FOSAD 2015

15th International School on Foundations of Security Analysis and Design

Secure Compilation Using Micro-Policies

Motivation, Key Points and Ongoing Activities

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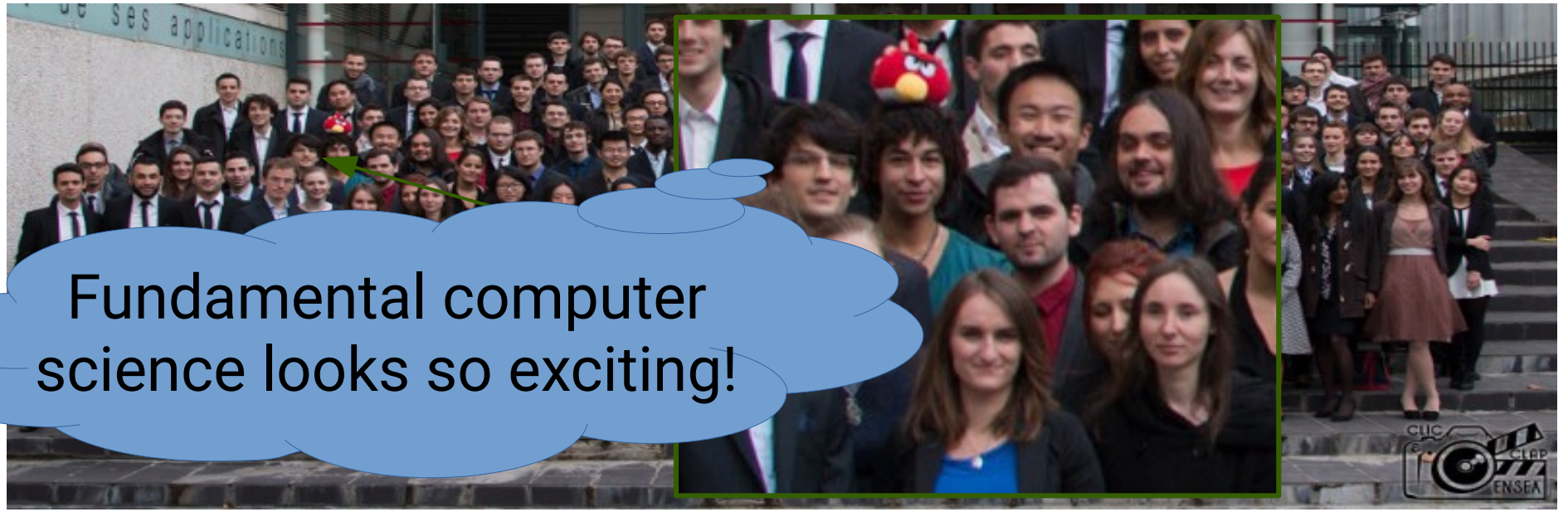
Self-Introduction

- Master's degree in **computer engineering** and **digital systems** from ENSEA (France)
- **Research-oriented** Master's degree in **computer science** from Université Paris Diderot
- Inria PhD student with **C. Hriţcu** and **B. Blanchet**



Micro-Policies Project

Formal methods & **hardware architecture**

Current team:

- **UPenn**

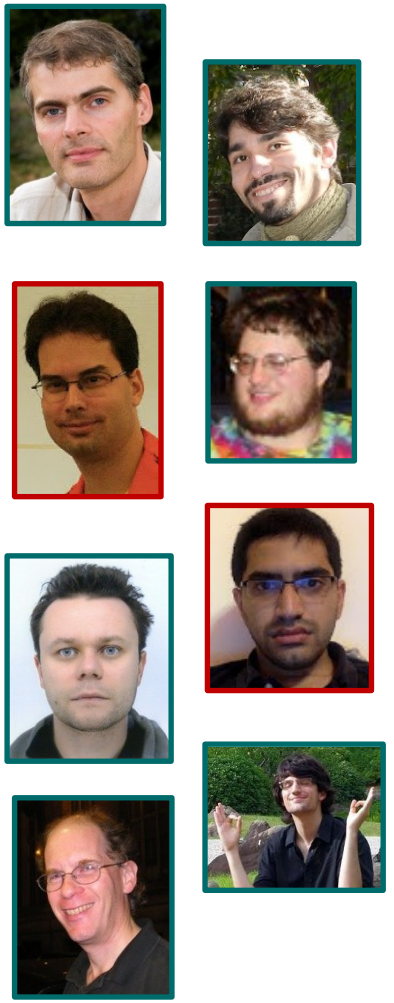
  Arthur Azevedo de Amorim, **André DeHon**, **Benjamin Pierce**, **Antal Spector-Zabusky**, **Udit Dhawan**

