UNIVERSITÀ di VERONA
Dipartimento di INFORMATICA

Securing Cross-App Interactions in IoT Platforms

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Introduction

Scenario

Platforms for IoT Apps

Scenario

Platforms for IoT Apps

Physical devices

Scenario

Platforms for IoT Apps

Physical devices

Digital services

Scenario

Platforms for IoT Apps

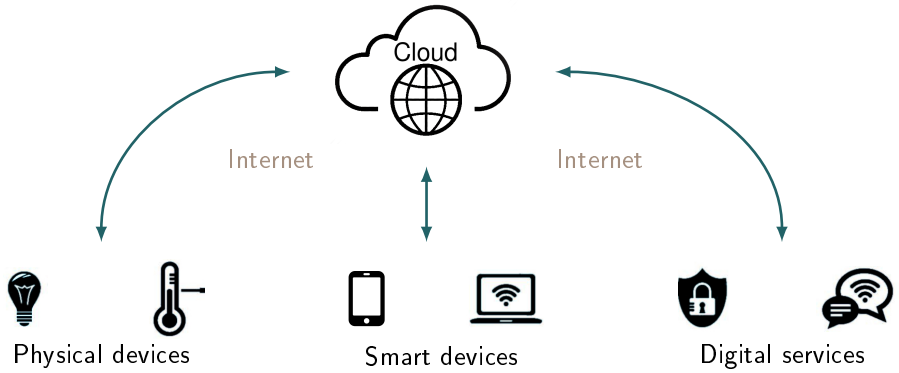
Physical devices

Smart devices

Digital services

Scenario

Platforms for IoT Apps



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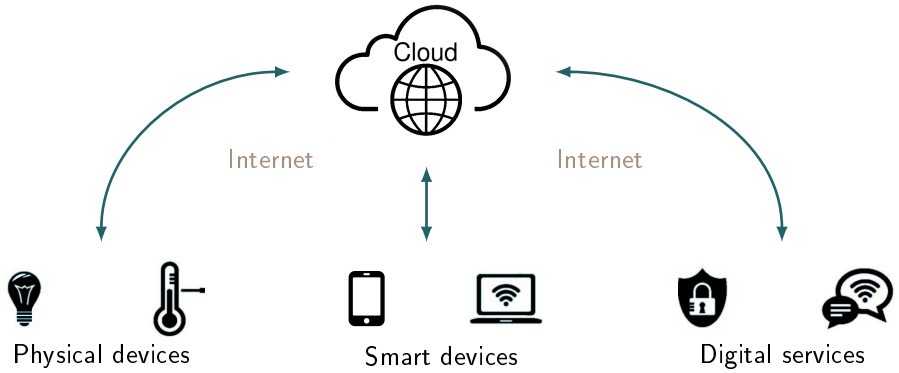


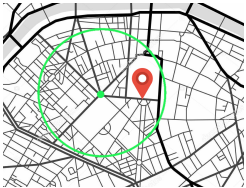
IoT apps platforms: IFTTT, Stringify, Microsoft Flow, etc

How it works

Trigger/action paradigm

App

App



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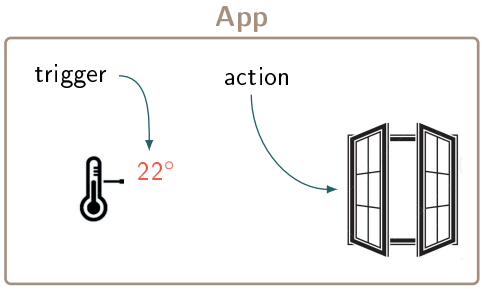

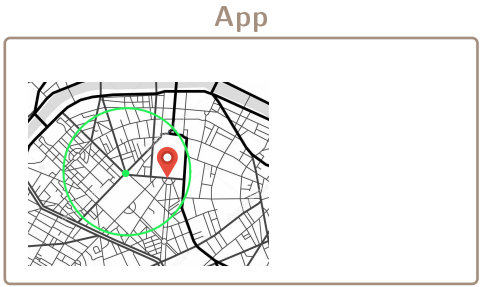

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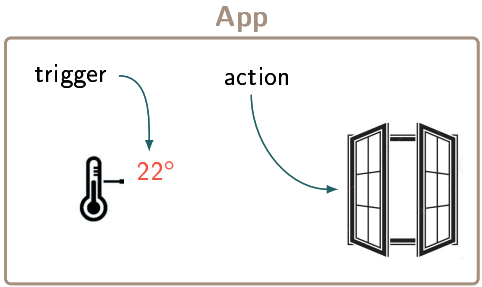

