SECOMP

Efficient Formally Secure Compilers to a Tagged Architecture

Cătălin Hrițcu

INRIA Paris

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5 year vision

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European Research Council

fresh grant

The problem: devastating low-level attacks

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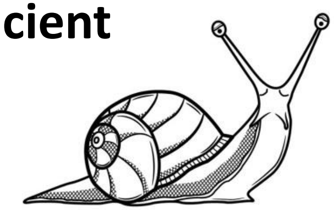
  - **unsafe interoperability:** all high-level safety guarantees lost
- **Today's languages & compilers plagued by low-level attacks**
  - **main culprit: hardware provides no appropriate security mechanisms**
  - fixing this purely in software would be way **too inefficient**



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software-defined, hardware-accelerated, tag-based monitoring

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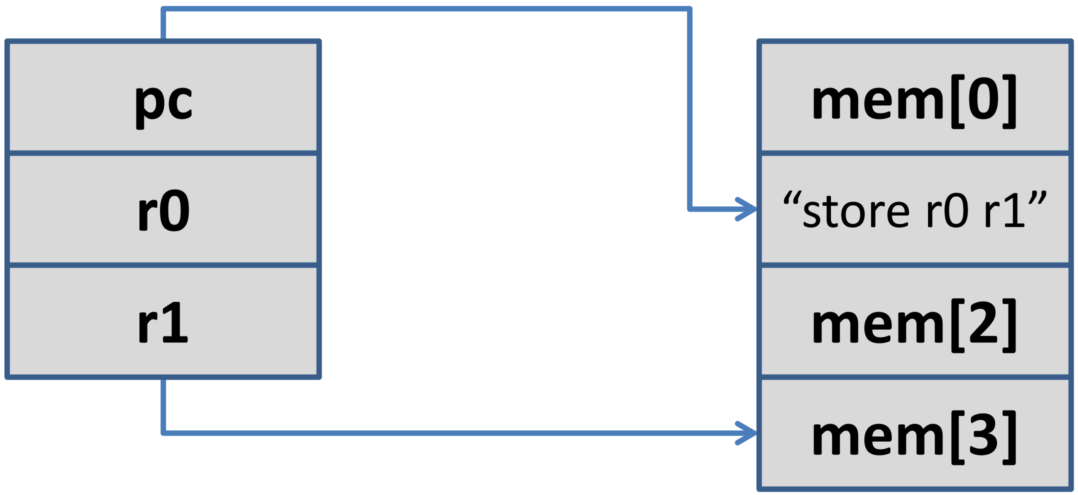

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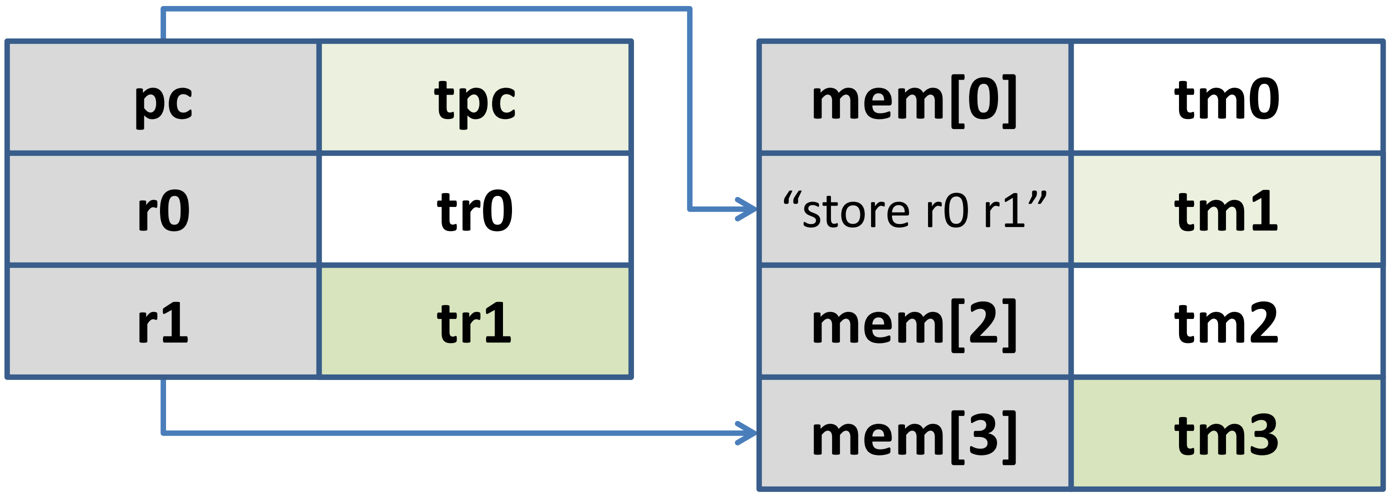

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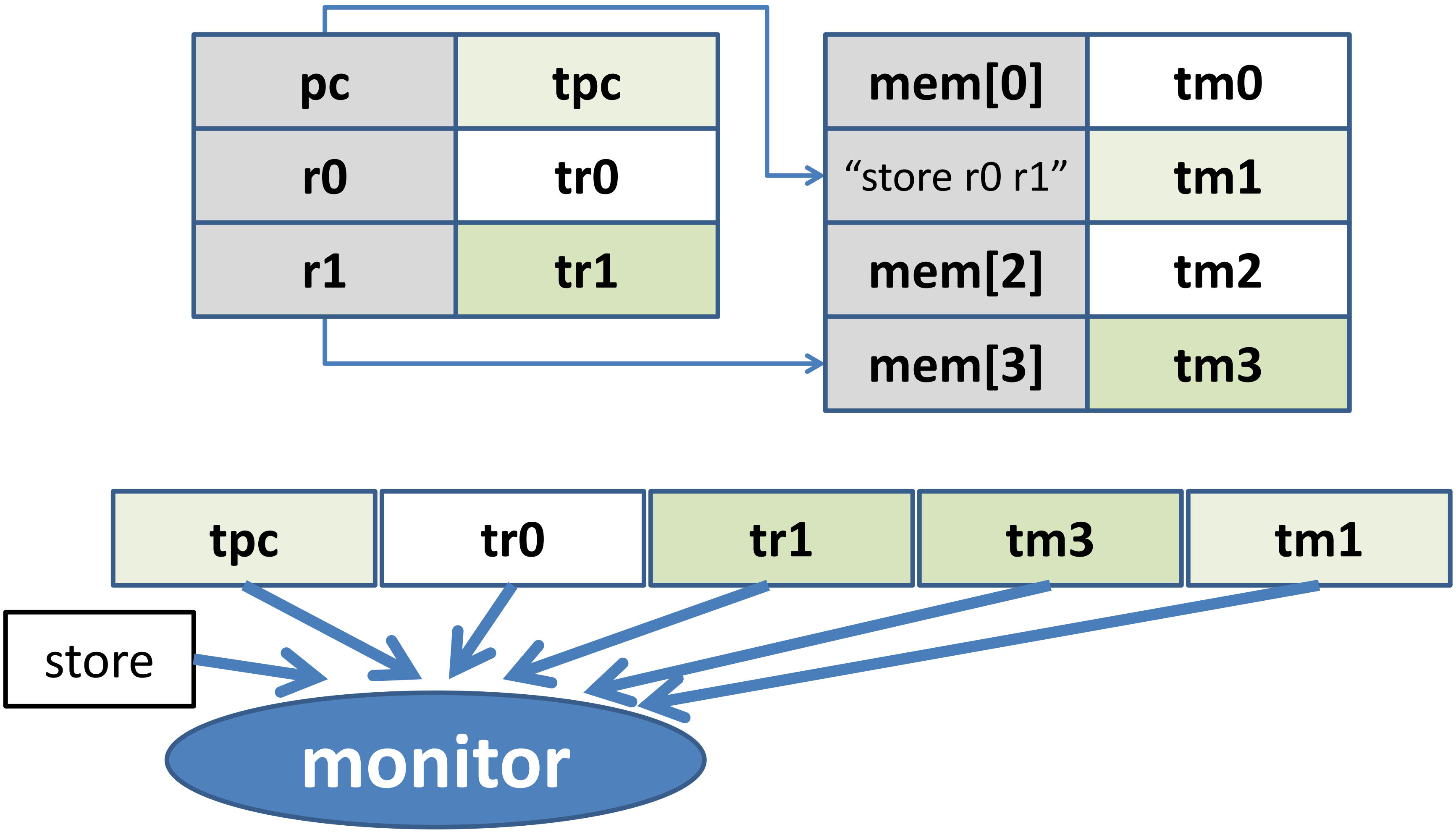

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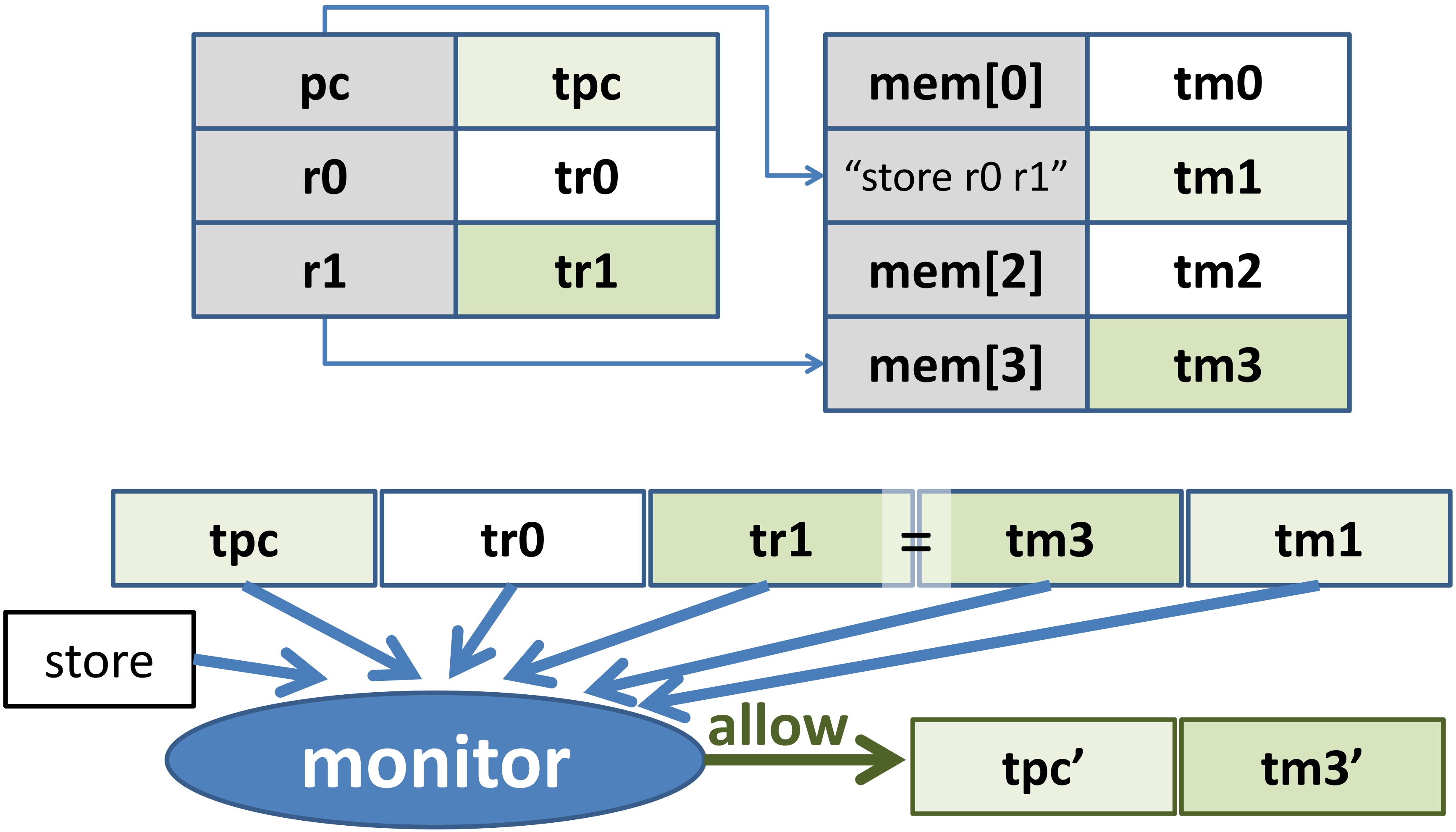