- **Inria**

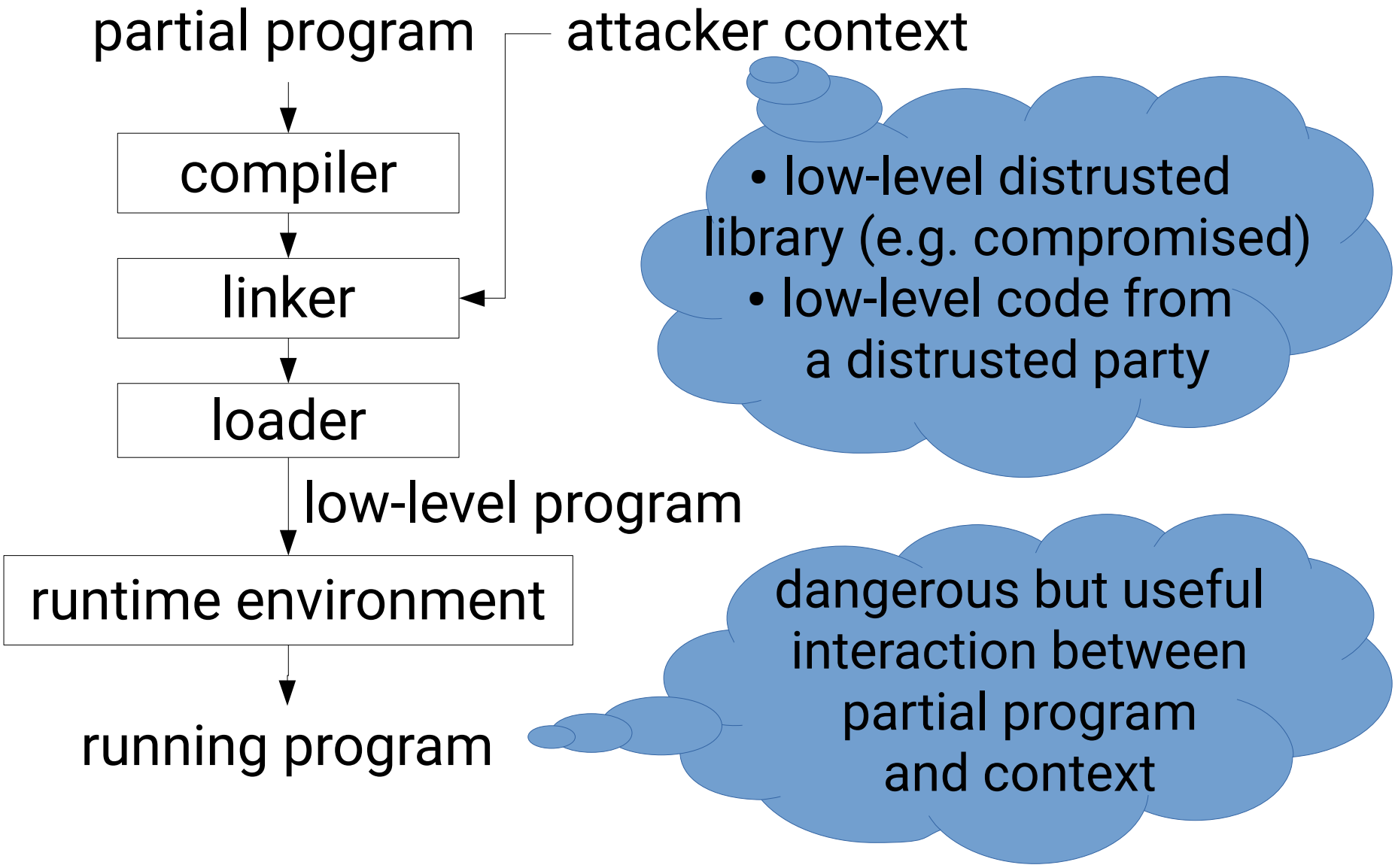
  Cătălin Hriţcu, **Yannis Juglaret**

- **Portland State**

  Andrew Tolmach

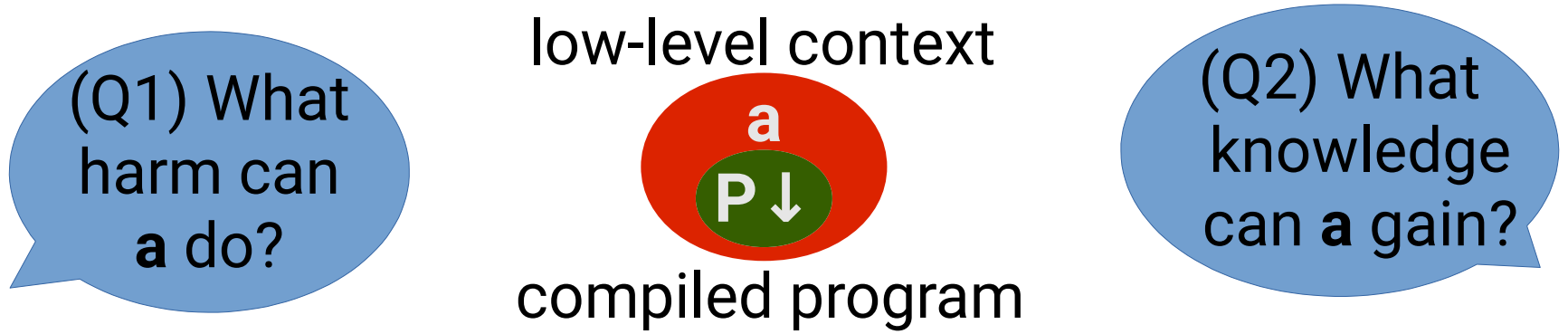


Typical Secure Compilation Layout

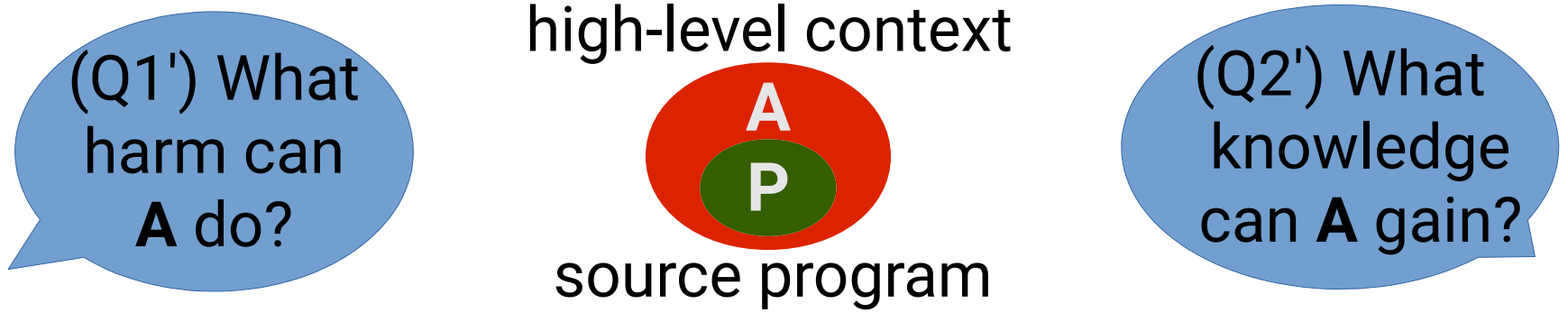


Partial Programs Security Reasoning

- Study **interaction** with attacker contexts

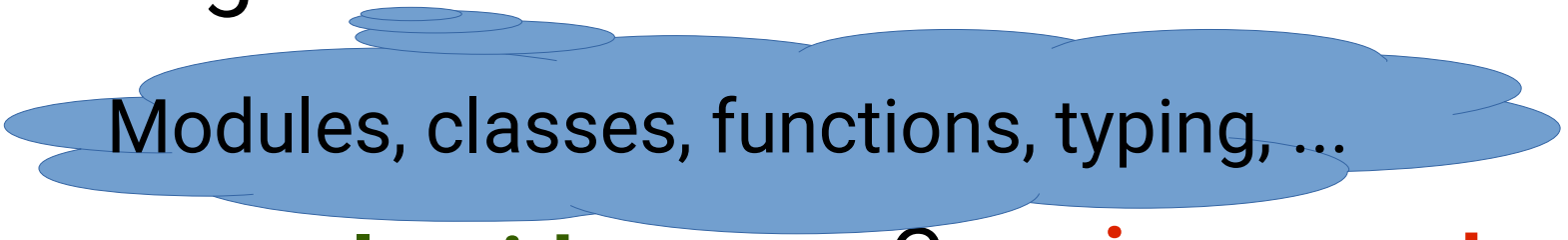


- Secure compilation **reduces** Q1,Q2 to Q1',Q2'



