SECOMP

Efficient Formally Secure Compilers to a Tagged Architecture

Cătălin Hrițcu

Prosecco team

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5 year vision

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European Research Council

new grant

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  - designed in an era of scarce hardware resources
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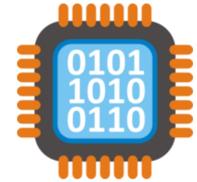
- **programming languages, compilers, and hardware architectures**
  - designed in an era of scarce hardware resources
  - too often trade off security for efficiency
- **the world has changed** (2016 vs 1972*)
  - security matters, hardware resources abundant
  - time to revisit some tradeoffs

* "...the number of UNIX installations has grown to 10, with more expected..."
-- *Dennis Ritchie and Ken Thompson, June 1972*

Hardware architectures



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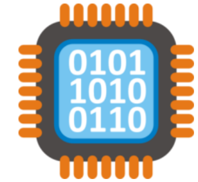

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"Spending silicon to improve security"

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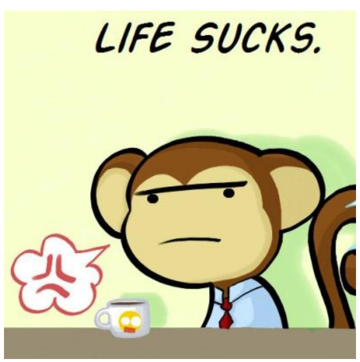

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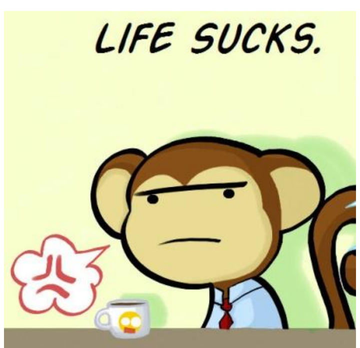

[PATCH] CVE-2015-7547 --- glibc getaddrinfo() stack-based buffer overflow

- *From*: "Carlos O'Donell" <carlos at redhat dot com>
- *To*: GNU C Library <libc-alpha at sourceware dot org>
- *Date*: Tue, 16 Feb 2016 09:09:52 -0500
- *Subject*: [PATCH] CVE-2015-7547 --- glibc getaddrinfo() stack-based buffer overflow
- *Authentication-results*: sourceware.org; auth=none
- *References*: <56C32C20 dot 1070006 at redhat dot com>

The glibc project thanks the Google Security Team and Red Hat for reporting the security impact of this issue, and Robert Holiday of Ciena for reporting the related bug 18665.

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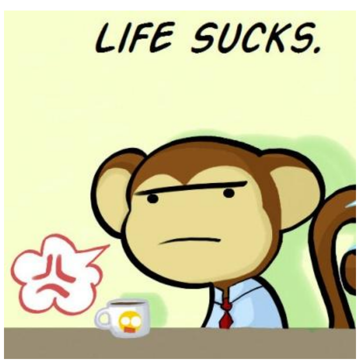

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DNS queries

...ell" <carlos at redhat dot com>

vulnerable since May 2008

- *Date*: Tue, 16 Feb 2016
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- **memory safe** (at a cost)
- **useful abstractions** for writing secure code:
  - GC, type abstraction, modules, immutability, ...
- **not immune to low-level attacks**
  - large runtime systems, in C++ for efficiency
  - **unsafe interoperability with low-level code**
    - libraries often have large parts written in C/C++
    - **enforcing abstractions all the way down too expensive**

Summary of the problem

- **1. inherently insecure low-level languages**
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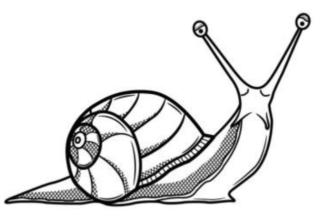
  - even code written in **safer high-level languages** has to interoperate with **insecure low-level libraries**
  - **unsafe interoperability:** all high-level safety guarantees lost
- **Today's languages & compilers plagued by low-level attacks**
  - **main culprit: hardware provides no appropriate security mechanisms**
  - fixing this purely in software would be way **too inefficient**



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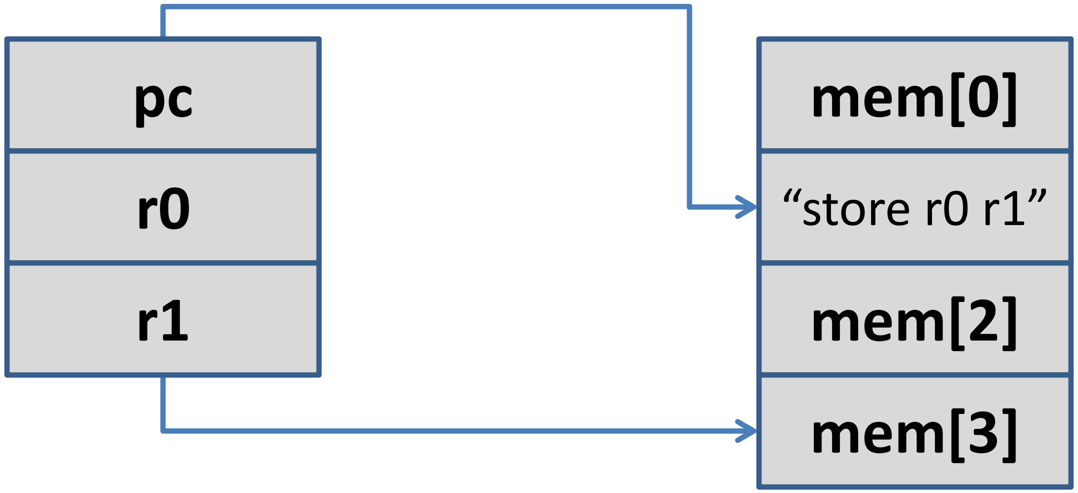

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software-defined, hardware-accelerated, tag-based monitoring