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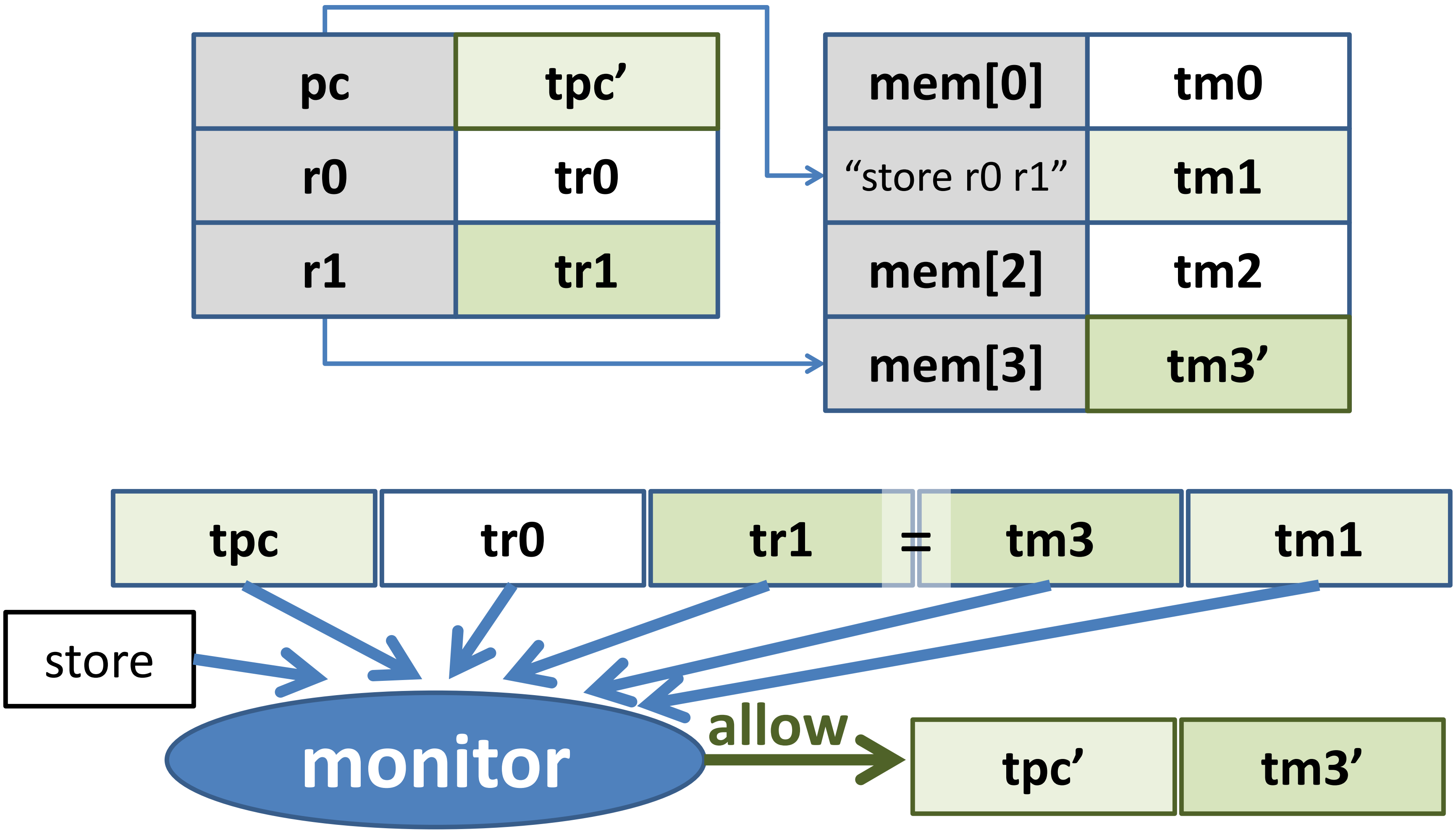

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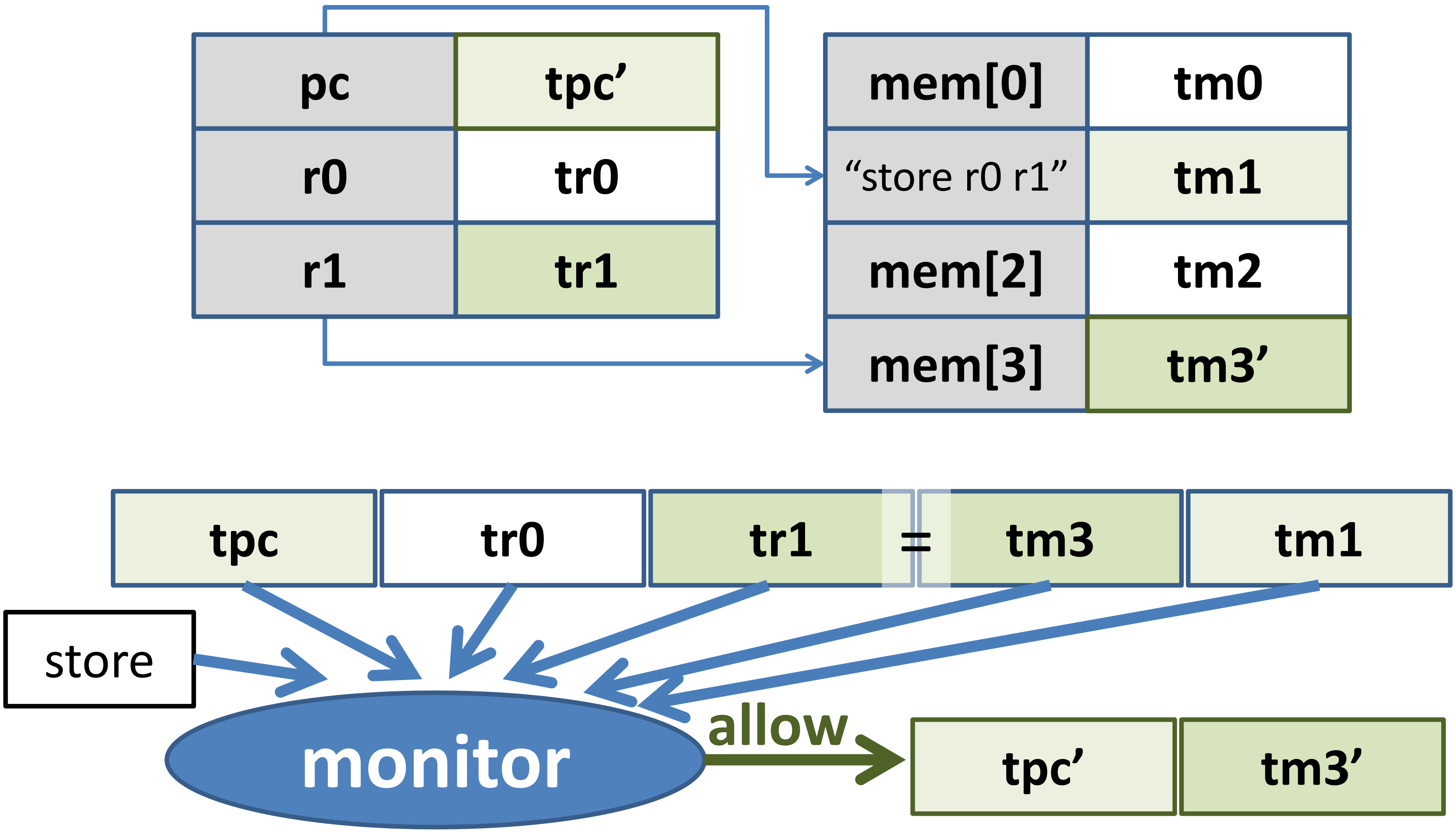

software monitor’s decision is hardware cached

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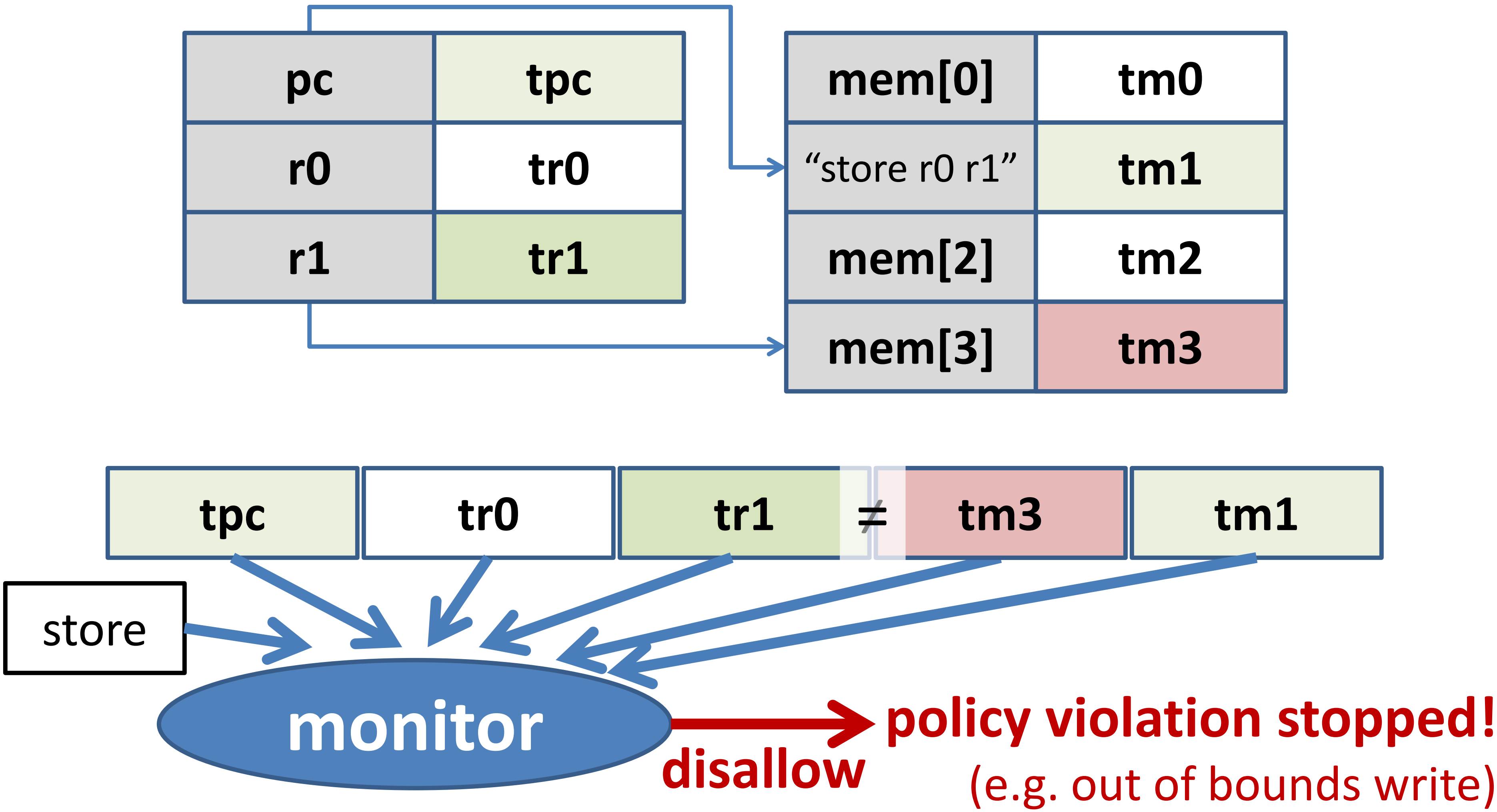

Micro-policies are cool!