- SC enables **easier, source-level reasoning**

Comparing Attacker Power



- Must **comply with abstractions**:
  - More **structure**
  - Restricted **interaction** and **communication**
- Hence **restricted attacker power**

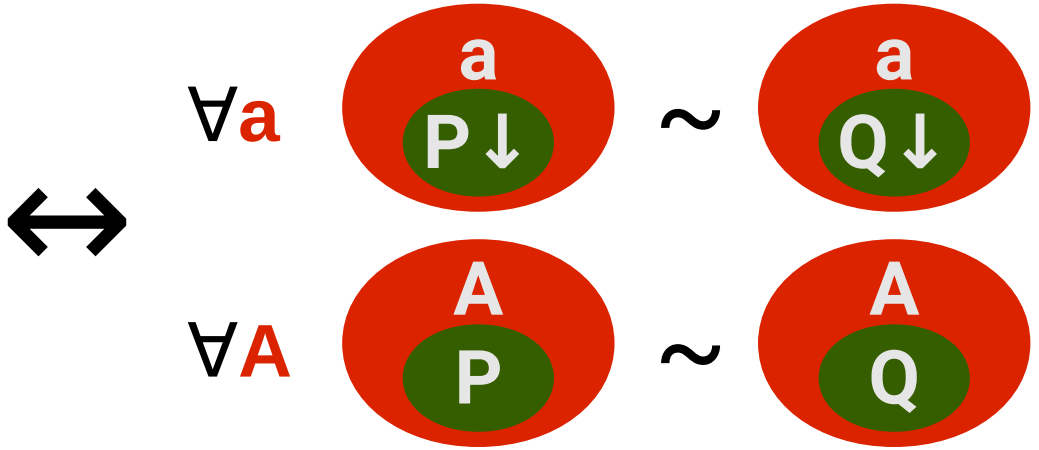
- Can **circumvent** abstractions:
  - Lacks structure
  - Typically unrestricted
    - Reads, writes, or jumps targeting any location
    - Untyped calls

Reasoning with high-level attackers is much easier!