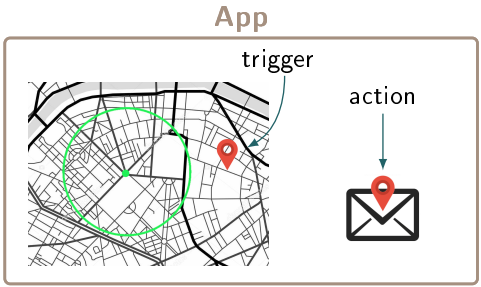

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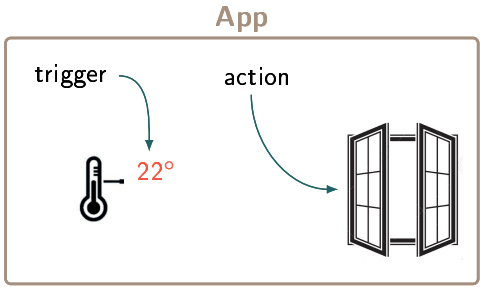

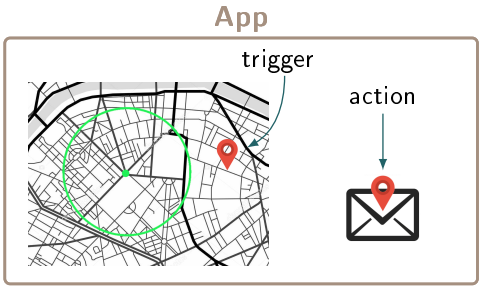

- Filter code before actions execution
- Third-parties apps development (malicious apps)

Vulnerabilities: Safety and Security

- Safety: unintended cross-app interactions

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"if the temperature is above 22° then open the window"

"if I leave my work location then turn on the heater at home"

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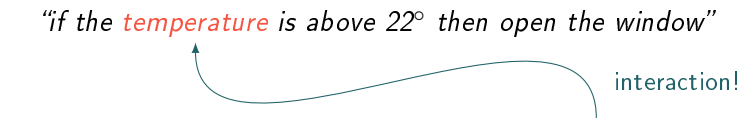

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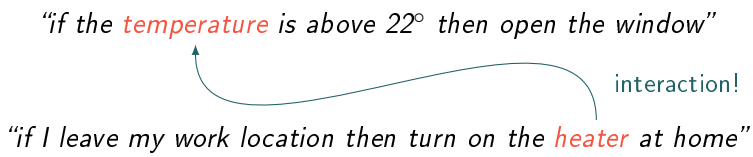

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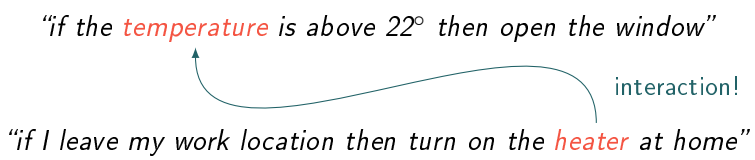

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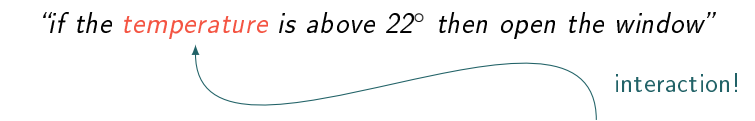

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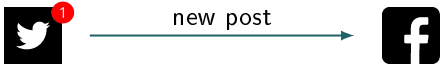

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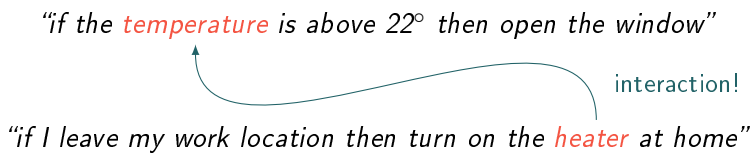