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- **low level + fine grained**: unbounded per-word metadata, checked & propagated on each instruction
- **flexible**: tags and monitor defined by software
- **efficient**: hardware caching, <10% overhead
  - heap safety, control-flow integrity, taint tracking
- **expressive**: complex policies for secure compilation
- **secure** and **simple** enough to verify security in Coq
- **real**: FPGA implementation on top of RISC-V

[Oakland ’13 & ’15, POPL ’14, ASPLOS ’15]

SECOMP grand challenge

Use micro-policies to build **the first efficient formally secure compilers f**or **realistic programming languages**

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1. **Provide secure semantics for low-level languages**
   – C with protected components and memory safety
2. **Enforce secure interoperability with lower-level code**
   – ASM, C, and F* [F* = ML + verification]

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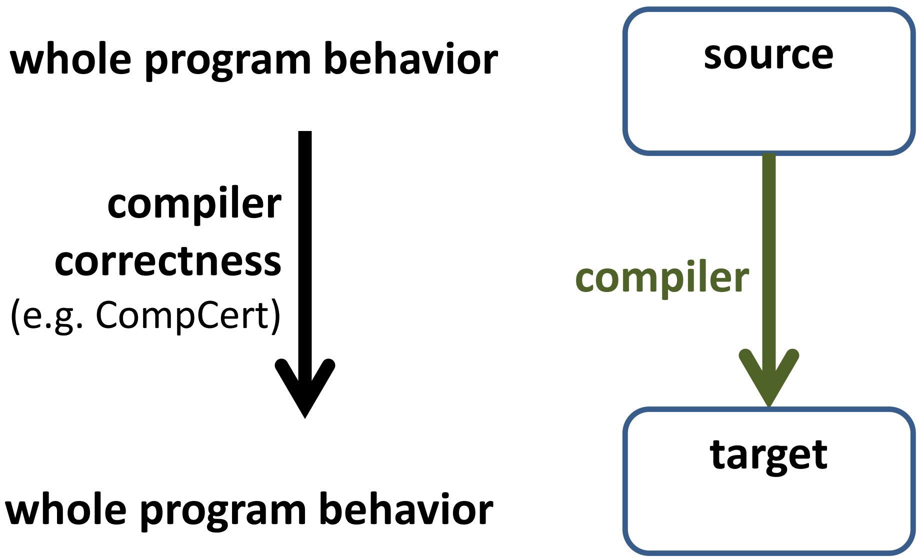

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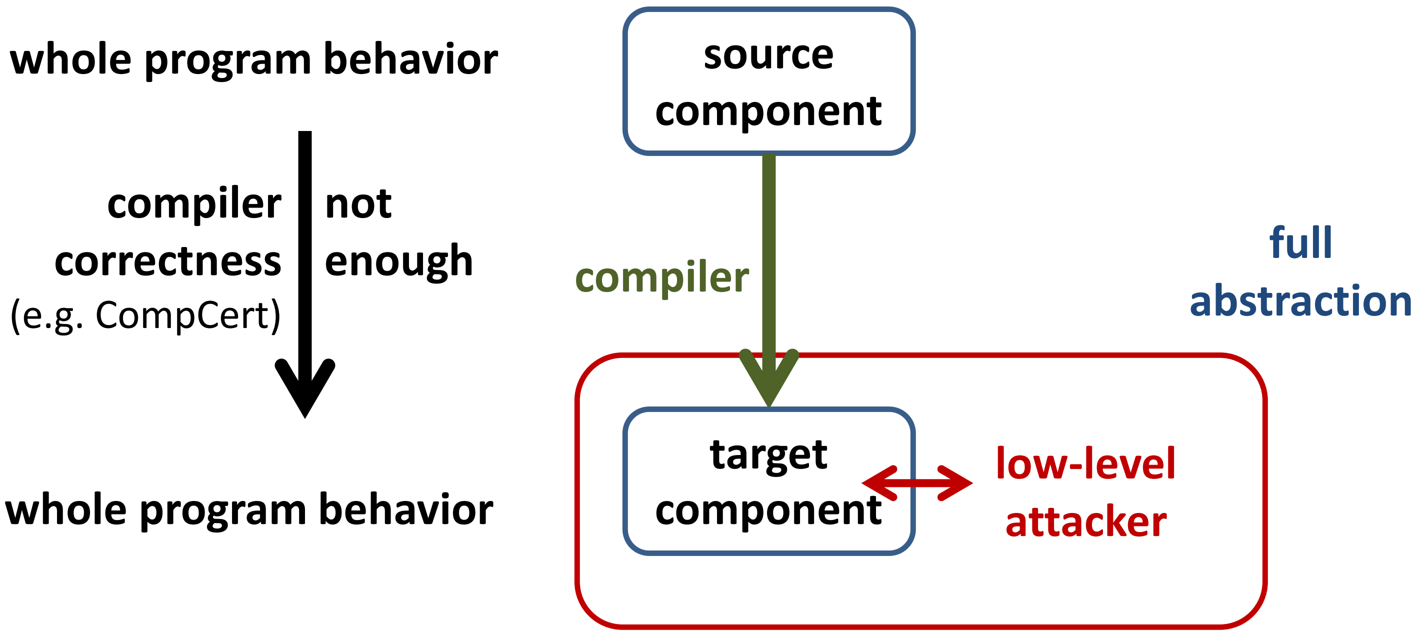

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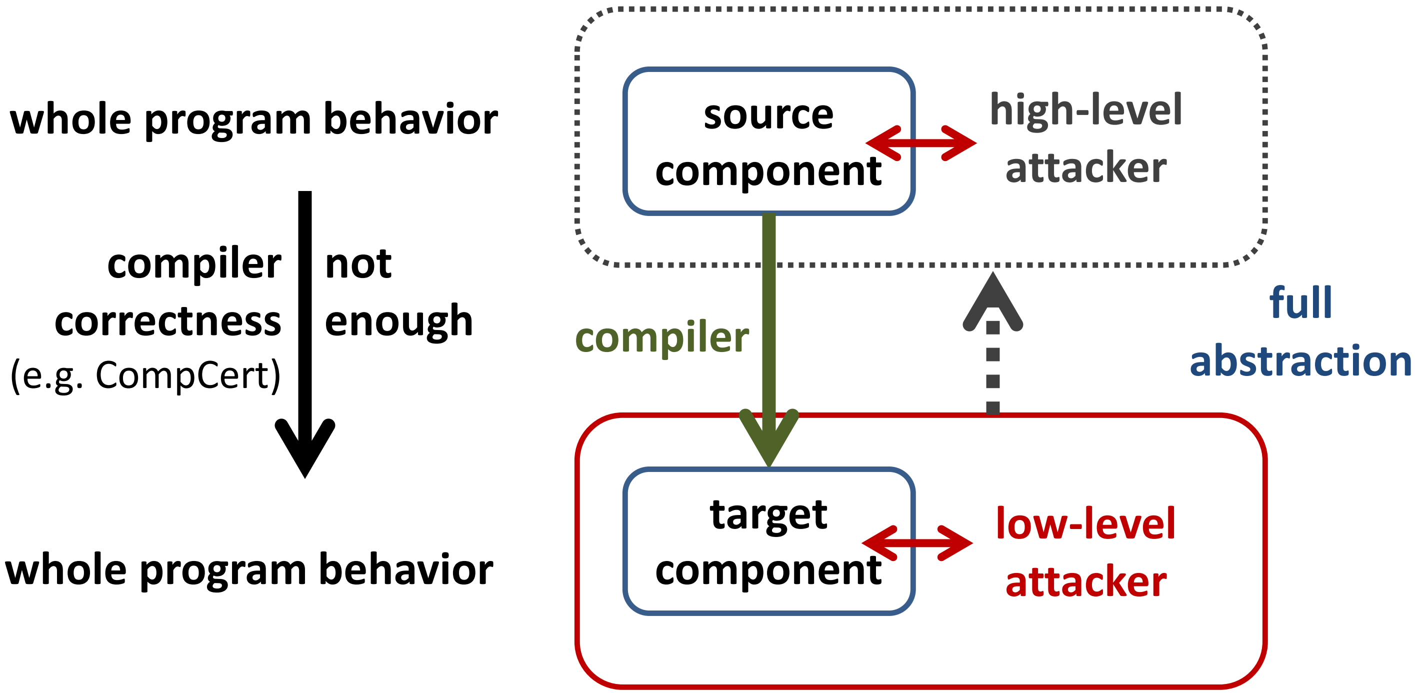

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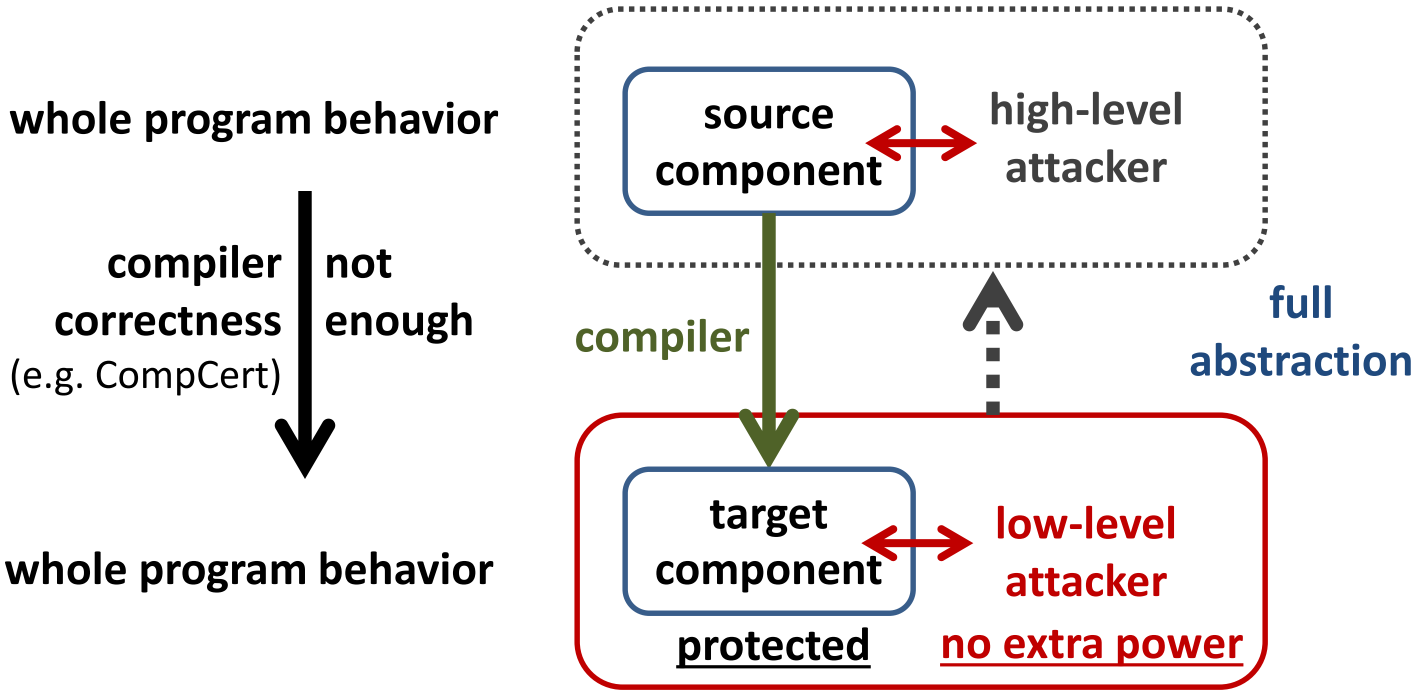

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whole program behavior

compiler correctness (e.g. CompCert) ↓ **not enough**

whole program behavior

source component ↔ **high-level attacker**

secure

full abstraction ↓

secure

Benefit: sound security reasoning in the source language

forget about compiler chain (linker, loader, runtime system)

forget that libraries are written in a lower-level language

SECOMP: achieving full abstraction at scale

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miTLS*

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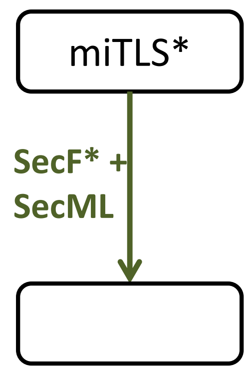

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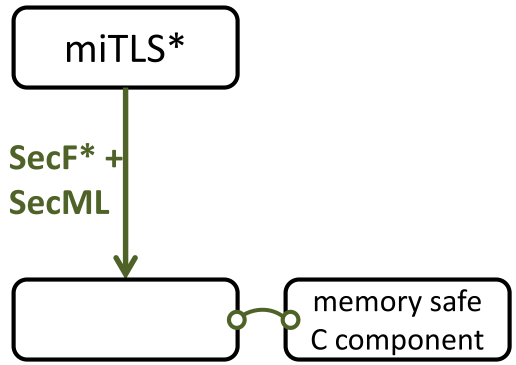

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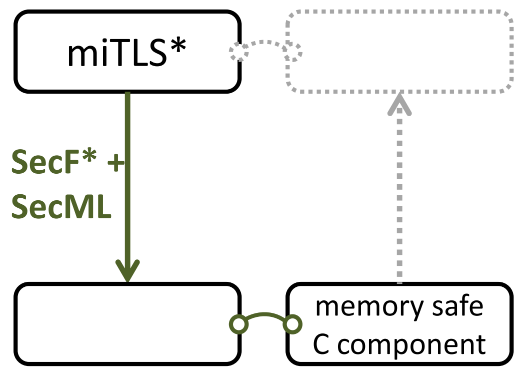