Full Abstraction

- A **formal characterization** of secure compilation

  “no low-level attacker can distinguish **P↓** from **Q↓**”



  “no high-level attacker can distinguish **P** from **Q**”

- Low- and high-level attackers **equally powerful**

  low-level ones **can't do more harm**

- **Very strong** property, hard to achieve

Enforcing Full Abstraction

- Apply standard security techniques
  - **randomization**: e.g. of address space layout
  - **code rewriting**: add extra software checks
- Use enhanced hardware
  - **protected module architectures**: e.g. Intel SGX
  - **generic protection mechanisms**?
- Our approach: use **micro-policies**
  - **efficient hardware implementation**: the PUMP
  - **mechanized metatheory**

ASPLOS '15 | Oakland S&P '15

Challenges in Secure Compilation

- **Efficiency**
  - main challenge in the domain
  - in our case, we want **low-overhead monitoring**
  - good hopes: **4 complex policies <10% overhead**
- **Transparency**
  - mustn't reject **benign low-level contexts**, neither **statically** nor **dynamically**
  - in our case, we want **permissive monitoring**
  - need to enforce **exactly what is required**

A Finer-Grained View on Programs

- FA is stated for **contexts** and **partial programs**
- Let us view programs as **linked components**

- The previous setting is recoverable

Starting Simple: Our Source Language

- Simple **class-based object-oriented language**

a component = **a class** + **objects of that class**

public methods, private fields static object definitions static typing	no primitive types no inheritance no dynamic allocation

```
e ::= this | arg | o          reference
    | e.f | e.f := e          selection, update
    | e.m(e)                  call
    | e == e ? e : e          object identity test
    | exit e                  early termination
    | e; e                    sequence
```

- **Many more abstractions** than you would expect

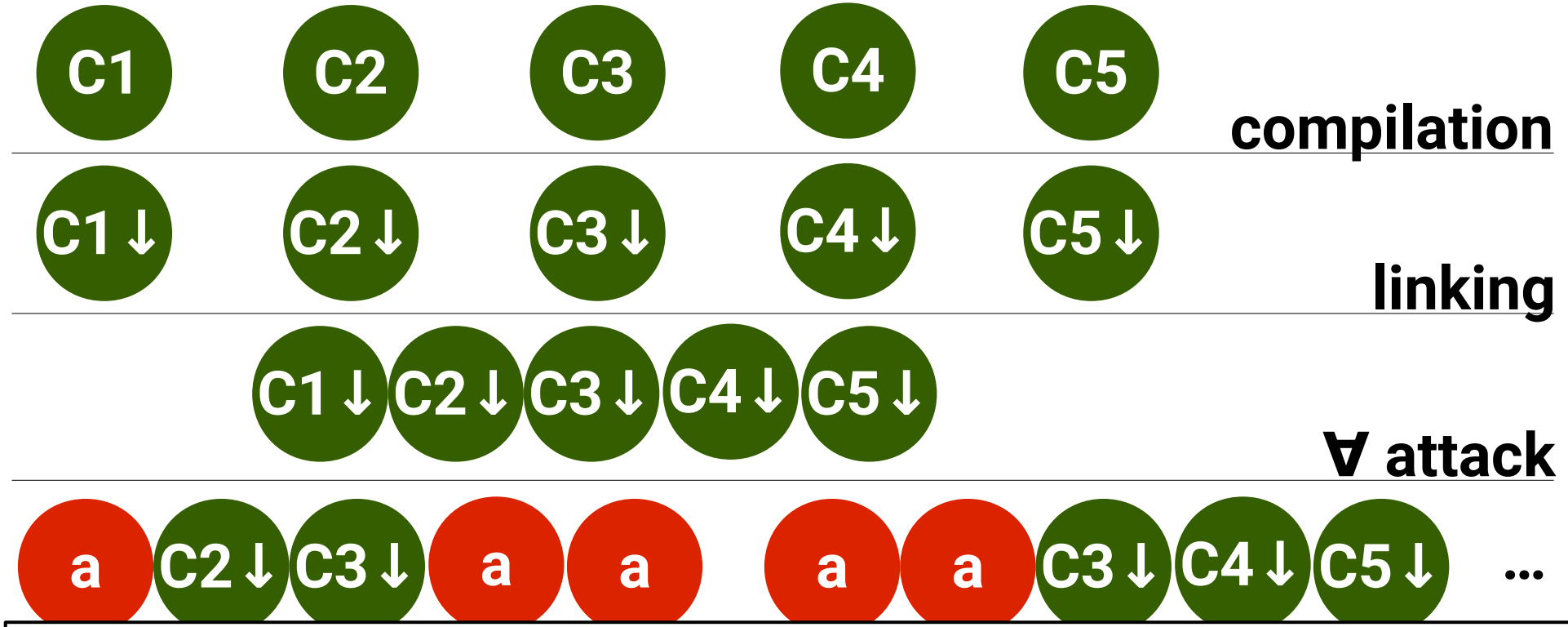
High-Level Abstractions

- Class isolation
  - **fields** are **private**
  - classes **can't read/write** each other's **code/data**
- Method call discipline
  - **method calls/returns** are the **only way to interact**
  - callees return **where callers expect them to**
  - callees give **no information** to callers except result
- Type safety