pc	tpc
r0	tr0
r1	tr1

mem[0]	tm0
“store r0 r1”	tm1
mem[2]	tm2
mem[3]	tm3

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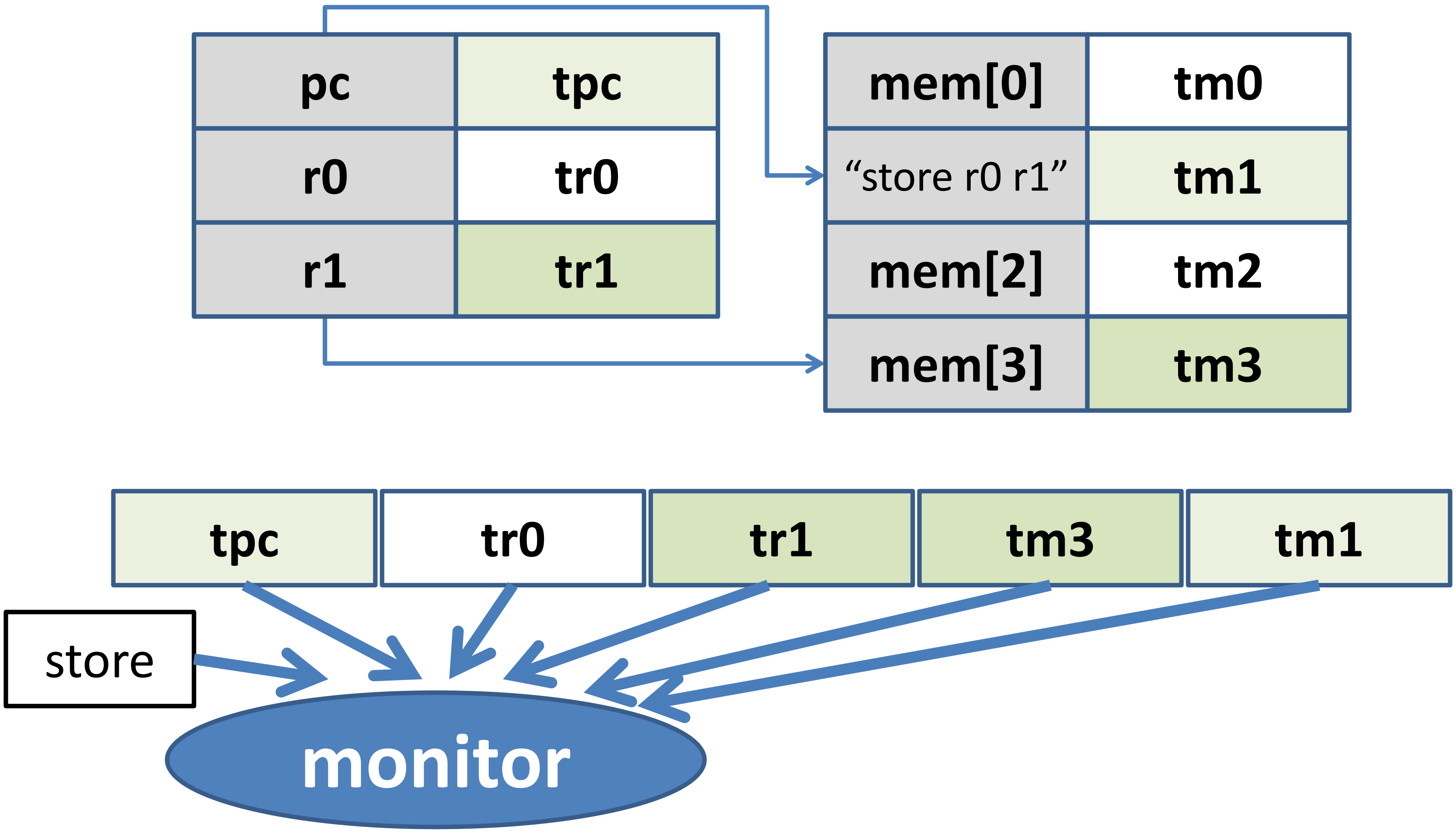

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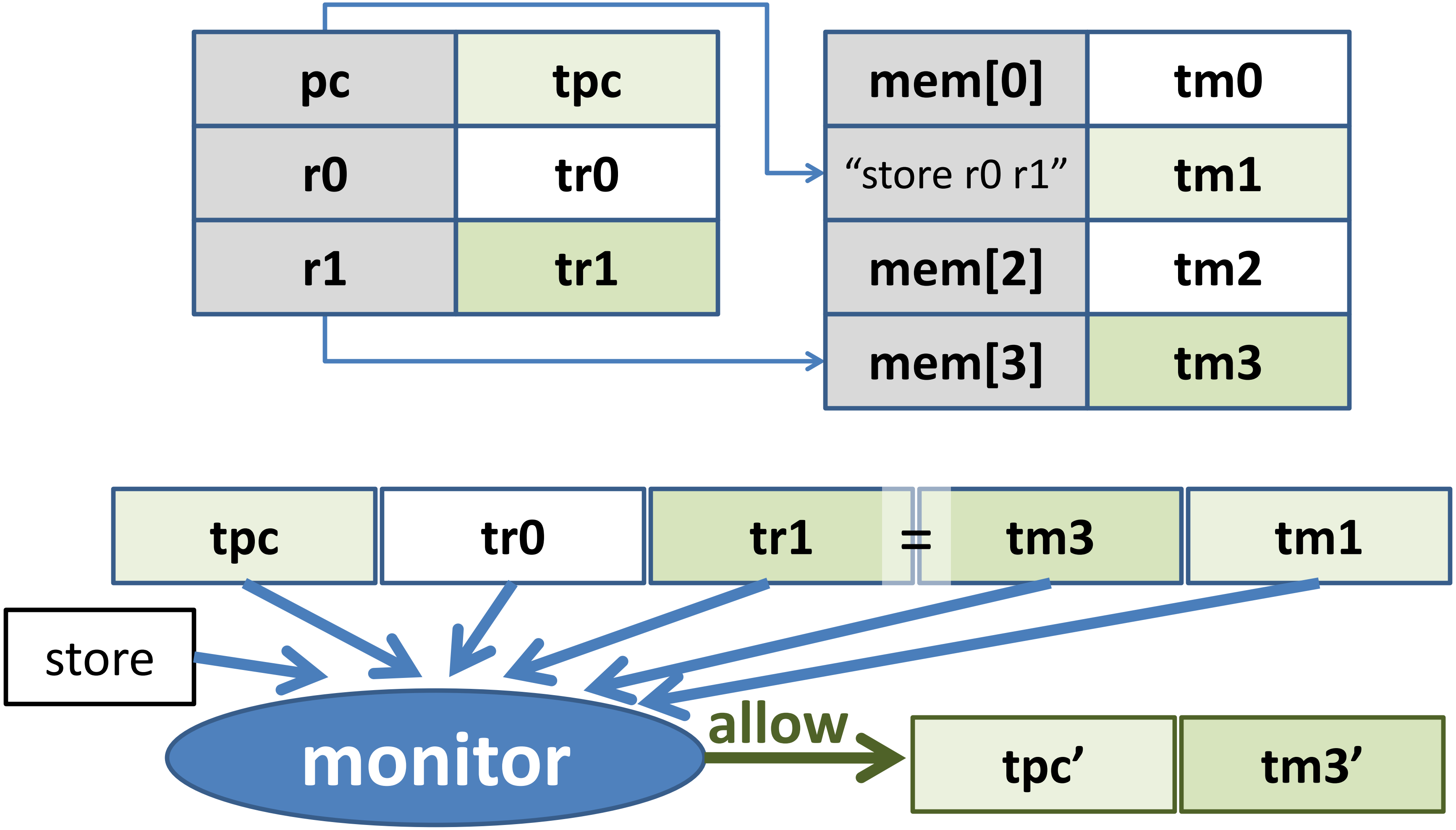