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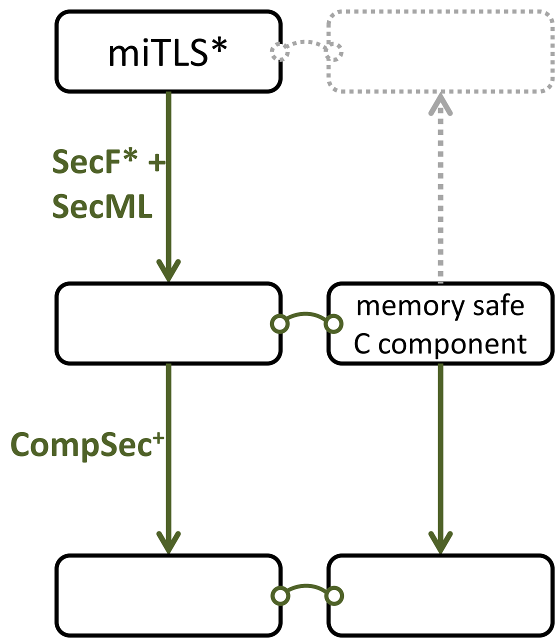

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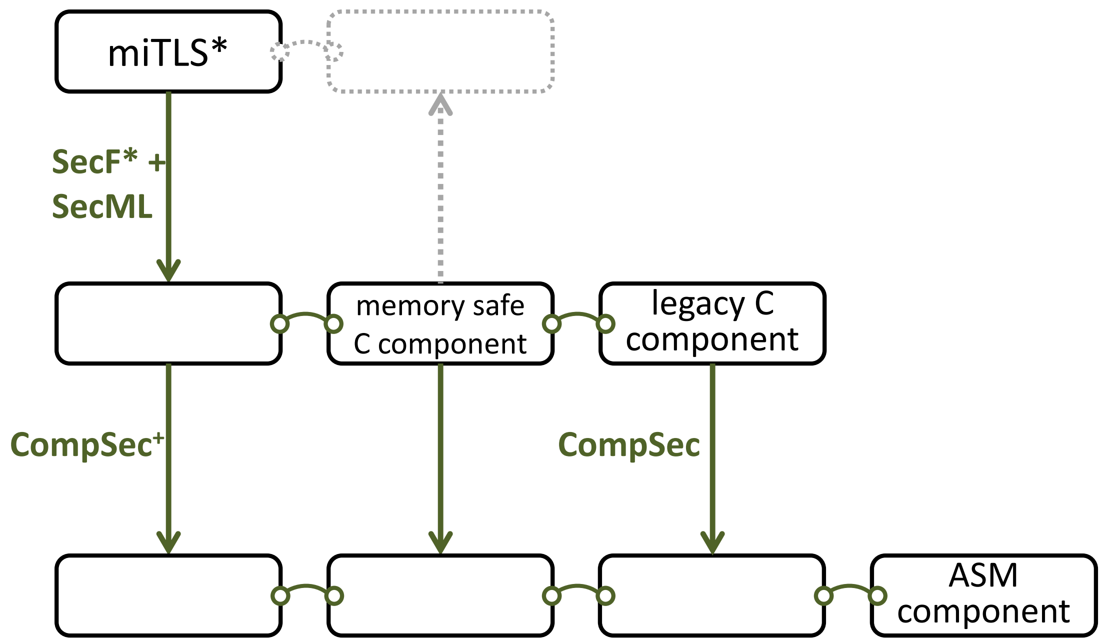

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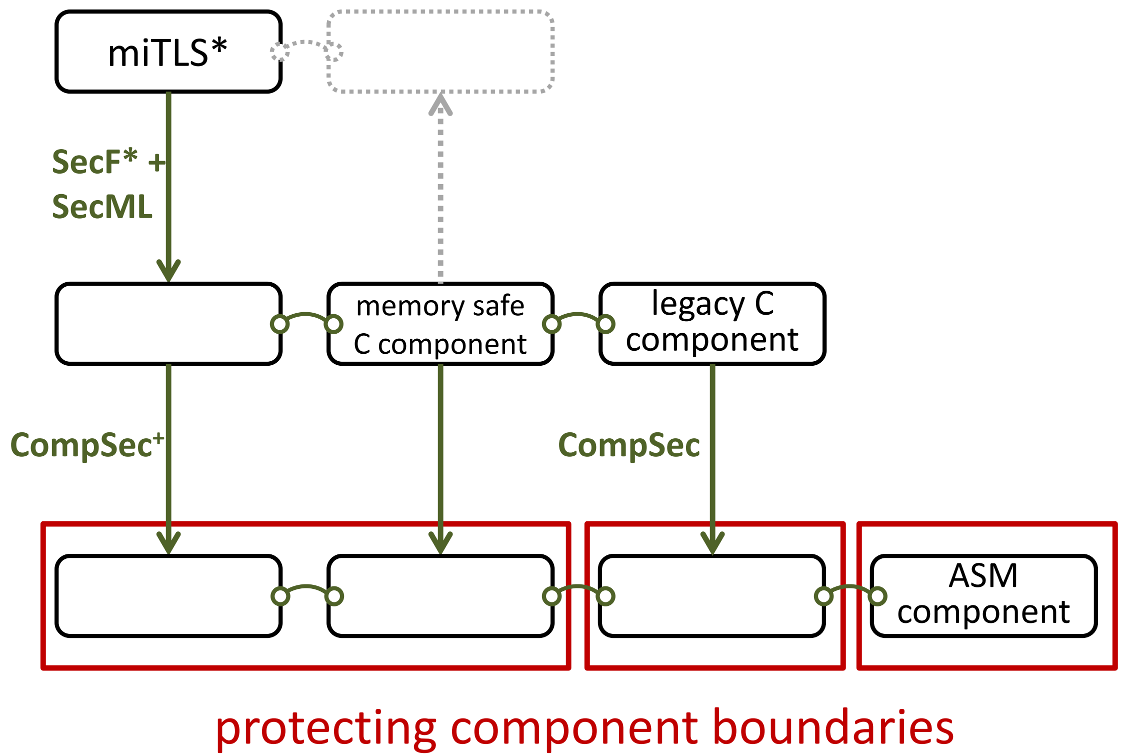

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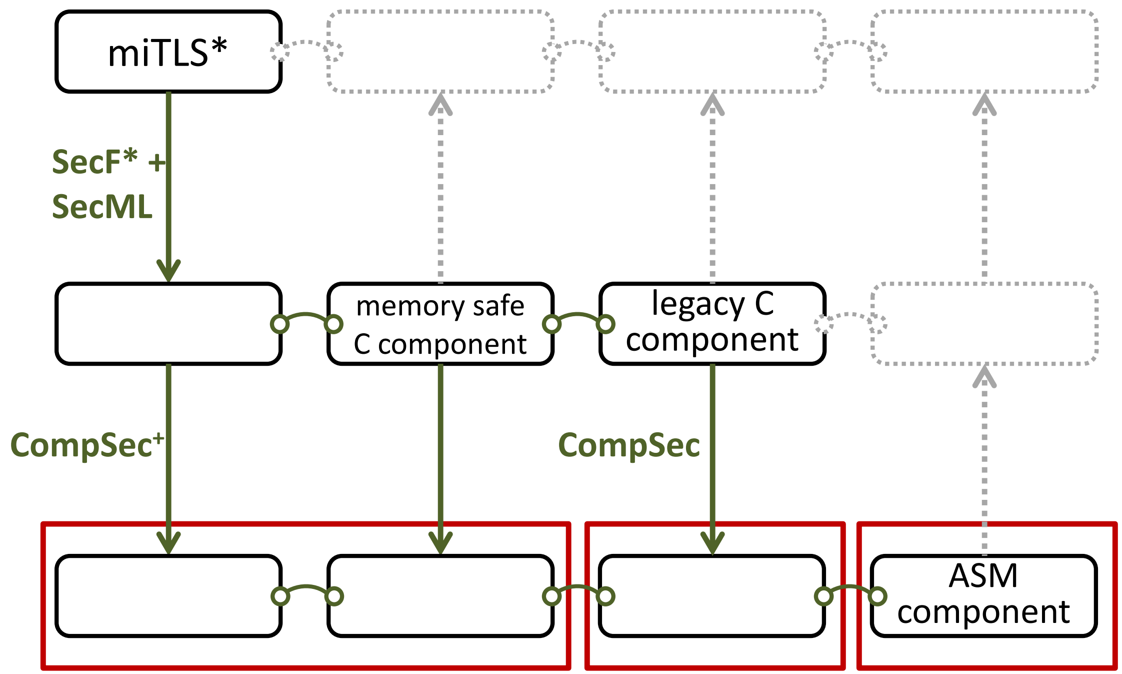

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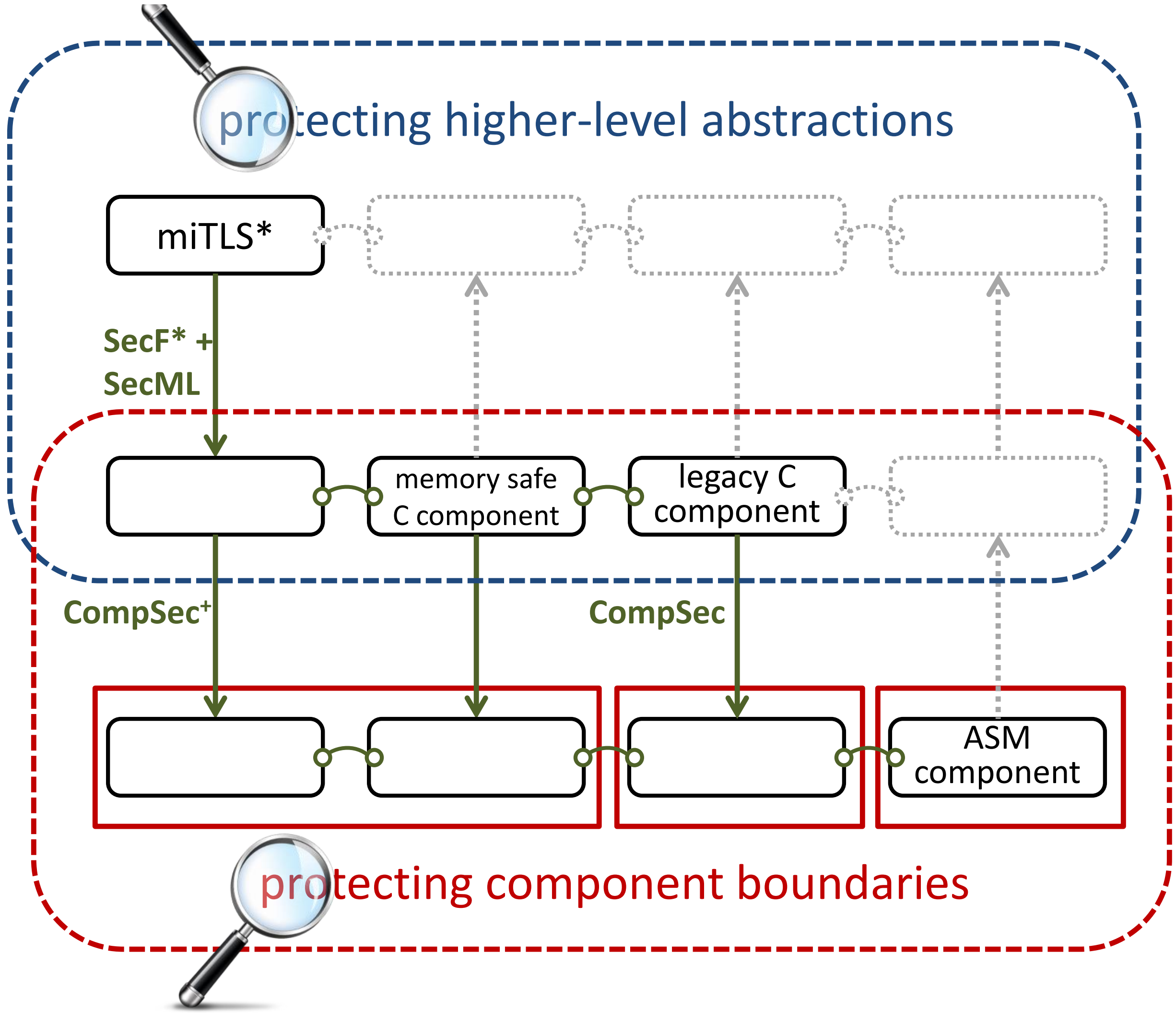