  method arguments/results are **well-typed**

What We Provide

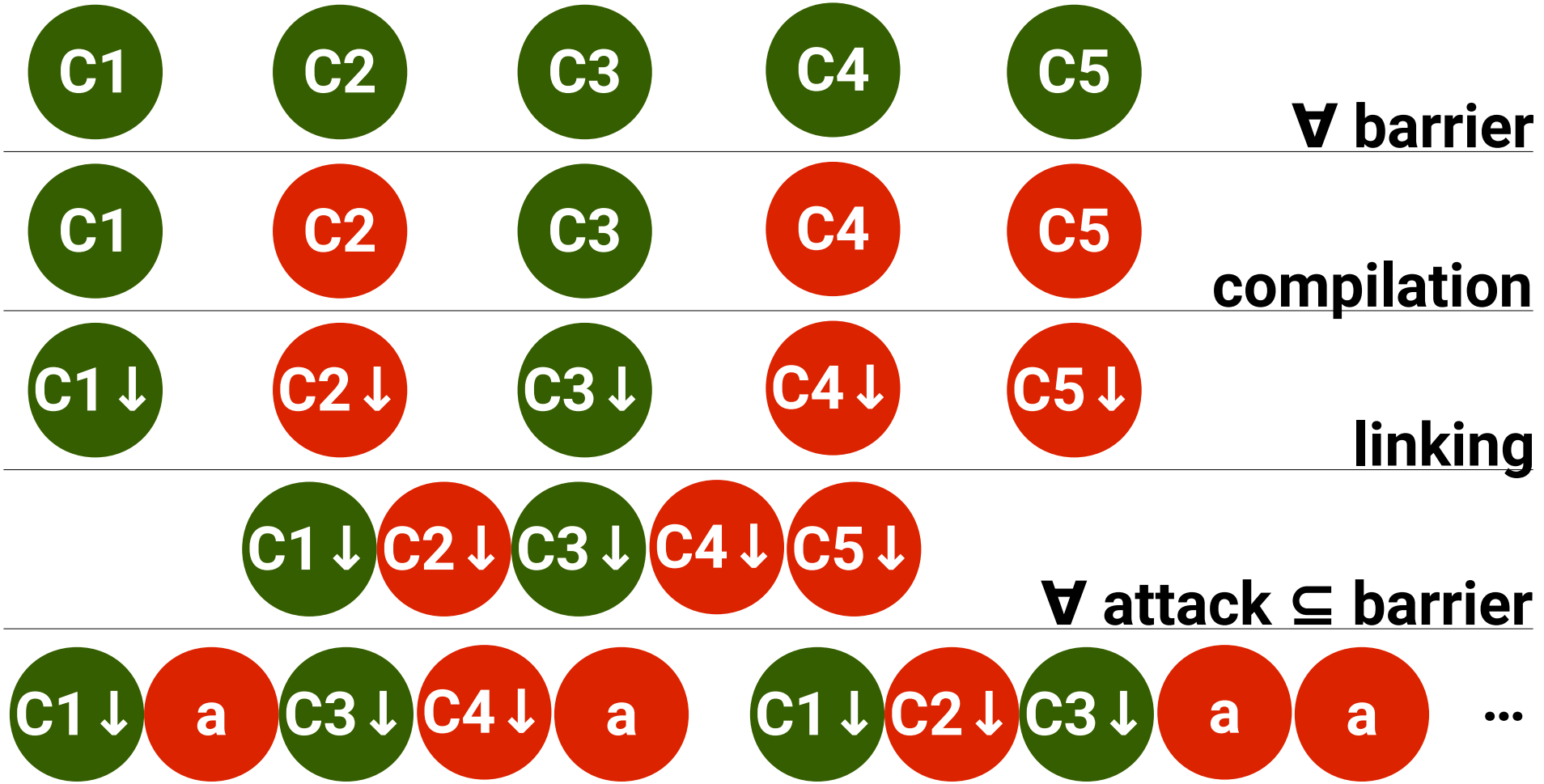
- **Mutual distrust at compile-time**
- **SC** for **non-compromised components**



→ compiler has **no knowledge** about **where** attacks happen
→ protection in **every dynamic compromise scenario**,
for every component that **behaves well**

What Full Abstraction Provides

- **Trusted/distrusted known at compile-time**
- Static protection: for **trusted components only**



Beyond Full Abstraction

- We achieve **more** than necessary

  need for a **full abstraction-like characterization**

- Two extended abstracts presented at FCS'15:
  - ***Multi-Module Full Abstraction*** by Patrignani et al.
  - ***Secure Compilation Using Micro-Policies***
- Ongoing research activities:
  - How to **properly formalize** this?
  - Do **proof techniques** for FA generalize? How?
  - Do **previous works** provide such guarantees?