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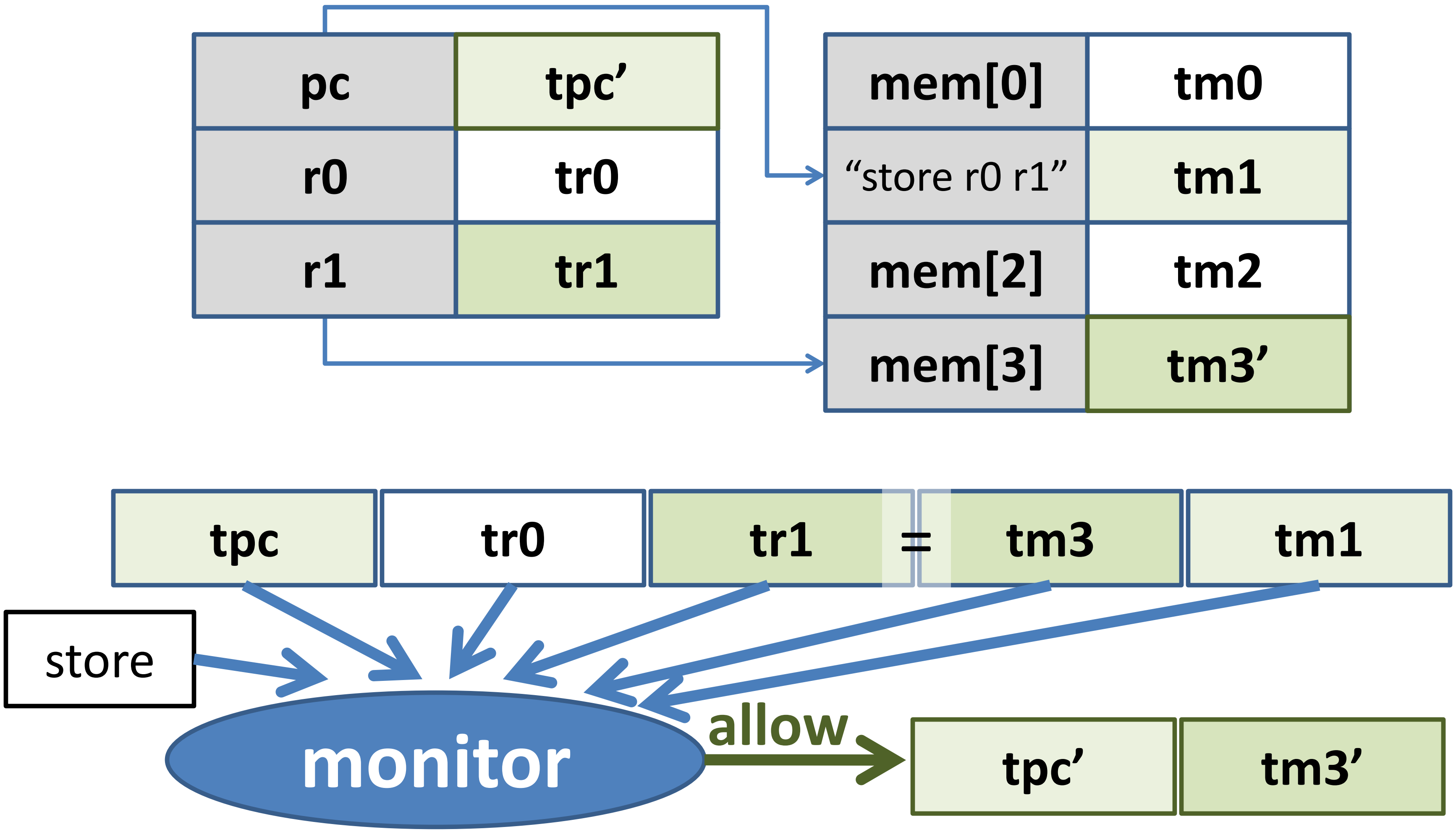

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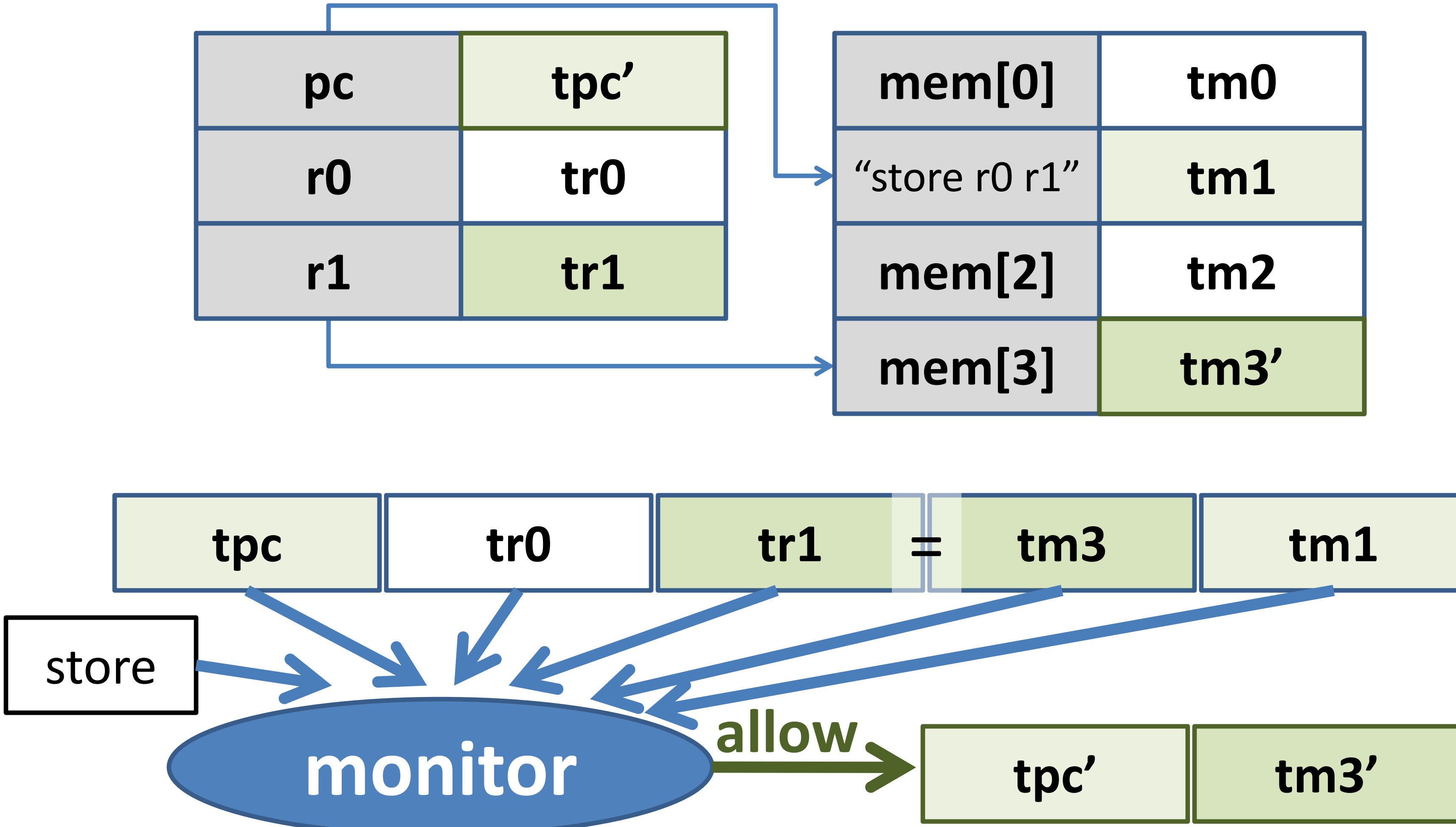