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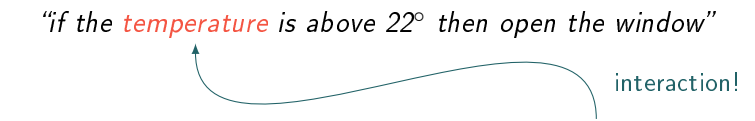

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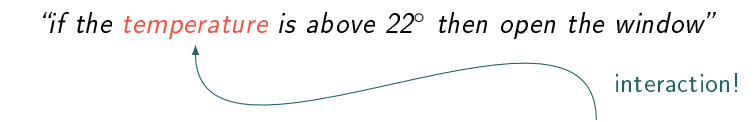

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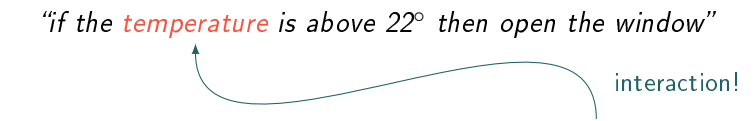

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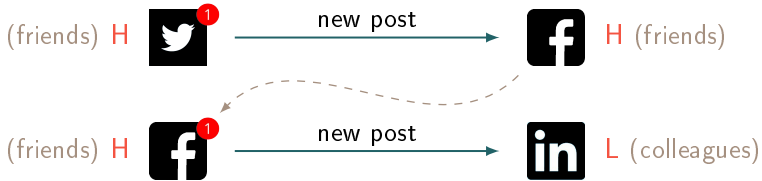

Goal: Securing IoT Apps

A formal framework for proving safety and security of IoT platforms

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   - safety: syntactic constraints for triggers and actions
   - security: flow-sensitive type system

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   - safety: syntactic constraints for triggers and actions
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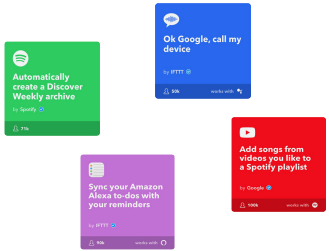
Future enforcement mechanisms can be proven sound w.r.t. our semantic conditions

The Calculus

A Calculus for IoT Apps: Features

Collection of apps belonging to the same user



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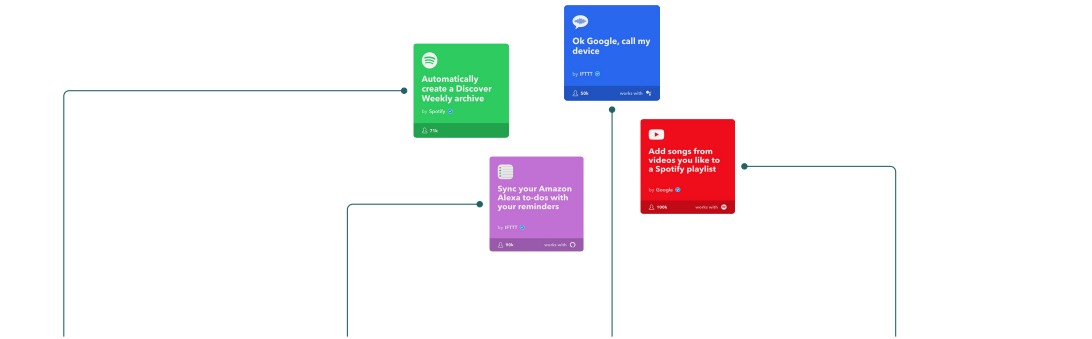

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$$\texttt{Discover}[\mathrm{Dcl}_{\mathrm{D}} \bowtie \mathrm{Pld}_{\mathrm{D}}] \parallel \texttt{Alexa}[\mathrm{Dcl}_{\mathrm{A}} \bowtie \mathrm{Pld}_{\mathrm{A}}] \parallel \texttt{CallDev}[\mathrm{Dcl}_{\mathrm{C}} \bowtie \mathrm{Pld}_{\mathrm{C}}] \parallel \texttt{Spotify}[\mathrm{Dcl}_{\mathrm{S}} \bowtie \mathrm{Pld}_{\mathrm{S}}]$$

A Calculus for IoT Apps: Features (contd.)