Ongoing Activities and Future Work

- **Formalize our secure compilation**
- **Prove** full abstraction

- **Measure** efficiency
- **Test** transparency, **mitigate** with **wrappers**
- (**Extend** current language)
- Move to **functional languages**
- Study **micro-policy composition**

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FIN

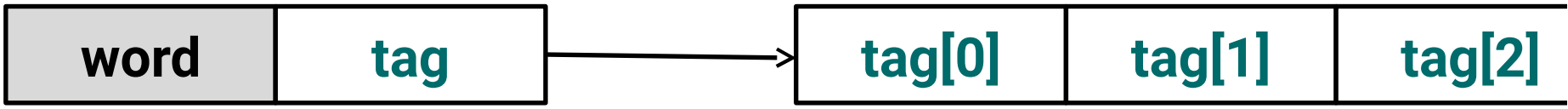
ASPLOS '15

Micro-Policies

Oakland S&P '15

- Add **large tag** to each machine word

unbounded metadata



- Words in memory and registers are all tagged

pc	tag
r0	tag
r1	tag
r2	tag

mem[0]	tag
mem[1]	tag
mem[2]	tag
mem[3]	tag

pc

* conceptual model, the hardware implements this efficiently

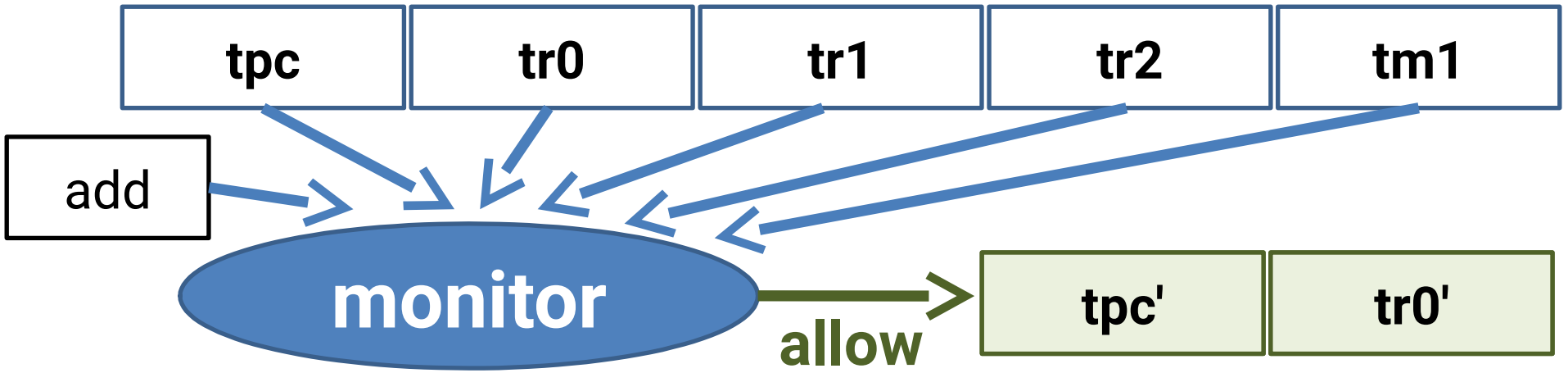
Tag-Based Instruction-Level Monitoring

pc	tpc
r0	tr0
r1	tr1
r2	tr2

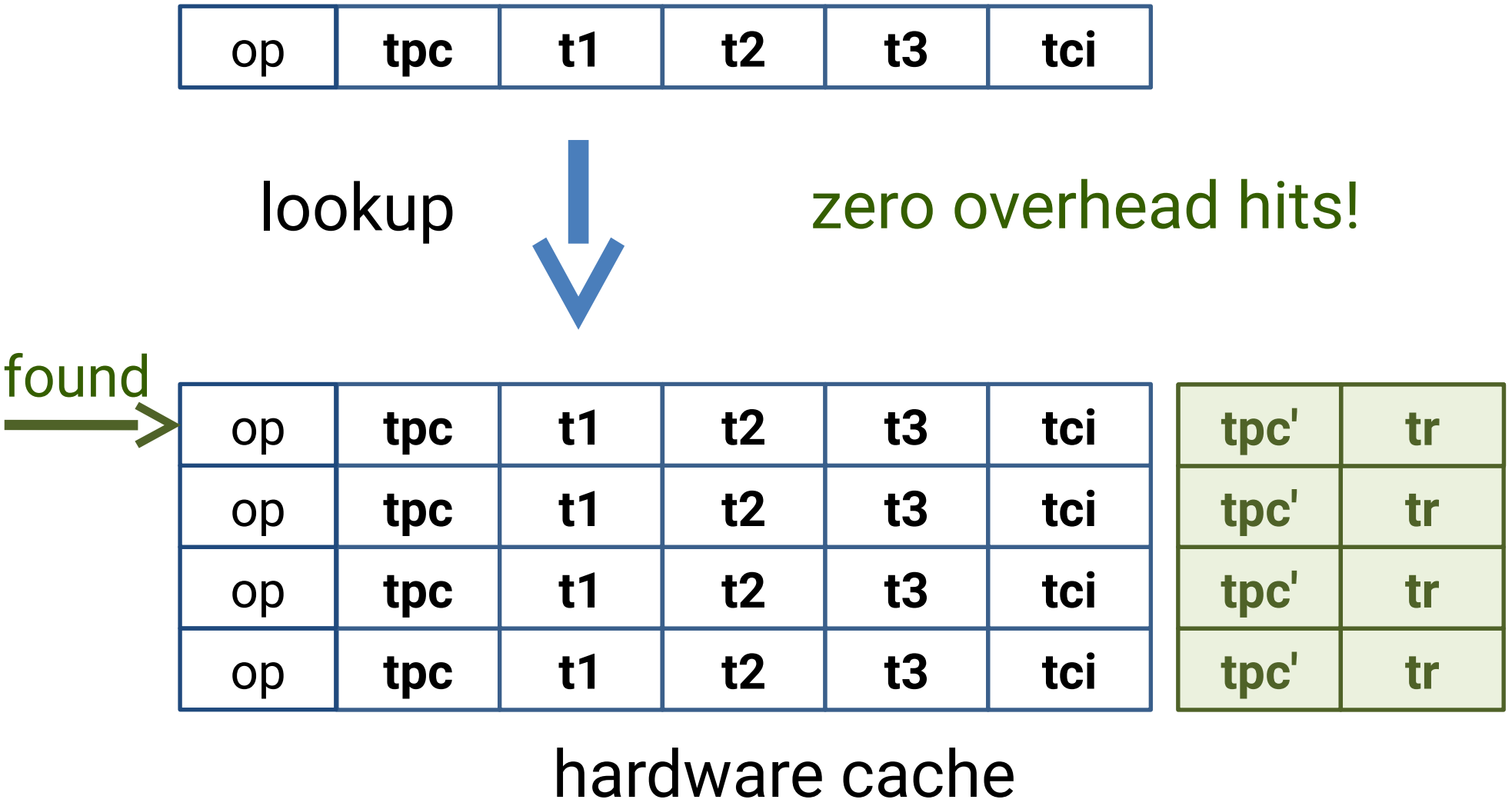
mem[0]	tm0
mem[1]	tm1
mem[2]	tm2
mem[3]	tm3