software monitor's decision is hardware cached

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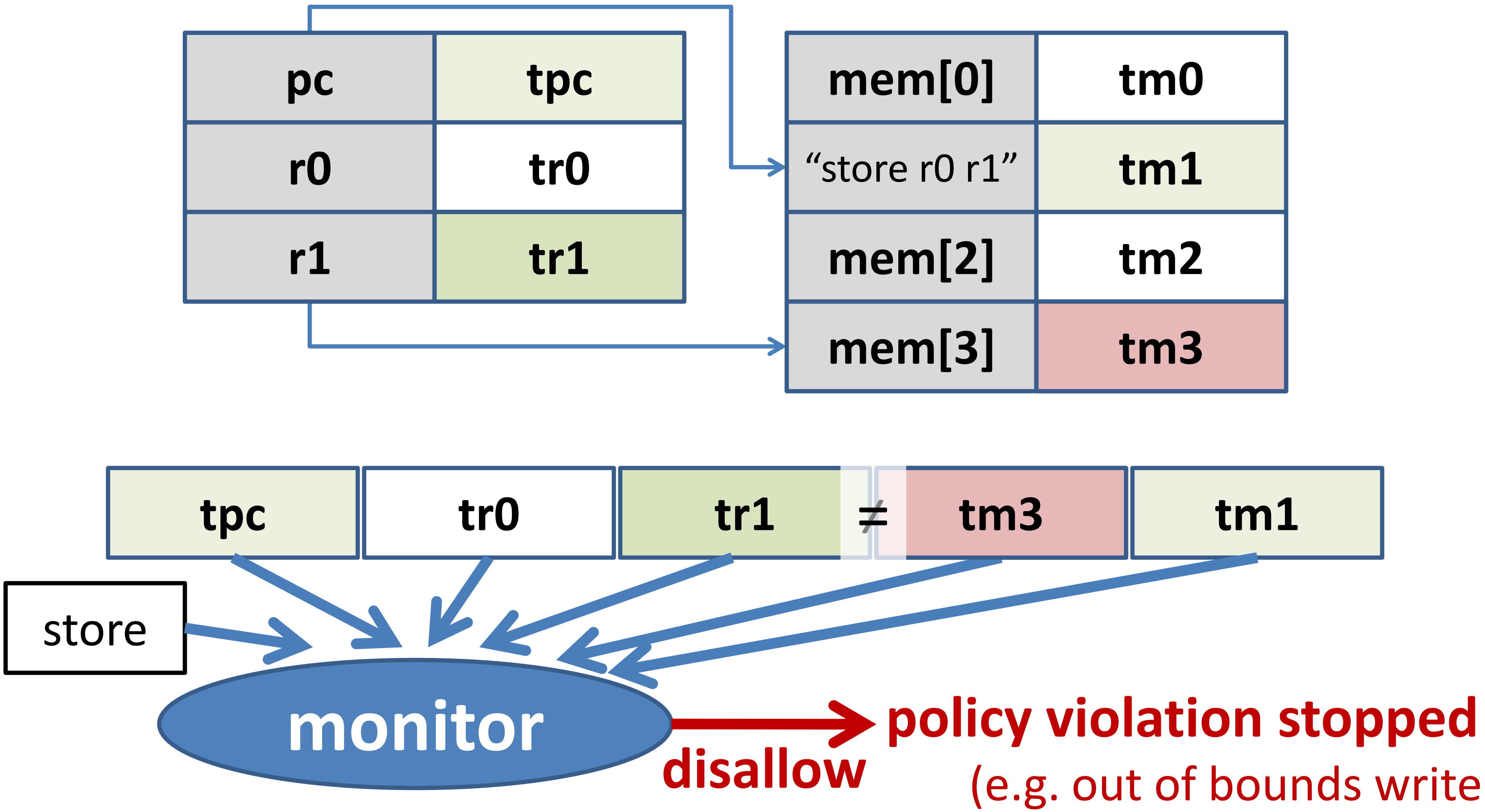

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- **flexible**: tags and monitor defined by software
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- **expressive**: complex policies for secure compilation
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DRAPER bluespec

Expressiveness

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Evaluated
(<10% runtime overhead)
[ASPLOS'15]

SECOMP grand challenge

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

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1. **Provide secure semantics for low-level languages**
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Use micro-policies to build **the first efficient formally secure compilers** for **realistic programming languages**

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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holy grail of secure compilation, enforcing abstractions all the way down

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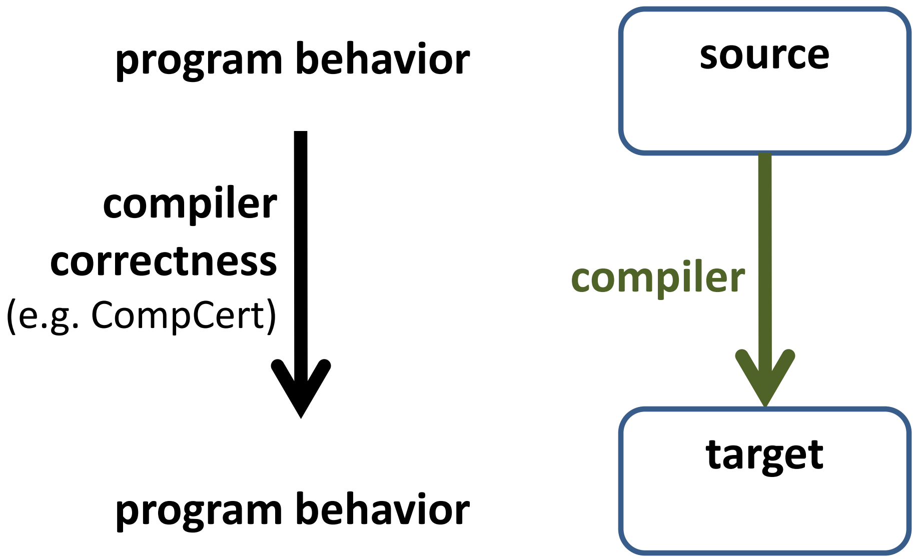