Physical and Logical resources are cloud services

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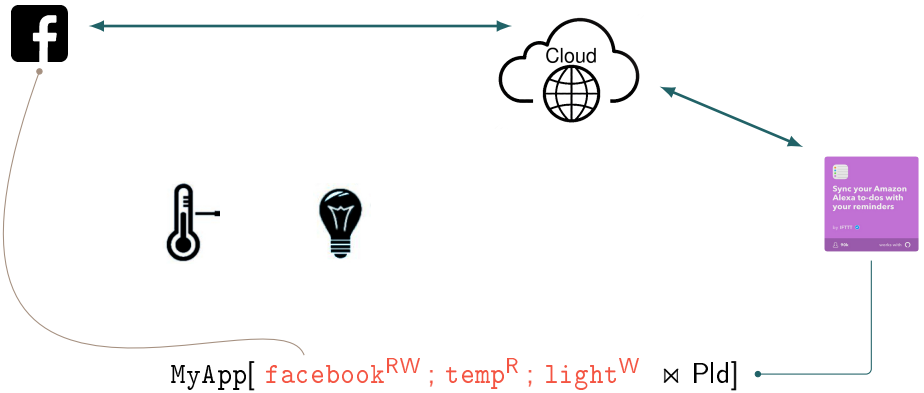

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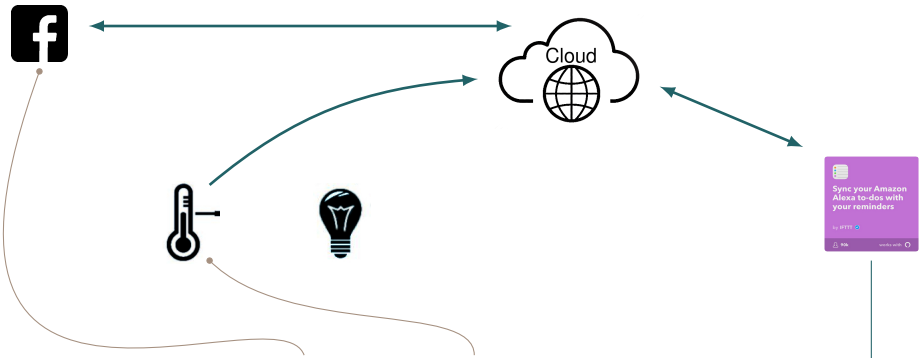

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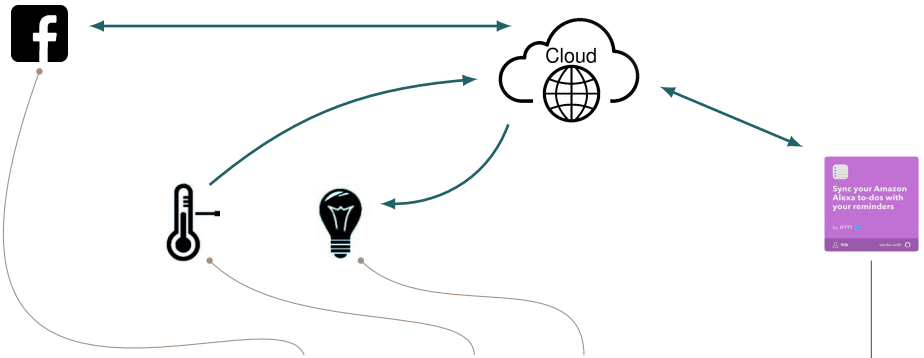

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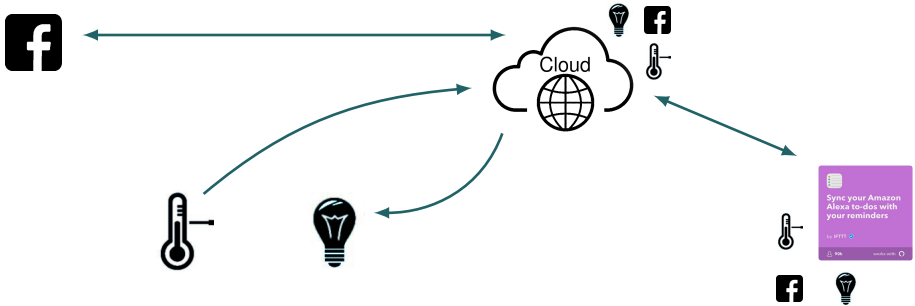
Cloud and local view of services