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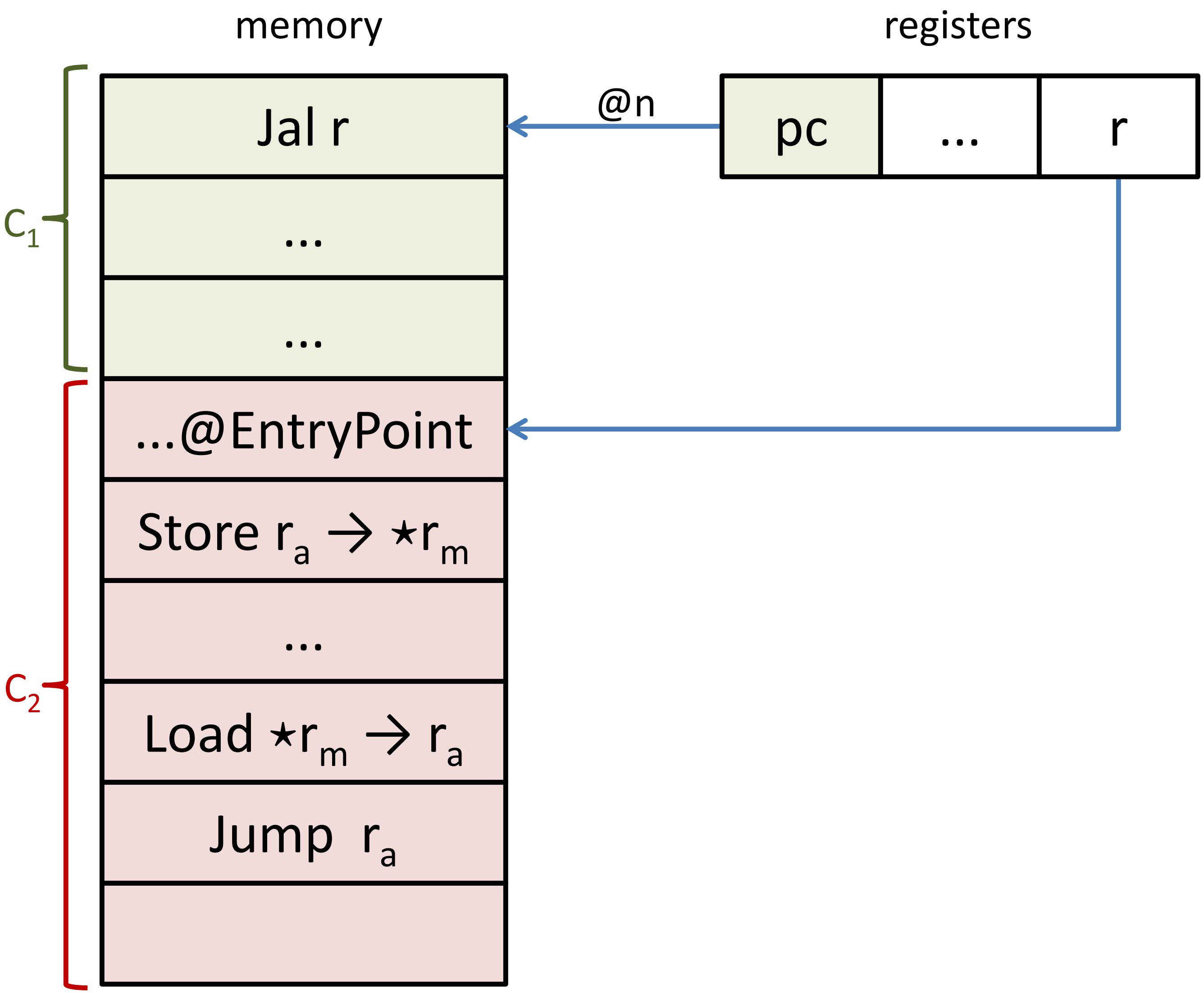
Recent preliminary work, joint with Yannis Juglaret et al

Compartmentalization micro-policy



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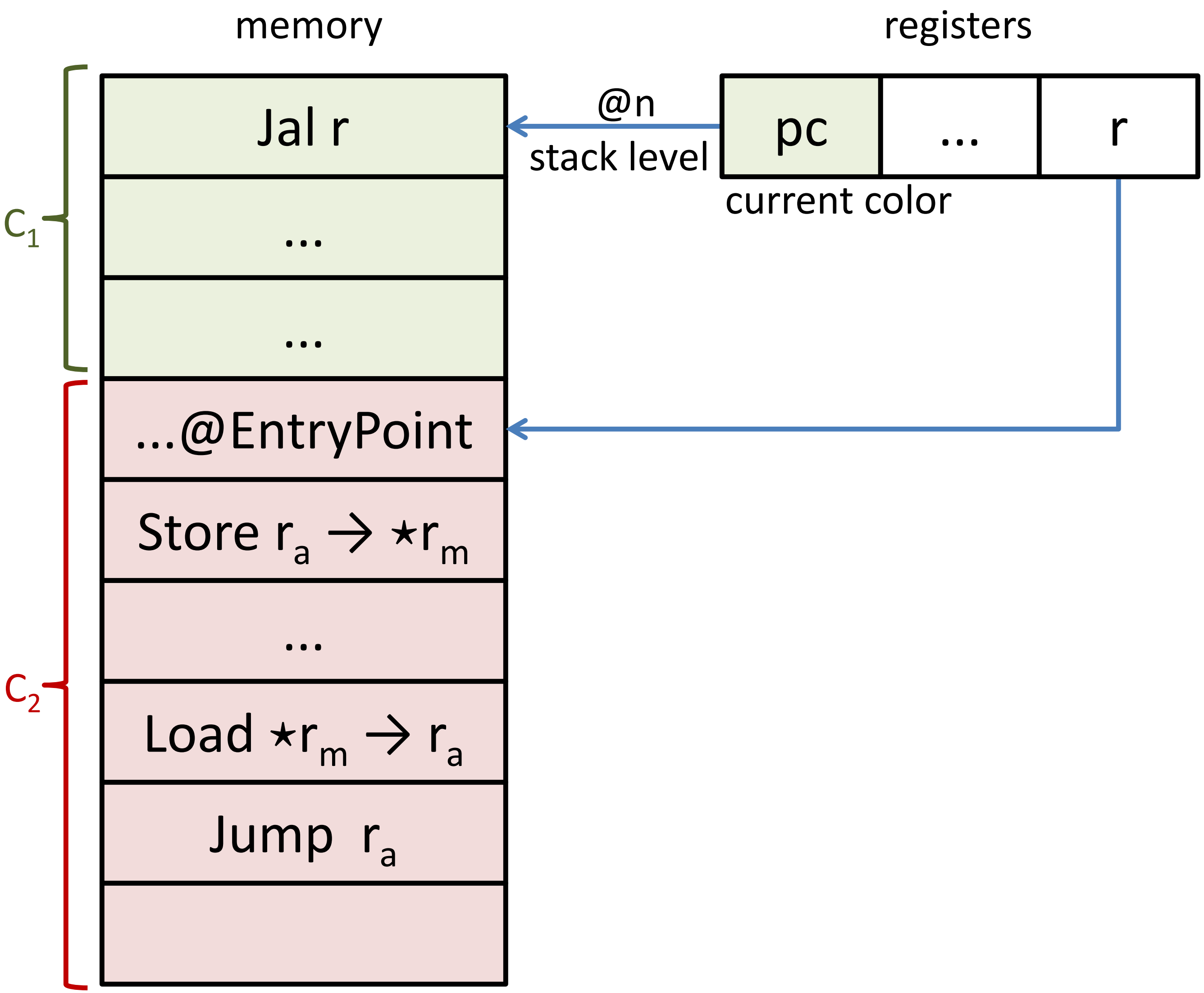

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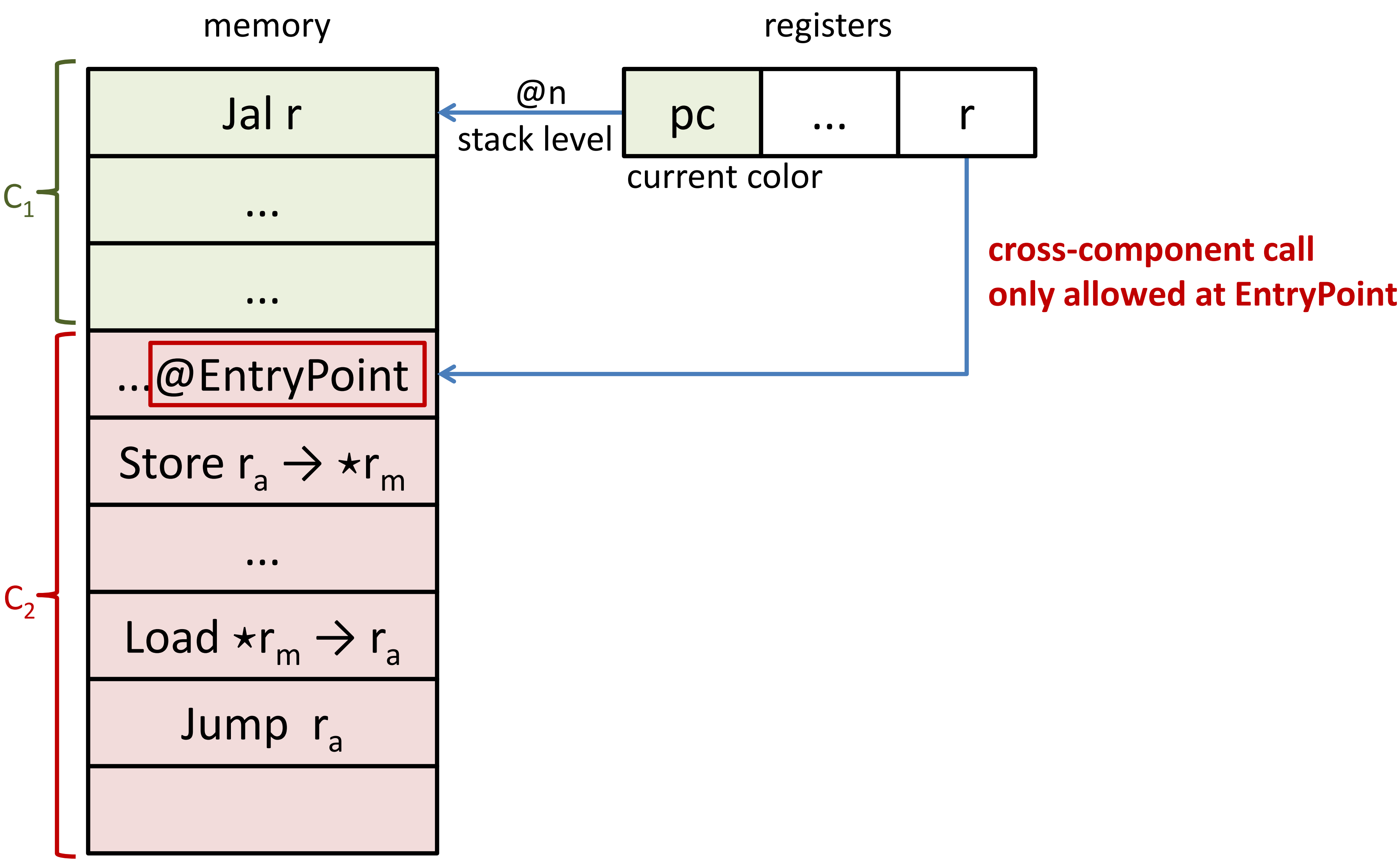