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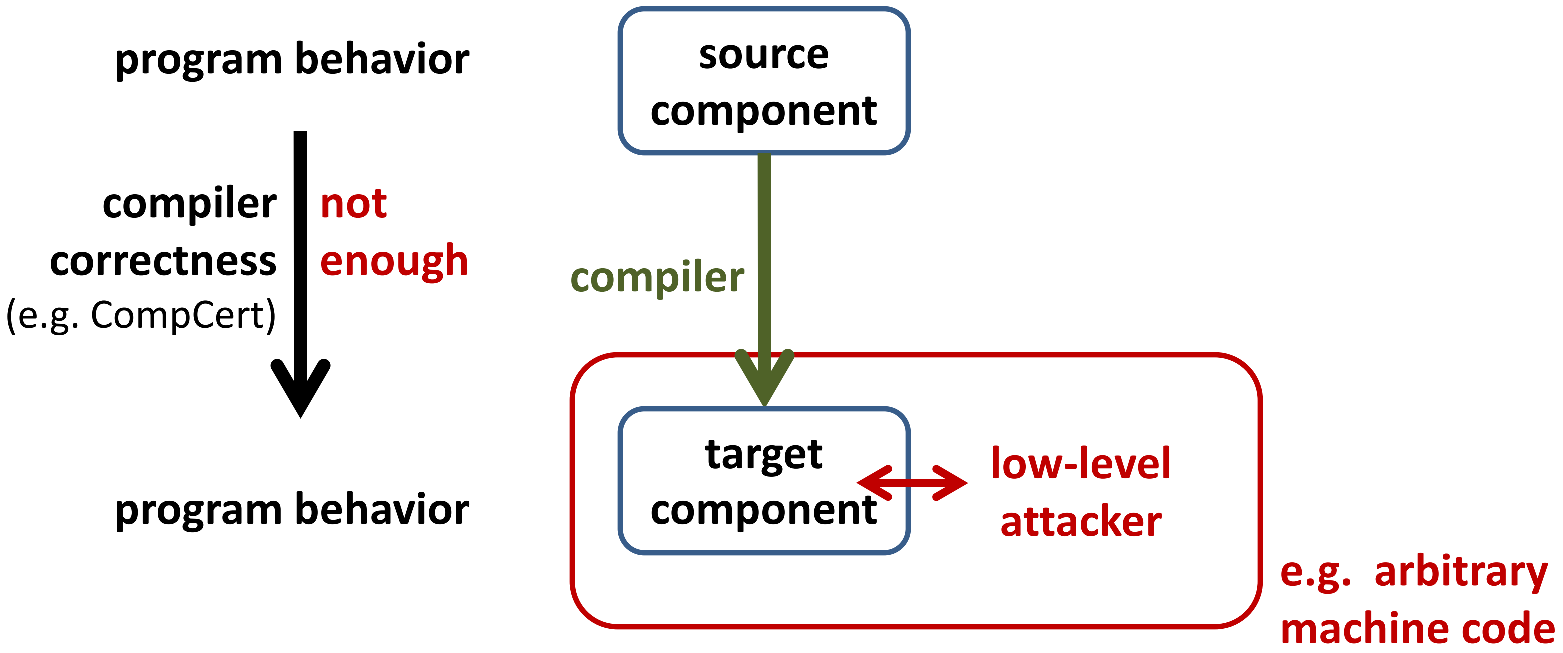

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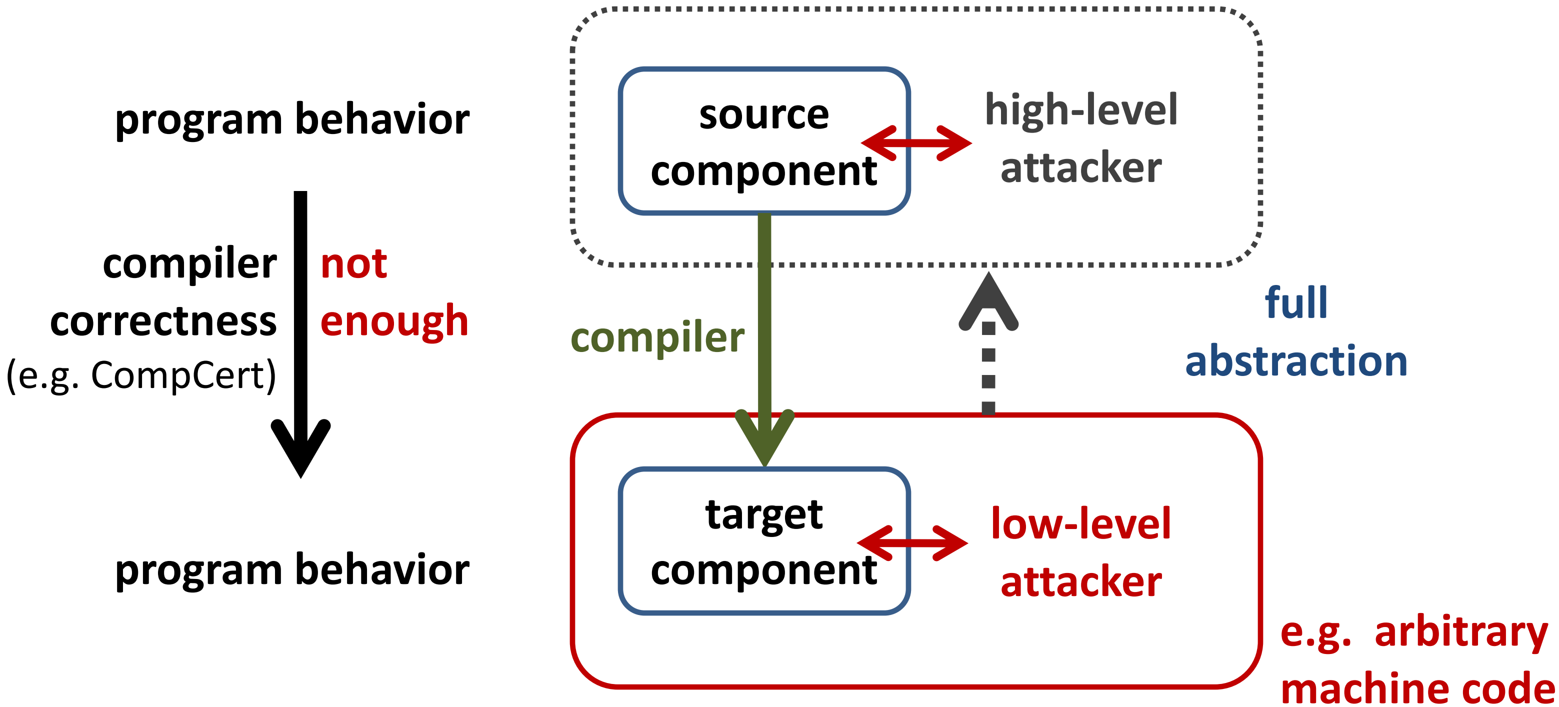