pc

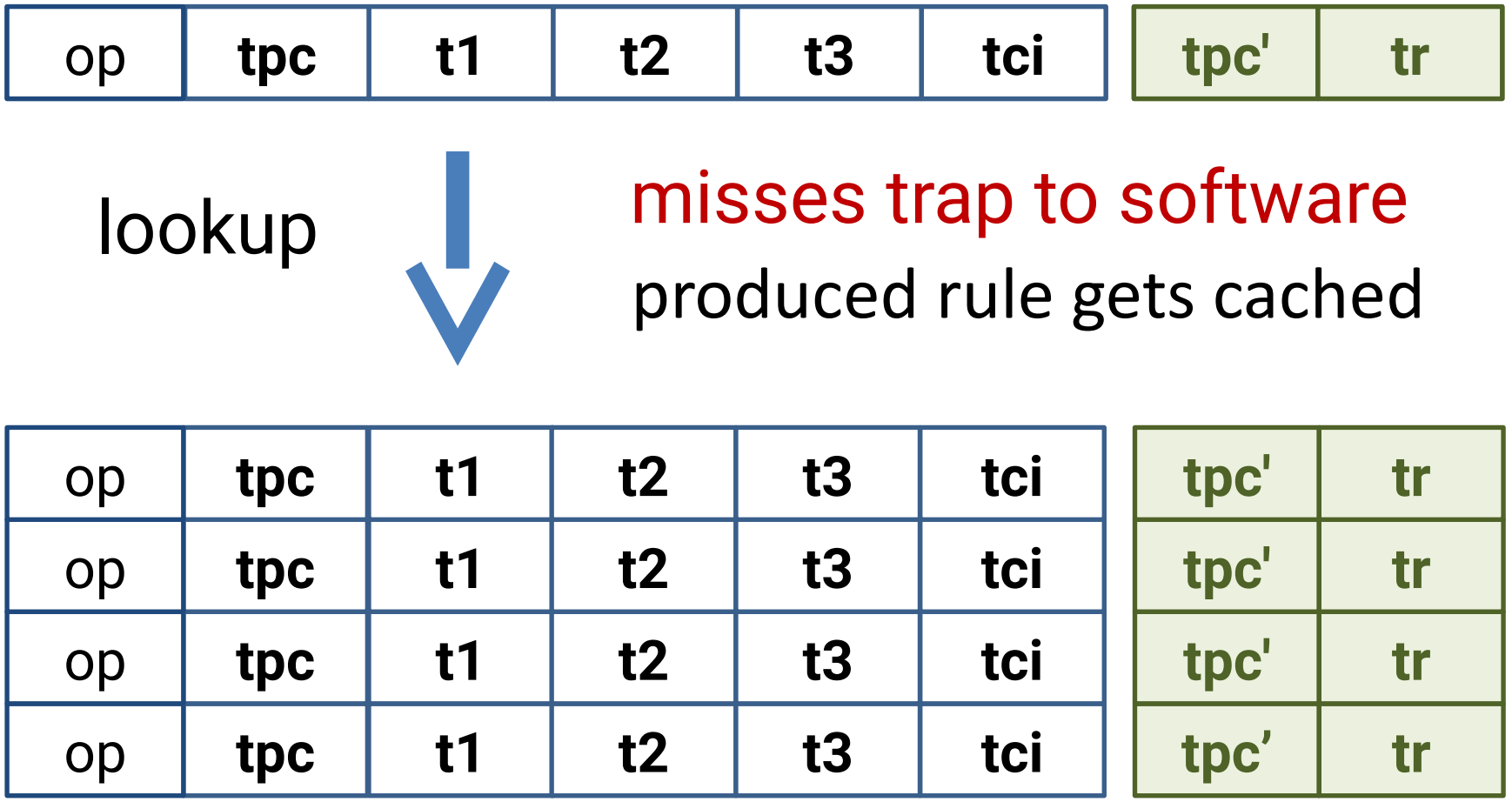
decode(mem[1]) = add r0 r1 r2



Efficiently Executing Micro-Policies



Efficiently Executing Micro-Policies

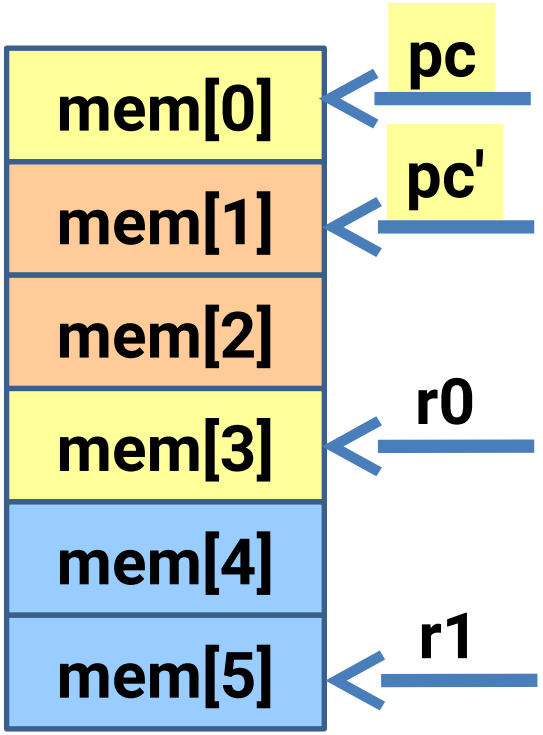


Micro-Policy Enforcing Abstractions

- Class isolation: by **compartmentalization**
- Method call discipline
  - distinguish **entry points**
  - use **linear return capabilities**
  - **clear registers** upon call and return
- Type safety: via **dynamic type-checking**
  - tag values with their **type**
  - tag entry points with **method signatures**
  - tag return capability with **expected return type**

Isolation Micro-Policy

Memory+PC tags embed a **class name** (a color)



decode(mem[0]) = store r0 r2

store: **tpc = tm0 = tm3 … → ✓ tpc tm3**

decode(mem[1]) = nop