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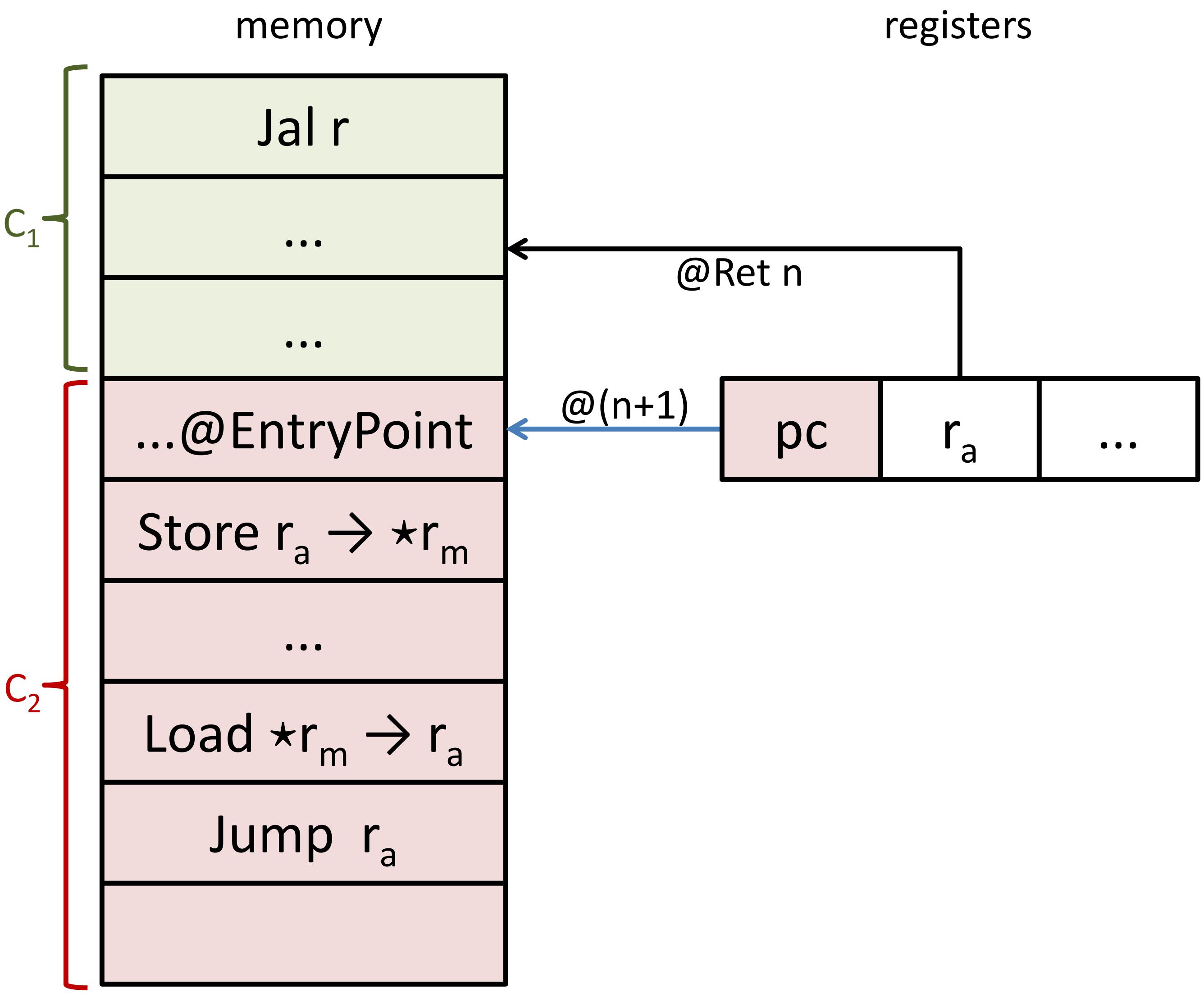

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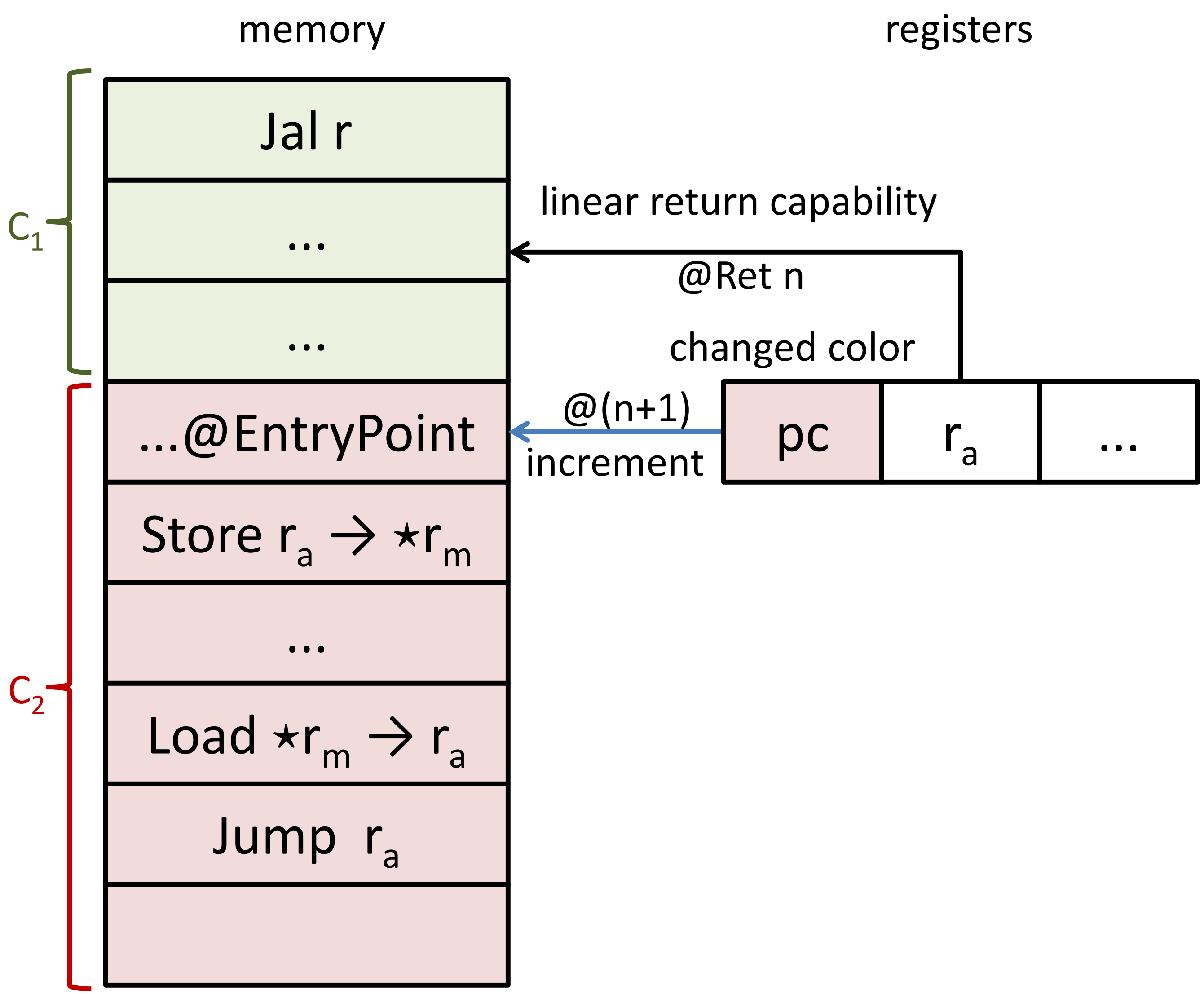

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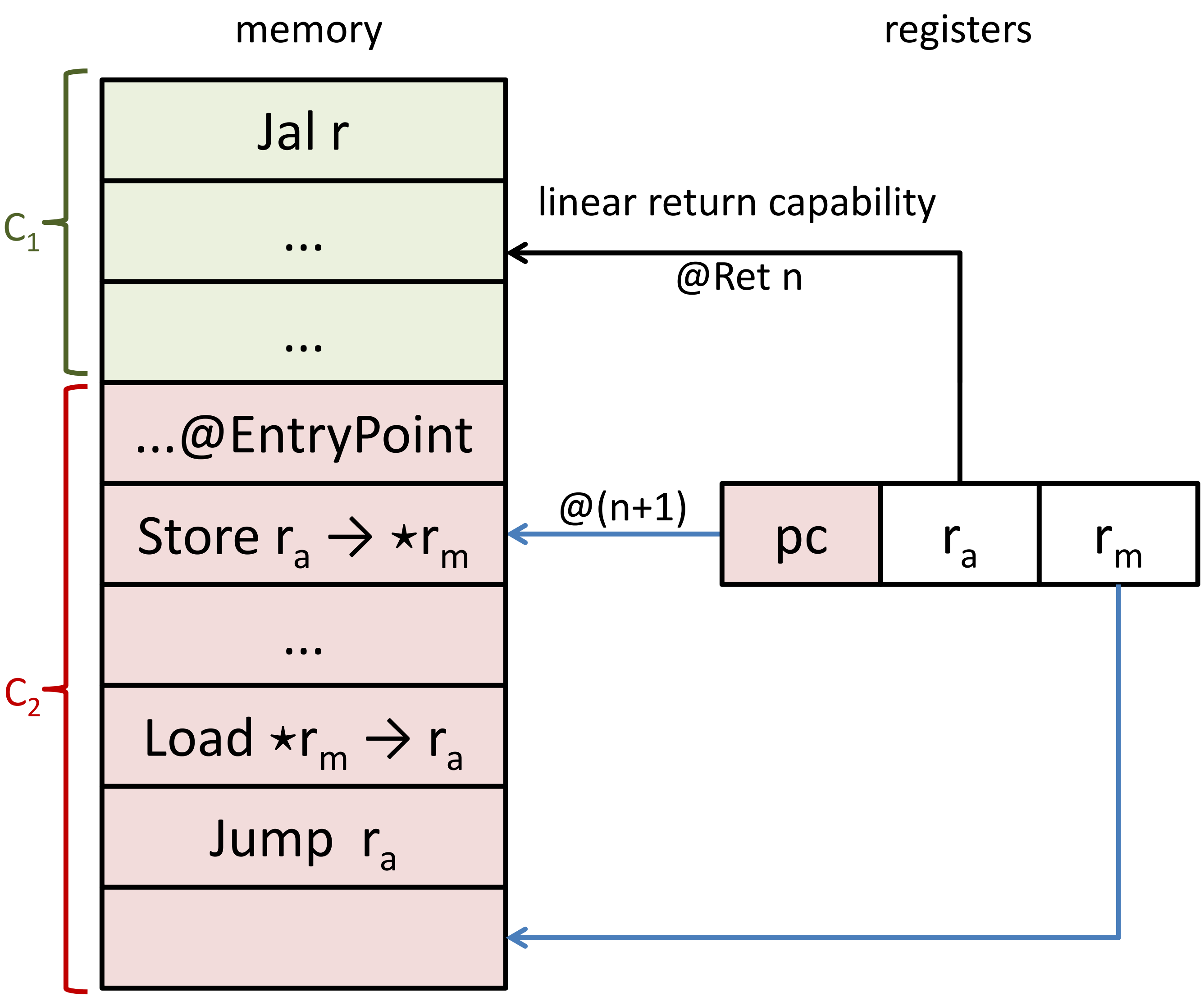

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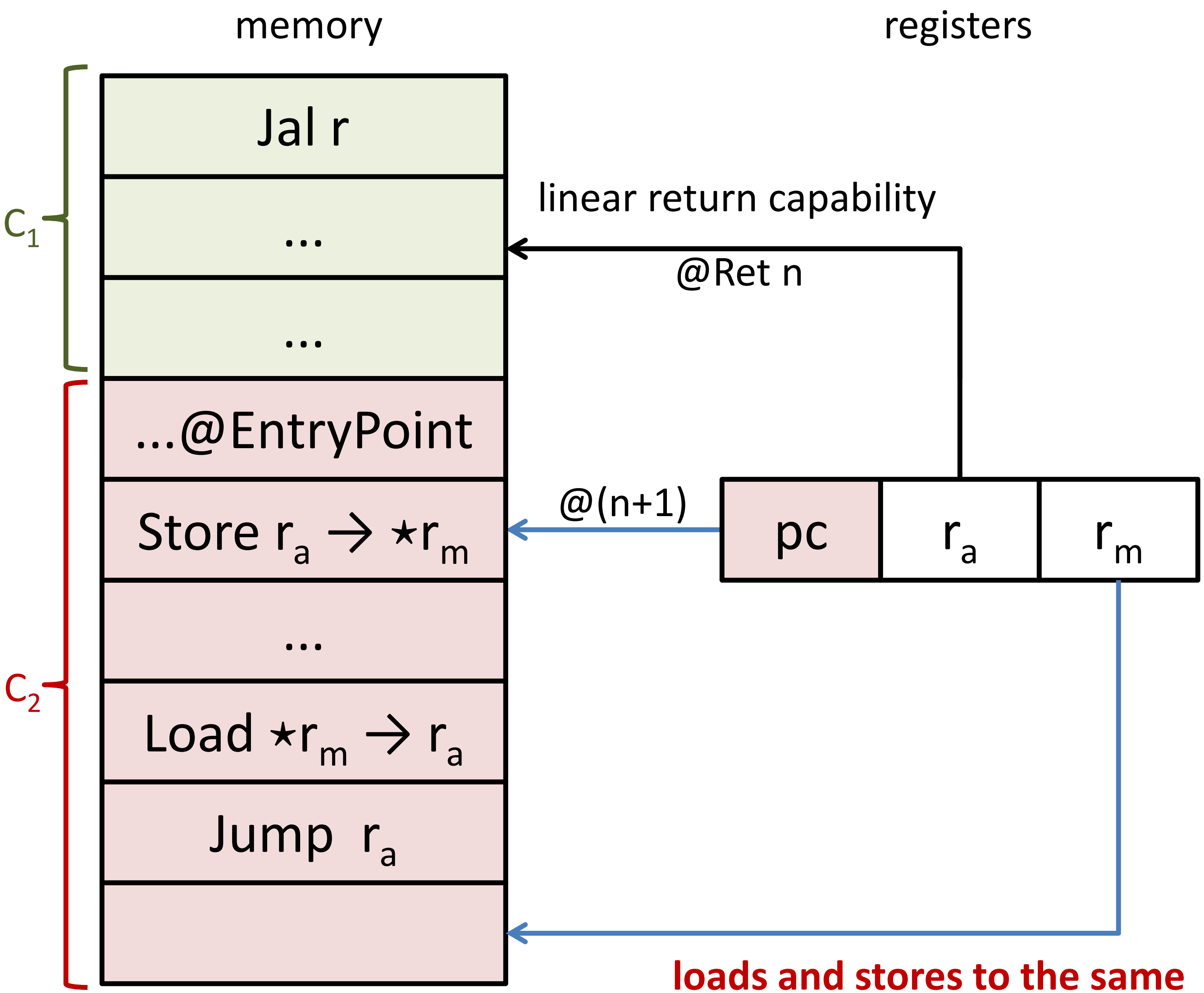