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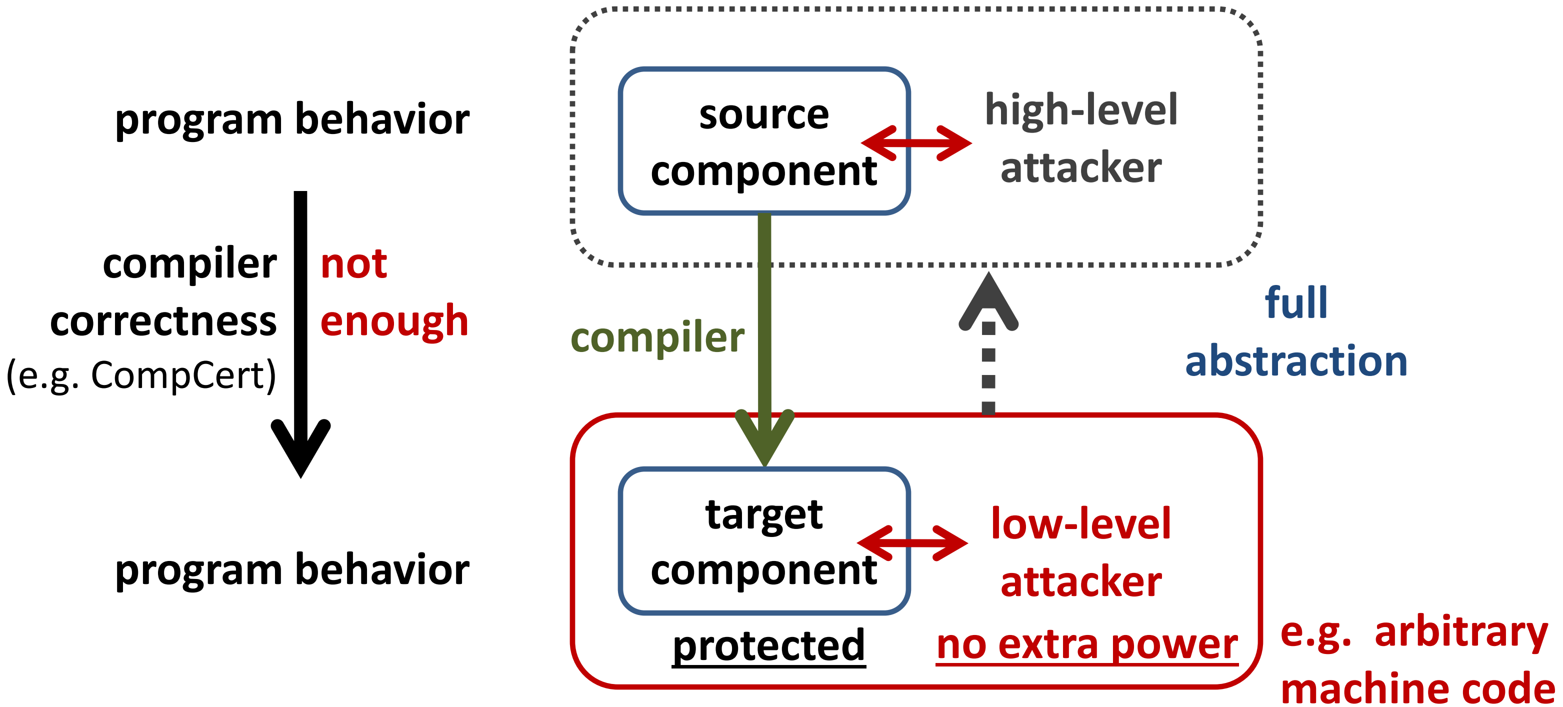

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source component ⟷ high-level attacker

program behavior

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

program behavior

secure

full abstraction ↓ *folklore

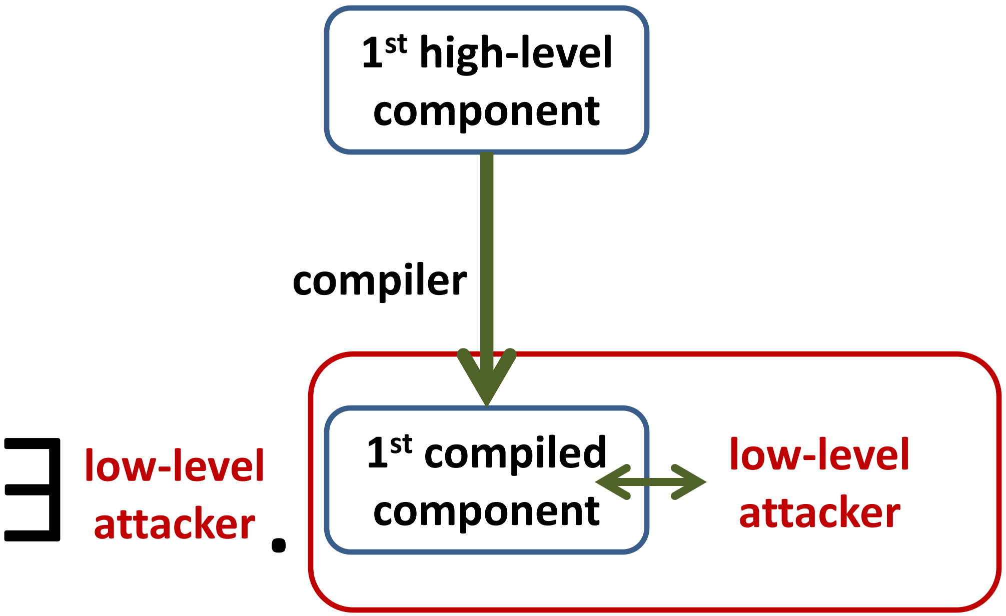
secure

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

Fully abstract compilation, definition



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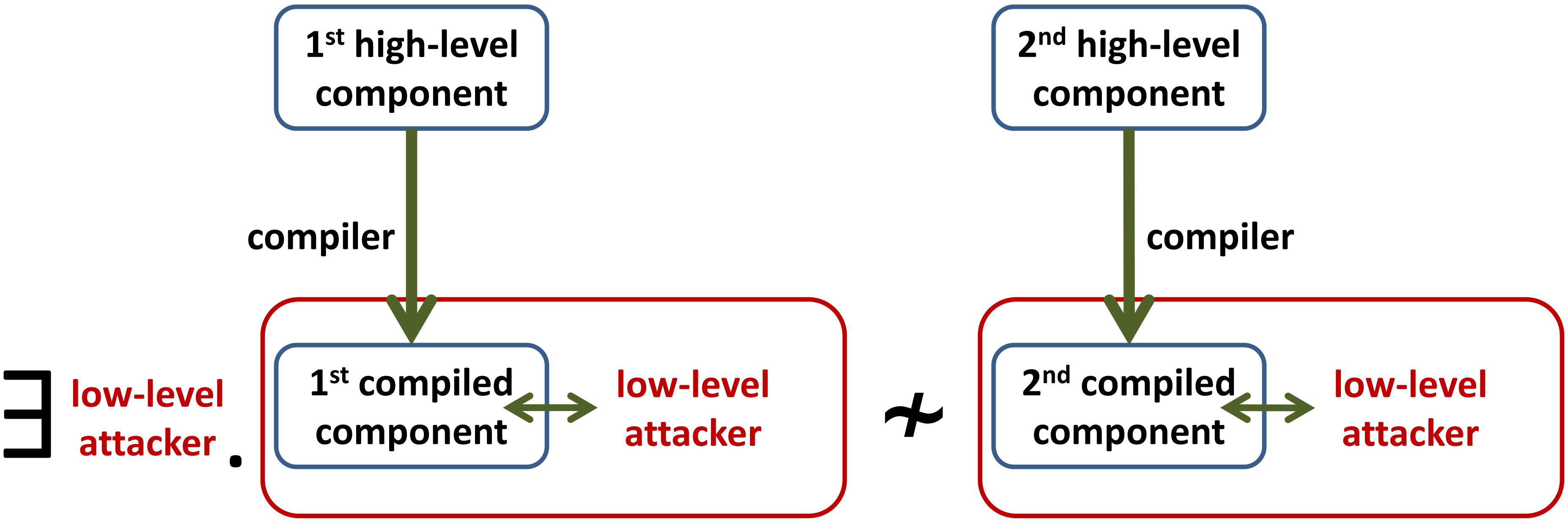