_: tpc' ≠ tm1 … → ✗ failstop

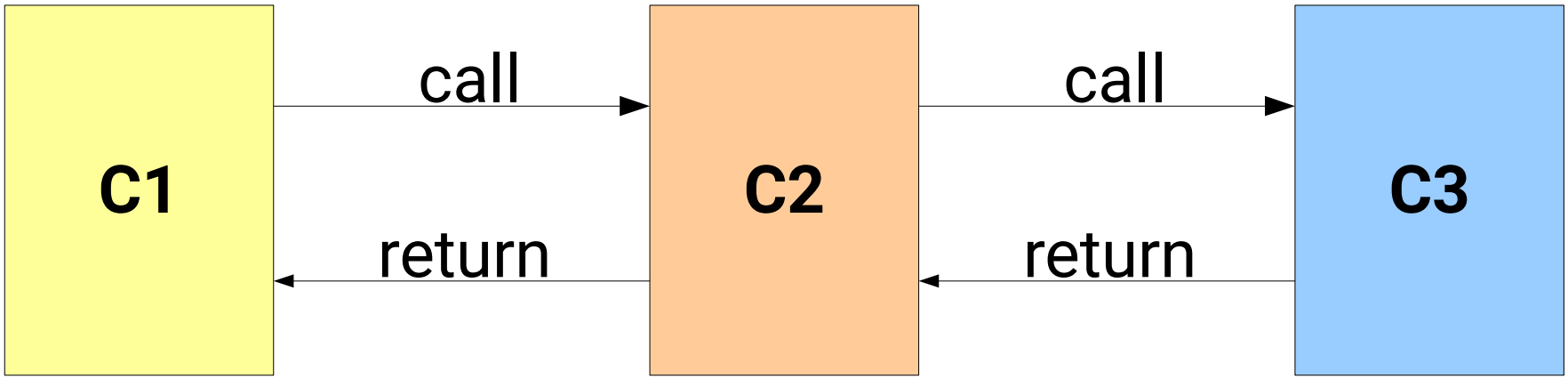
decode(mem[0]) = load r1 r2

load: tpc = tm0 ≠ tm5 … → ✗ failstop

Compilation of Method Calls

Low-level **call instruction**: Jal, jump and link

callee gets a **return address** in register ra



Matching sequence of low-level instructions:

Jal	Store ra	Jal	Jump ra	Load ra	Jump ra

Method Call Discipline Micro-Policy

- Use a different tag for **method entry points**
- Track **call depth** on PC tag
- Use **linear return capabilities**

```
Jal:    pc@d    m@Entry → pc@d+1  ra@d+1
Jump:   pc@d+1  r@d+1   → pc@d    r@⊥
Mov:    r@d             → r'@d    r@⊥
Store:  r@d             → m@d     r@⊥
Load:   m@d             → r@d     m@⊥
```

Jal | Store ra | Jal | Jump ra | Load ra | Jump ra