loads and stores to the same component always allowed

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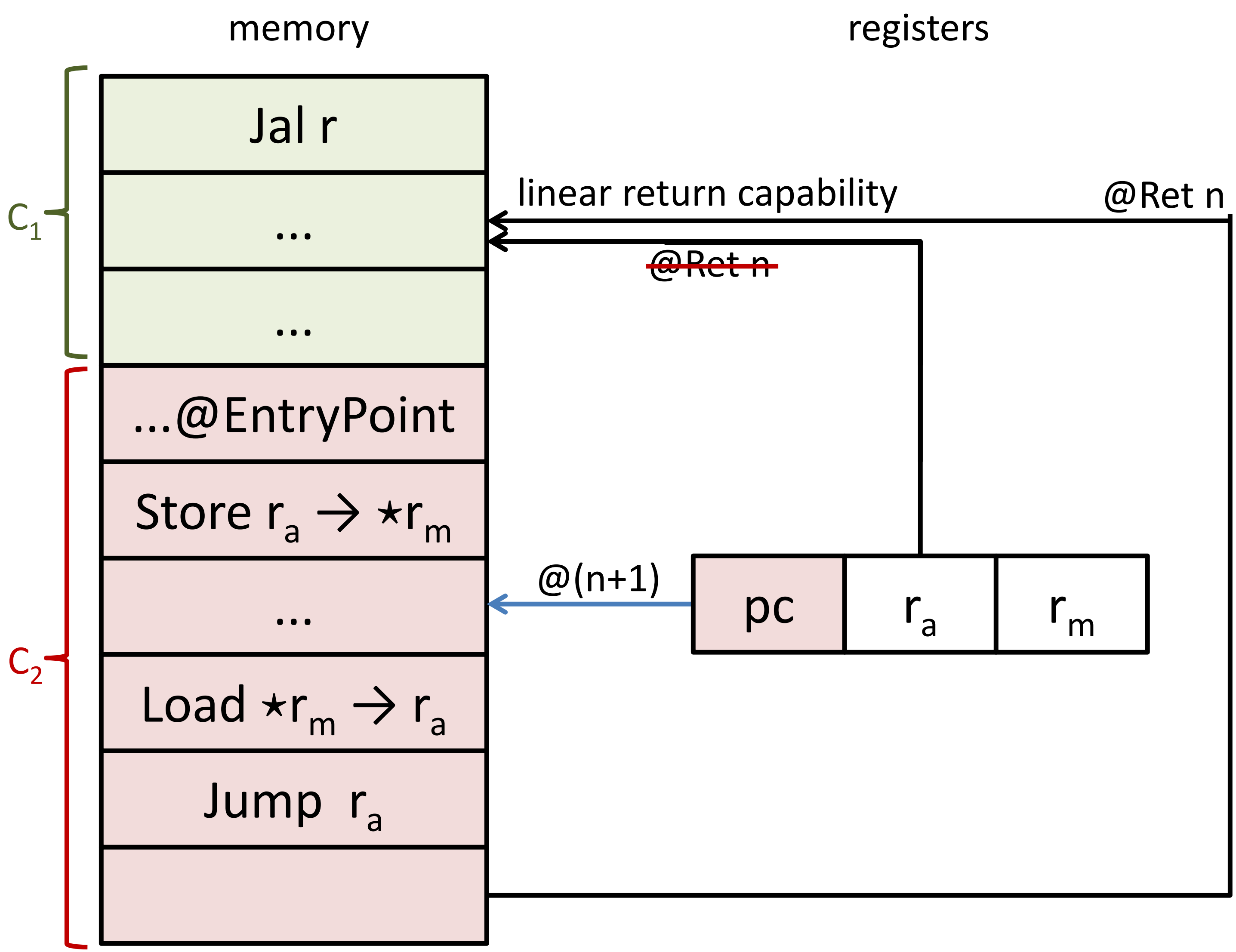

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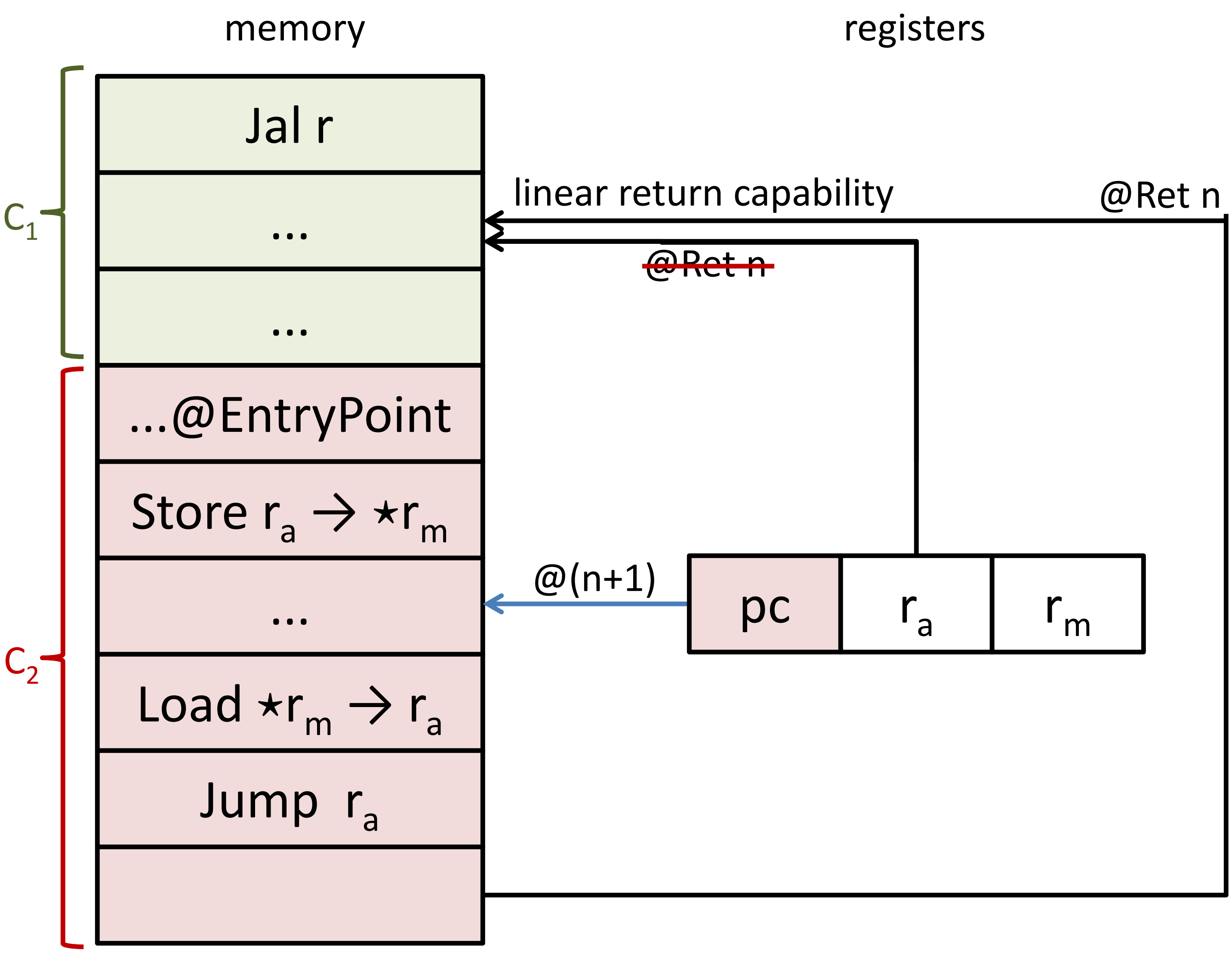

invariant:
at most one
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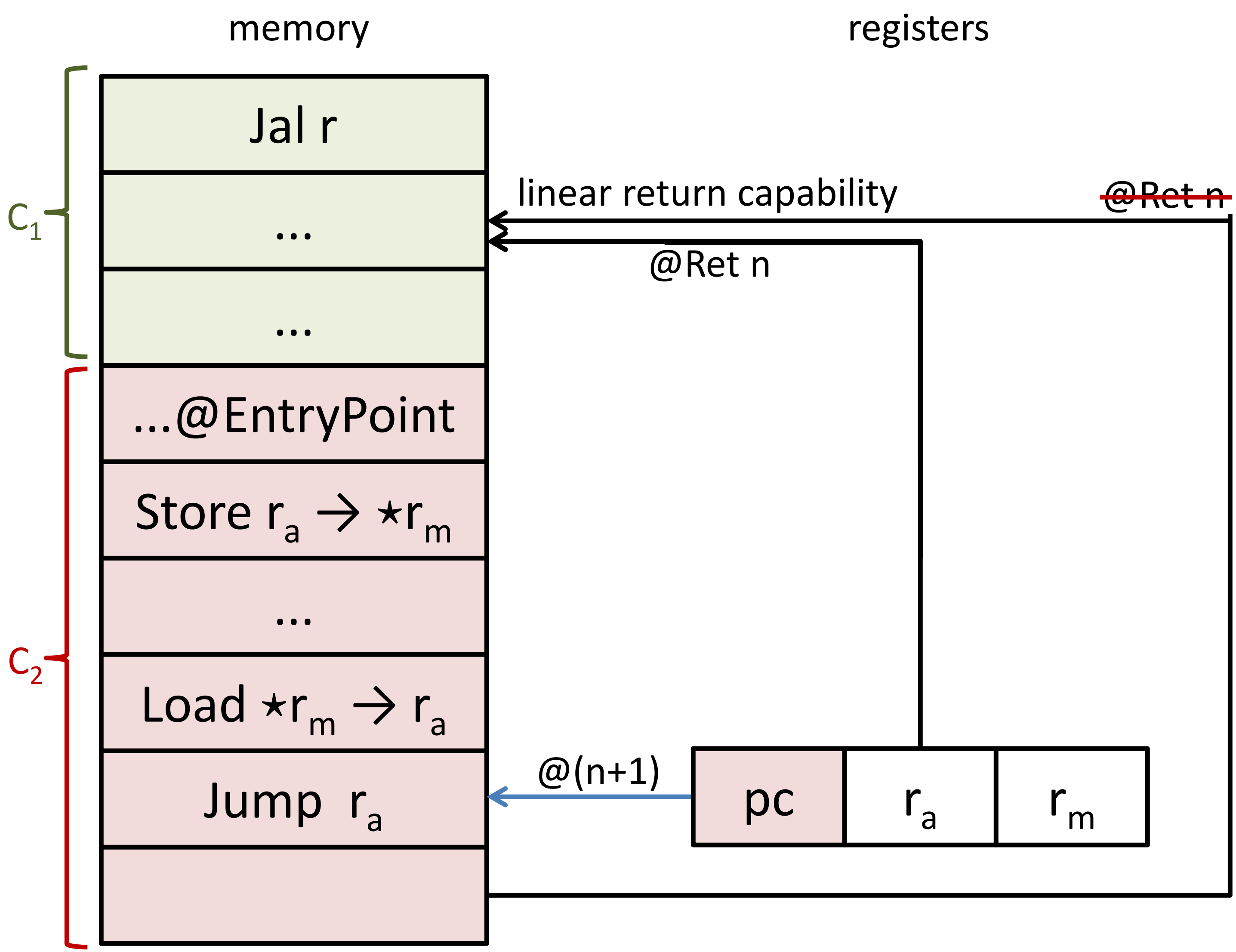