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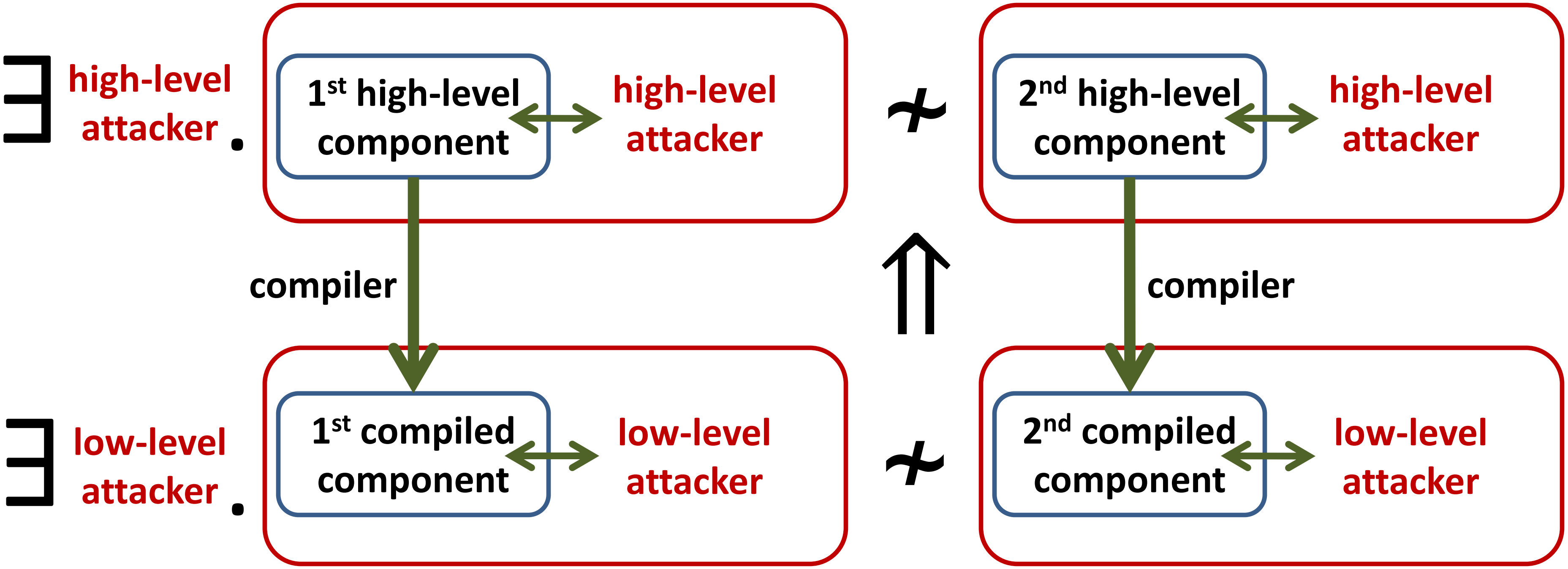

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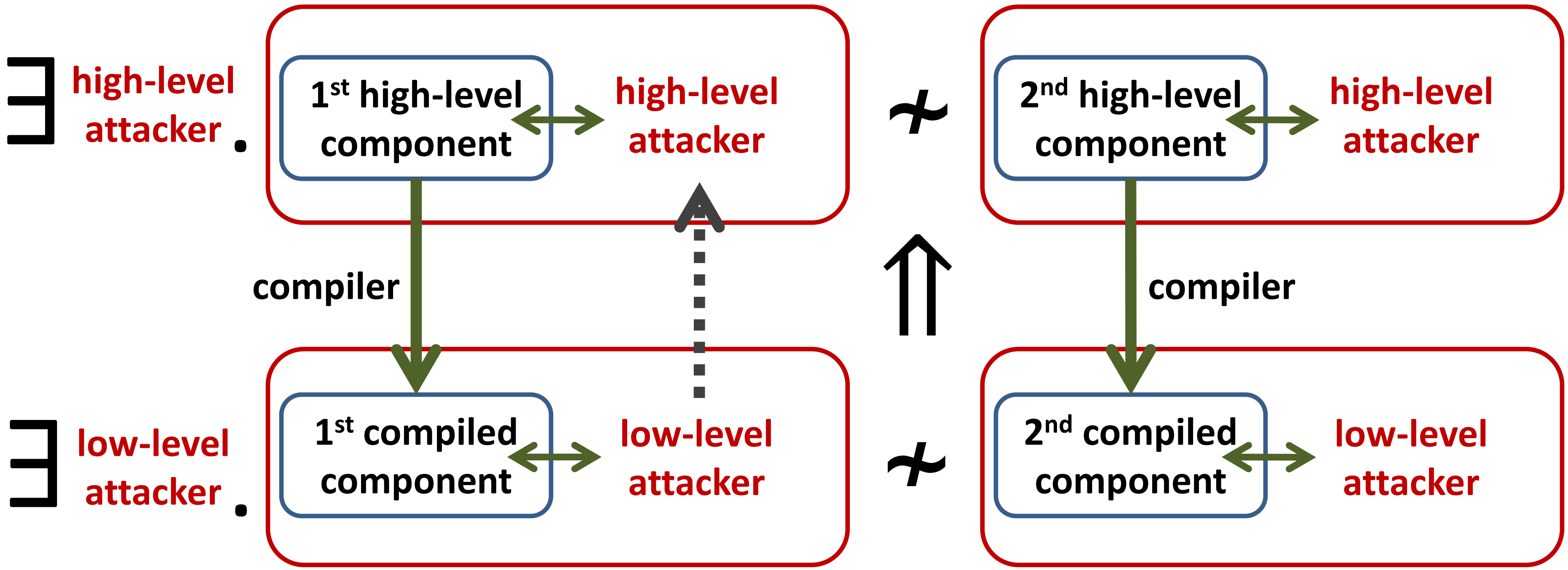

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(ML + verification)

miTLS*

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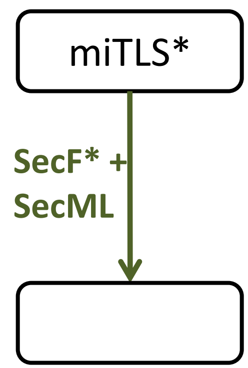