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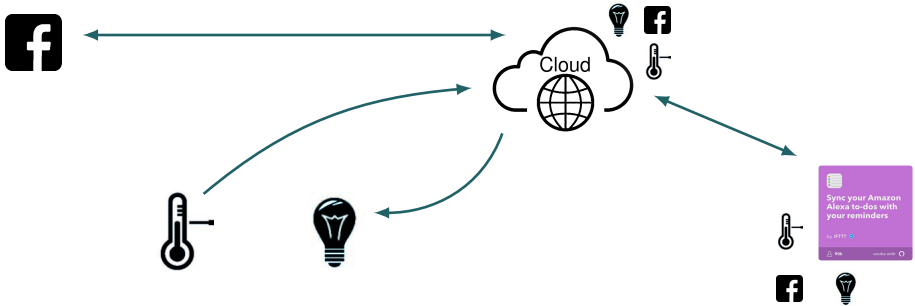

Apps retain a local view of cloud services

A Calculus for IoT Apps: Features (contd.)

Triggers

local services differ from the cloud ones
activation condition check

Global look-up

retrieves the values of cloud services

Isolated execution

computations affect only local services

Actions

update cloud services with local info

SmokeAlarm

$$\mathsf{fix}\ \mathbb{X} \bullet \mathtt{listen}(\mathtt{smoke})\ ;\ \mathtt{smoke} \leftarrow \mathtt{read}(\mathtt{smoke})\ ;\ \mathsf{if}\ (\mathtt{smoke} = \mathit{yes})\ \mathsf{then}\ \{\ \mathtt{alarm} \leftarrow \mathit{On}\ ;\ \mathtt{lights} \leftarrow \mathit{On}\ ;\ \mathtt{update}(\mathtt{alarm}, \mathtt{lights})\ \}\ ;\ \mathbb{X}$$

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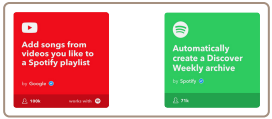
Safety Condition

Safety: Cross-App Interactions

app1 noninteracting with app2:



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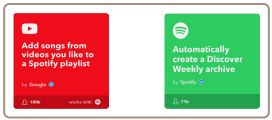
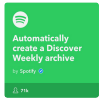


$\approx_H$

Hiding bisimulation



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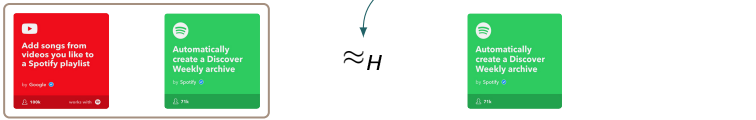

- $\approx_H$ hides the observables contained in H

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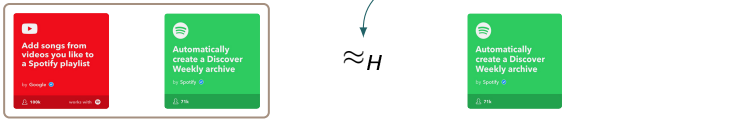

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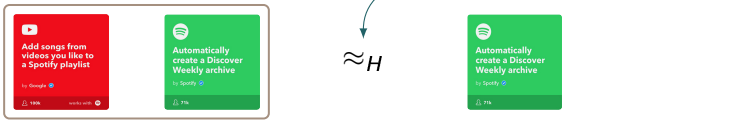

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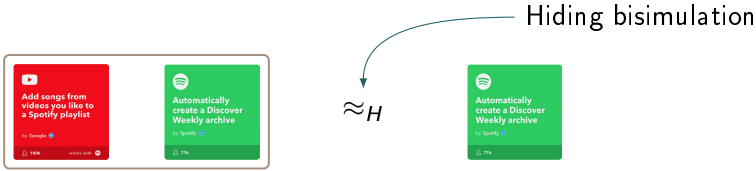

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$$\text{app1} \parallel \text{app2} \approx_{H_{\text{app1}}} \text{app2}$$