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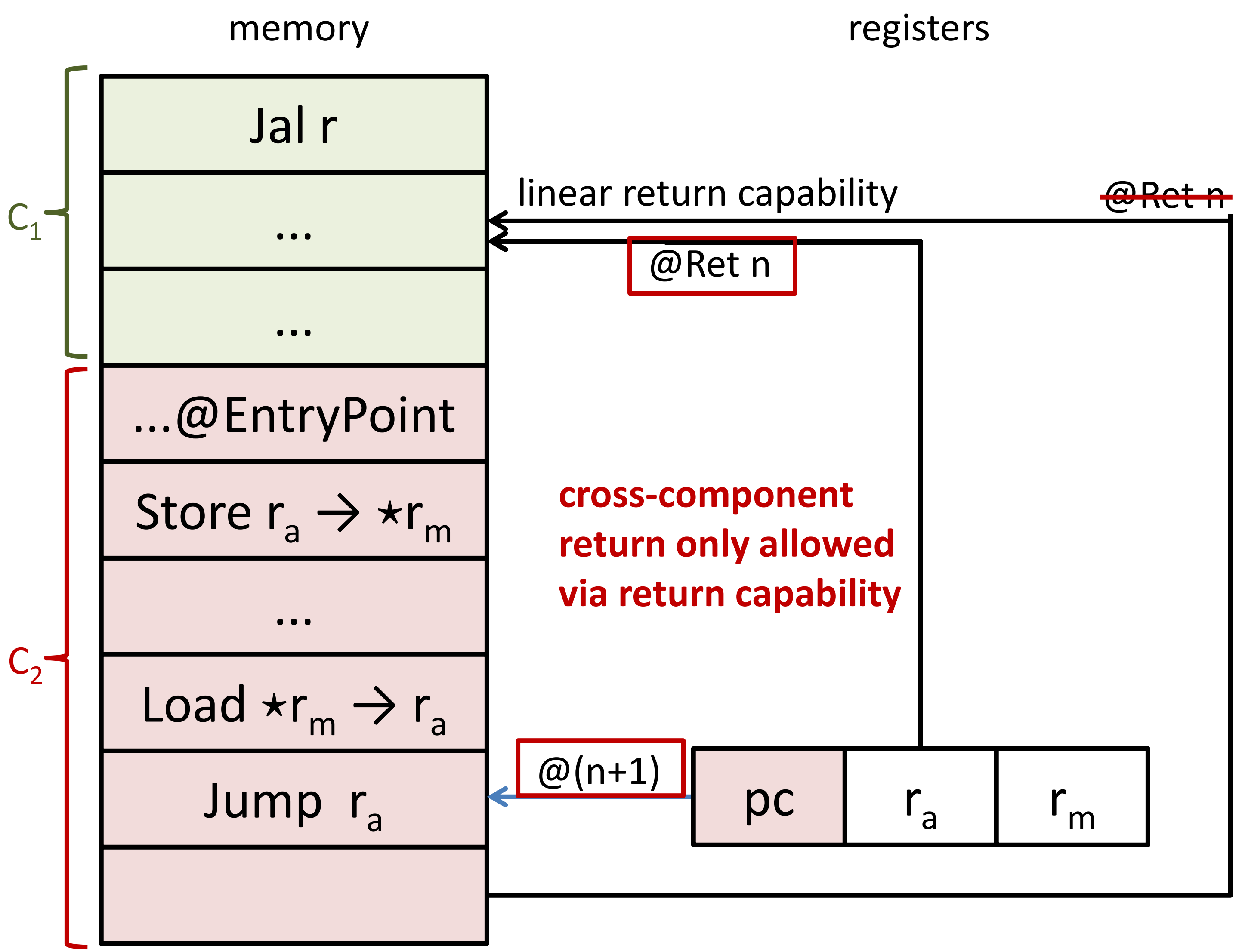

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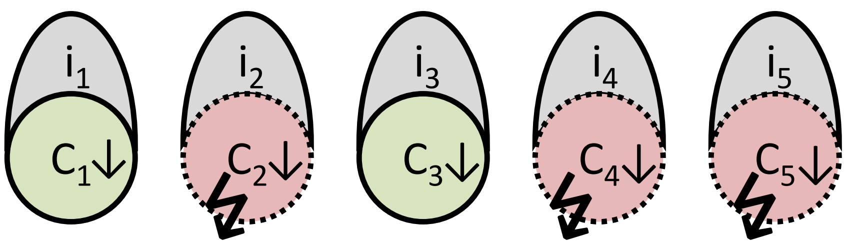
Secure compartmentalizing compilation

∀compromise scenarios.



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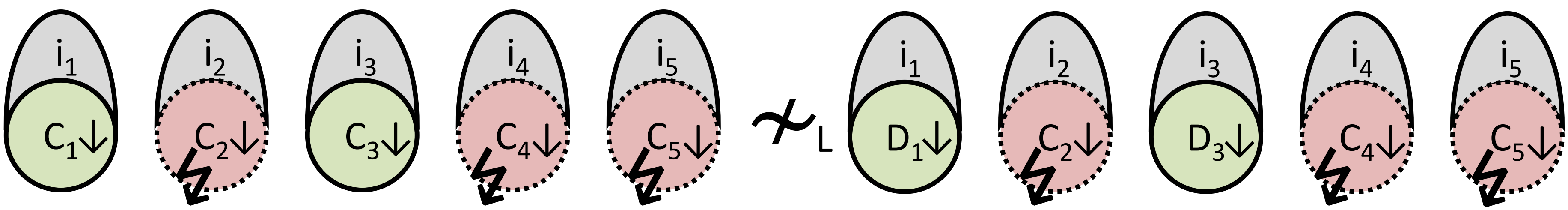

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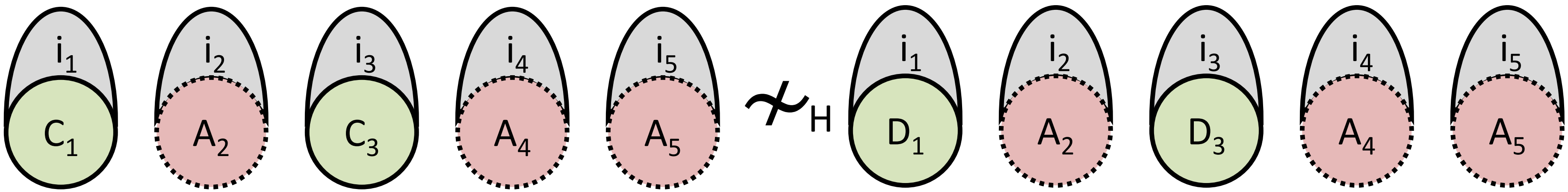
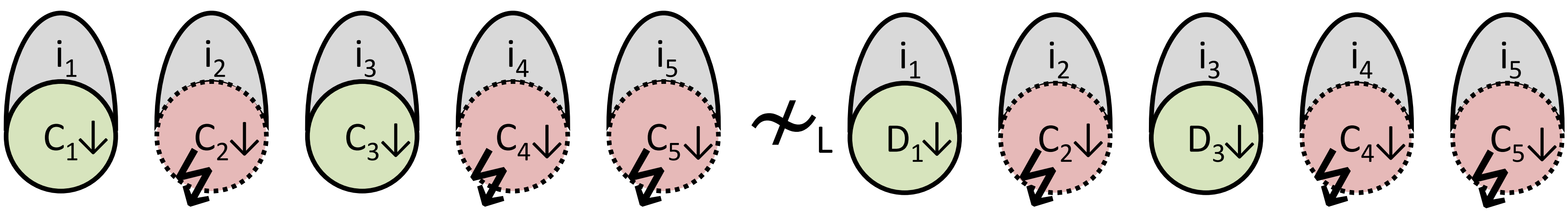


∀ low-level attack from compromised $C_2\downarrow$, $C_4\downarrow$, $C_5\downarrow$
∃ high-level attack from some fully defined A_2, A_4, A_5



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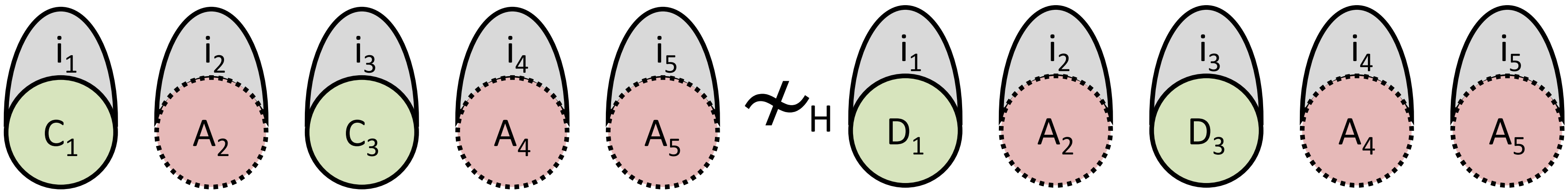

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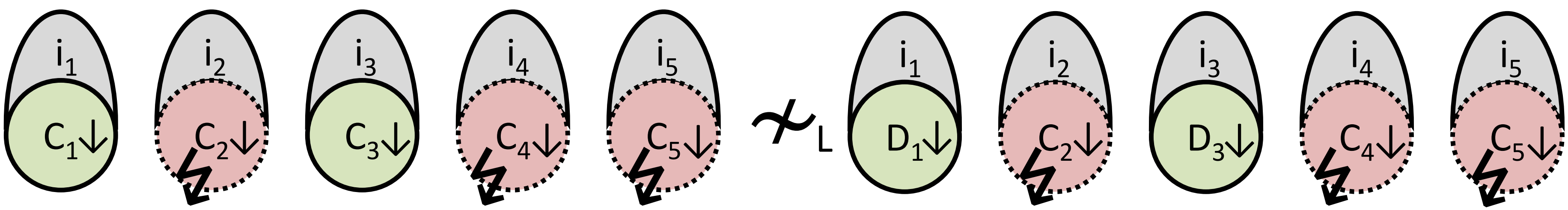

follows from "structured full abstraction for unsafe languages" + "separate compilation"

[Beyond Good and Evil, Juglaret, Hritcu, et al, CSF'16]

Protecting higher-level abstractions

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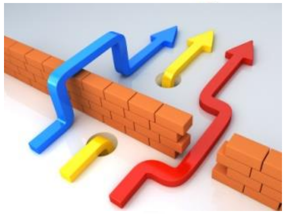

  - functional purity, termination, relational reasoning
  - **push these limits further and combine with static analysis**

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- **Secure micro-policy composition**
  - micro-policies are **interferent** reference monitors
  - one micro-policy's behavior can break another's guarantees
    - e.g. composing anything with IFC can leak

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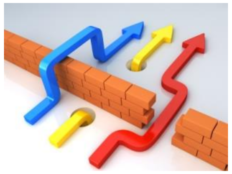

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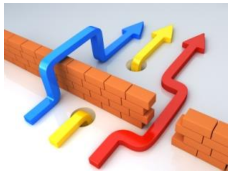

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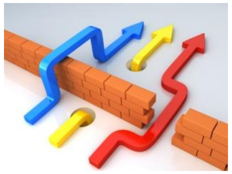

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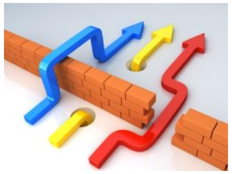
- **We need more secure languages, compilers, hardware**
- **Key enabler: micro-policies** (software-hardware protection)
- **Grand challenge: the first efficient formally secure compilers** for **realistic programming languages** (C, ML, F*)
- **Answering challenging fundamental questions**
  – attacker models, composition, micro-policies for C and ML



- **Achieving strong security properties like full abstraction**
  \+ testing and proving formally that this is the case
- **Measuring & lowering the cost of secure compilation**

- Most of this is **vaporware** at this point but ...
  – trying to build a community and looking for collaborators & students & PostDocs to try to make some of this real