
$$\Gamma \vdash^{s_d}_{\mathcal{L},\Sigma} M : s', \tau$$

Optimality

$$\Gamma \vdash^{k}_{\mathcal{L},\Sigma} M : s_1, \tau \quad \textbf{and} \quad \Gamma \vdash_{\mathcal{L},\Sigma} M : \langle s_2, s_d^2 \rangle, \tau$$
$$\Downarrow$$
$$k \sqsubseteq s_d^2$$

Flow Relations as IF Setting Relaxations

Ingredients

- **Set of Principals: Pri**
- **Security levels:** subsets of **Pri**
- **Security lattice:** $\langle \mathcal{P}(\mathbf{Pri}), \supseteq \rangle$
- **Flow Relations:** binary relations on **Pri**
  - $(A, B) \in F$: information may flow from principal A to principal B

Flow Relations as IF Setting Relaxations

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- **Flow Relations:** binary relations on **Pri**

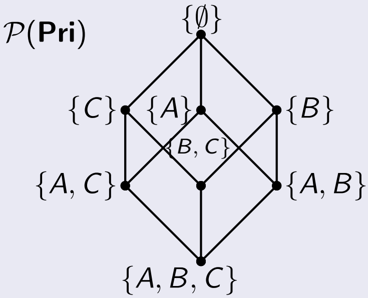
Remark

Flow Relations correspond to the co-additive kernels on Pri

Flow Relations as IF Setting Relaxations

Original IF Setting

$$\textbf{Pri} = \{A, B, C\}$$



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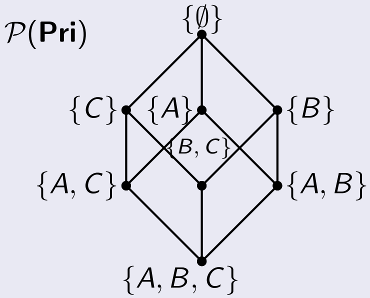
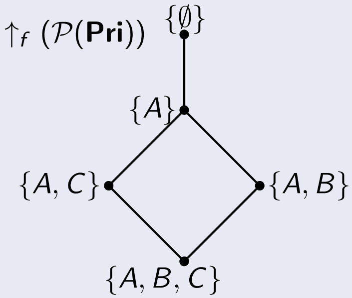


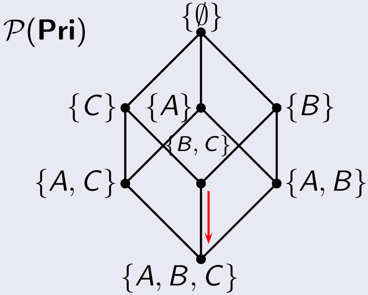
Relaxed IF Setting

$$\mathbf{f} = \{(B, A), (C, A)\}$$



Flow Relations as IF Setting Relaxations

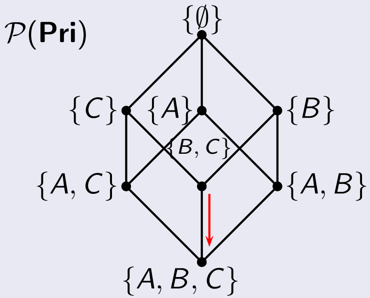
IF Setting



$$(b_{\{A\}} := (!a_{\{B,C\}}))$$

Flow Relations as IF Setting Relaxations

IF Setting



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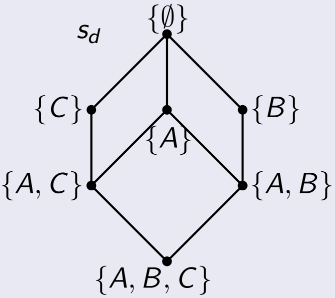
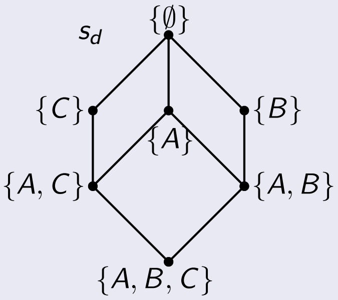
Declassification Effect

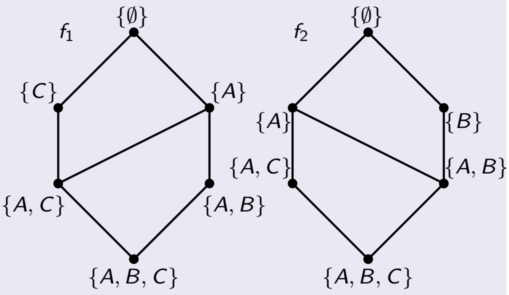


Flow Relations as IF Setting Relaxations

Declassification Effect



Flow Relations below s_d



No optimality result for flow relations!

- $f_1, f_2 \preccurlyeq s_d$ **and** $f_1 \not\preccurlyeq f_2$ **and** $f_2 \not\preccurlyeq f_1$

Permissivity Contexts as Kernels

Ingredients

- Model the **permissivity context** under which a program executes as a kernel
- The permissivity context $\Rightarrow$ Relaxation of the original IF setting
- Permissivity contexts are allowed to change dynamically

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Goal

Only the threads that respect **all** the permissivity contexts that were allowed during the program execution are allowed to terminate.

Permissivity Contexts as Kernels

Approach

- The current permissivity context - k_A - to configurations
- Add a mapping from thread names to their declassification effect - D - to configurations
- When the permissivity context changes remove the threads that are not compliant with it

Configurations

$$\langle P, S, D, k_A \rangle$$

Changing the permissivity context

$$\langle P, S, D, k_A \rangle \rightarrow \langle P', S, D, k_F \rangle$$

Future Work

Study new program constructs that **dynamically** interact with the permissivity context:

- Check if an expression is compliant with the current permissivity context
- Test the current permissivity context
- Kernels as values...

Thank You!

Questions...