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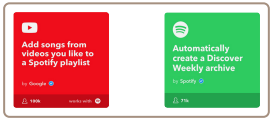

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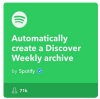

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$$S \parallel R \approx_{H_S} R$$

Enforcement: Syntactic Constraints for Triggers and Actions

Example of a simple syntactic enforcement mechanism

app1 noninteracting with app2:

- apps do not update common services $\quad \text{actions}(\texttt{app1}) \cap \text{actions}(\texttt{app2}) = \varnothing$
- app1 does not trigger app2 $\quad \text{actions}(\texttt{app1}) \cap \text{triggers}(\texttt{app2}) = \varnothing$

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Soundness: the syntactic enforcement implies the semantic safety condition

Enforcement: Syntactic Constraints for Triggers and Actions (contd.)

SmokeAlarm

```
fix 𝕏 • listen(smoke) ;
    smoke ← read(smoke) ;
    if (smoke = yes) then {
        alarm ← On ; lights ← On ;
        update(alarm, lights)
    } ; 𝕏
```

Sprinks

```
fix 𝕏 • listen(heat) ;
    heat ← read(heat) ;
    if (heat ≥ 45) then {
        waterV ← Open ;
        update(waterV)
    } ; 𝕏
```

Enforcement: Syntactic Constraints for Triggers and Actions (contd.)

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$$
\begin{array}{l}
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\quad \mathtt{if}\ \ (\mathtt{smoke} = \mathit{yes})\ \ \mathtt{then}\ \ \{ \\
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Semantic safety: $\mathtt{Sprinks} \parallel \mathtt{SmokeAlarm} \approx_{H_{\mathtt{Sprinks}}} \mathtt{SmokeAlarm}$

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We can state safety syntactically:

- apps do not update common services $\{\texttt{waterV}\} \cap \{\texttt{alarm}, \texttt{lights}\} = \varnothing$
- Sprinks does not trigger SmokeAlarm $\{\texttt{waterV}\} \cap \{\texttt{smoke}\} = \varnothing$

Security Condition

Security: Information Flows

Services with different security clearance

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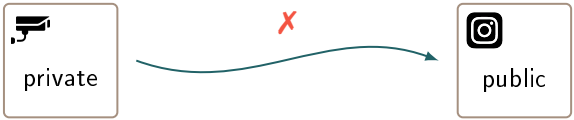

Security: Information Flows

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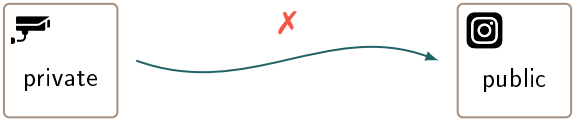

Security policy:

- lattice of security levels $\langle \mathrm{SL}, \preccurlyeq \rangle$
- security levels assignment Σ to services
- σ-equivalence $\equiv_\sigma$: stores agree on services with security levels $\preccurlyeq \sigma$

Security: Information Flows (contd.)

Noninterference:

$$\forall \mathfrak{G}, \mathfrak{G}' \in \mathbb{S}.\ \mathfrak{G} \equiv_\sigma \mathfrak{G}' \Rightarrow \langle \mathfrak{G}, \mathfrak{L} \rangle \triangleright \mathsf{S} \approx \langle \mathfrak{G}', \mathfrak{L} \rangle \triangleright \mathsf{S}$$

Security: Information Flows (contd.)

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hide updates greater than σ

Security: Information Flows (contd.)

Noninterference:

ignore "termination" leakage — [Demange and Sands, ESOP 2009]

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fix $\mathbb{X}$ • listen(`tw`) ; `tw` ← read(`tw`) ;
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`Fb2Ld`

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$\Sigma(\mathtt{tw}) = \Sigma(\mathtt{fb}) = \mathsf{H}$ and $\Sigma(\mathtt{ld}) = \mathsf{L}$

$$\langle \mathfrak{G}, \mathfrak{L}_\perp \rangle \triangleright \mathtt{Tw2Fb} \parallel \mathtt{Fb2Ld} \not\approx^{\mathrm{ti}}_{H_\mathsf{L}} \langle \mathfrak{G}', \mathfrak{L}_\perp \rangle \triangleright \mathtt{Tw2Fb} \parallel \mathtt{Fb2Ld}$$

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Enforcement: Security Type System

Enforcement

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- input/output check-points

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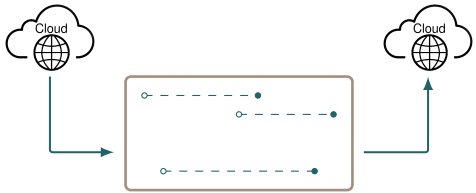

Information flows are allowed only if they do not affect the cloud

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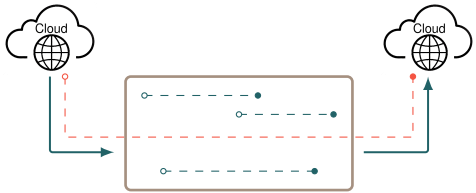

Information flows are allowed only if they do not affect the cloud

Enforcement: Security Type System (contd.)

- Type system parametric in an initial (fixed) security typing Σ
- Judgments (for apps) of the form: $pc \vdash \Gamma\{\mathsf{Pld}\}\Gamma'$ — no flows from $\sigma \succ pc$ to pc
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Soundness: well-typed systems are noninterfering

Conclusion

Contributions

Foundational framework for securing cross-app interactions

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  - Enforcement: syntactic constraints for triggers and actions (Sound)
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Thanks for attention!

Bonus slides

Safety extension: Implicit Interactions

Implicit interactions: semantically-related services with different syntax

Safety extension: Implicit Interactions

Implicit interactions: semantically-related services with different syntax

Therm

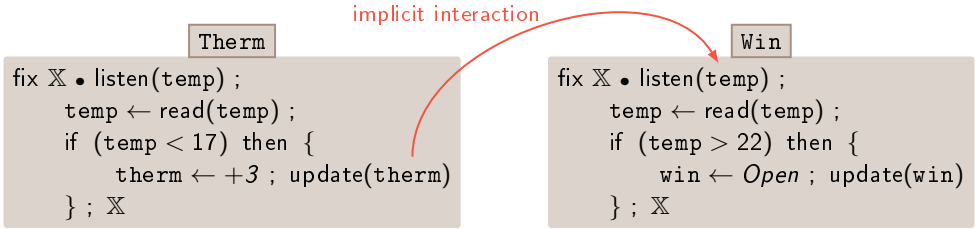
```
fix 𝕏 • listen(temp) ;
      temp ← read(temp) ;
      if (temp < 17) then {
          therm ← +3 ; update(therm)
      } ; 𝕏
```

Win

```
fix 𝕏 • listen(temp) ;
      temp ← read(temp) ;
      if (temp > 22) then {
          win ← Open ; update(win)
      } ; 𝕏
```

Safety extension: Implicit Interactions

Implicit interactions: semantically-related services with different syntax



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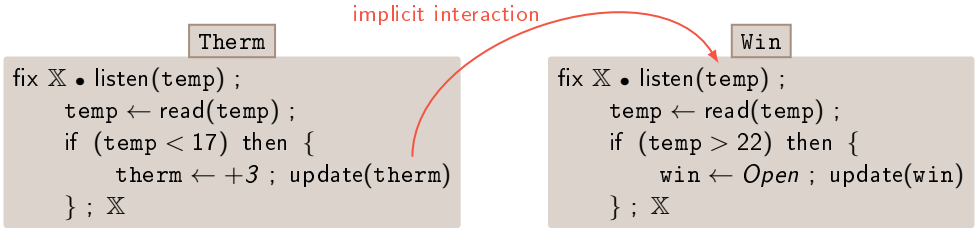

- Dependency policy $\Delta \subseteq \text{Services} \times \text{Services}$
- $y \in \mathfrak{clo}(\Delta, x)$, non-deterministic update on y
- Parametric LTS and hiding bisimulation

Safety extension: Priorities

The user intentionally allows some interactions

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Noninteraction up-to priority level $\mathfrak{p} \in \mathrm{PL}$

- Indistinguishable behavior observing services at priority level greater than $\mathfrak{p}$
- We hide the updates of services lower than, or equal to, $\mathfrak{p}$
- Parametric LTS and hiding bisimulation