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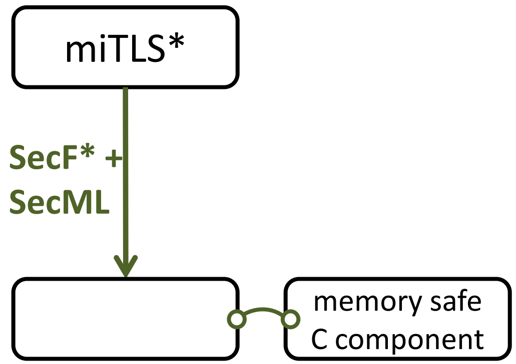

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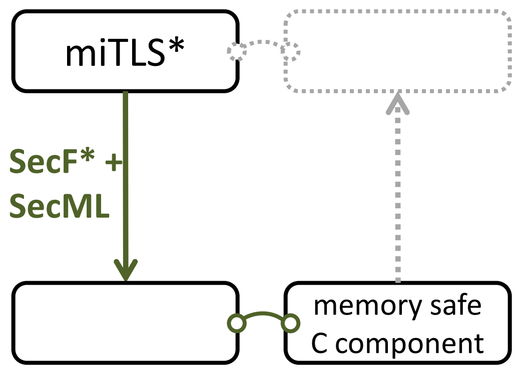

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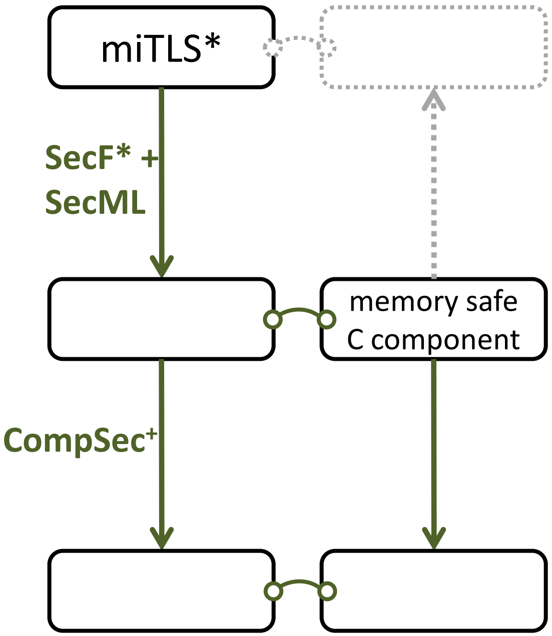

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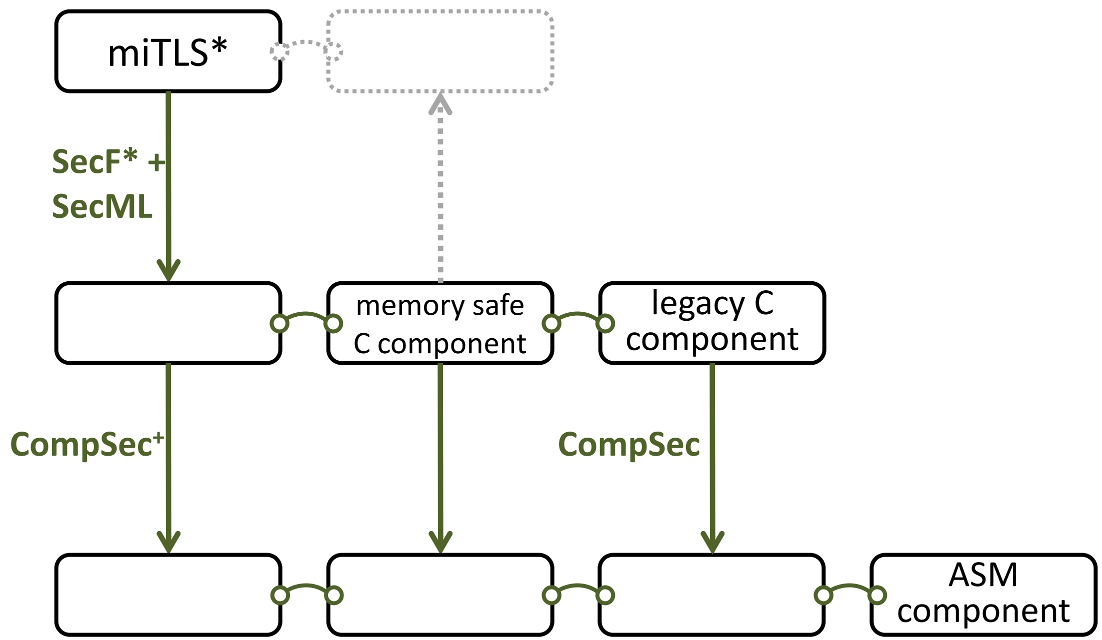

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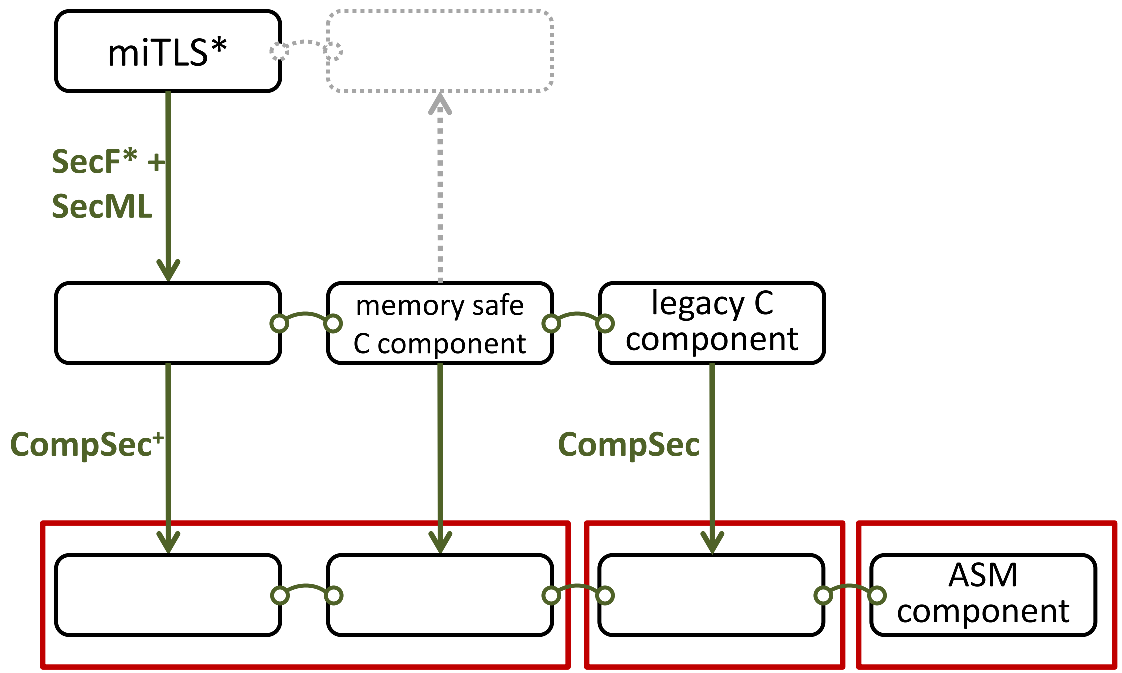

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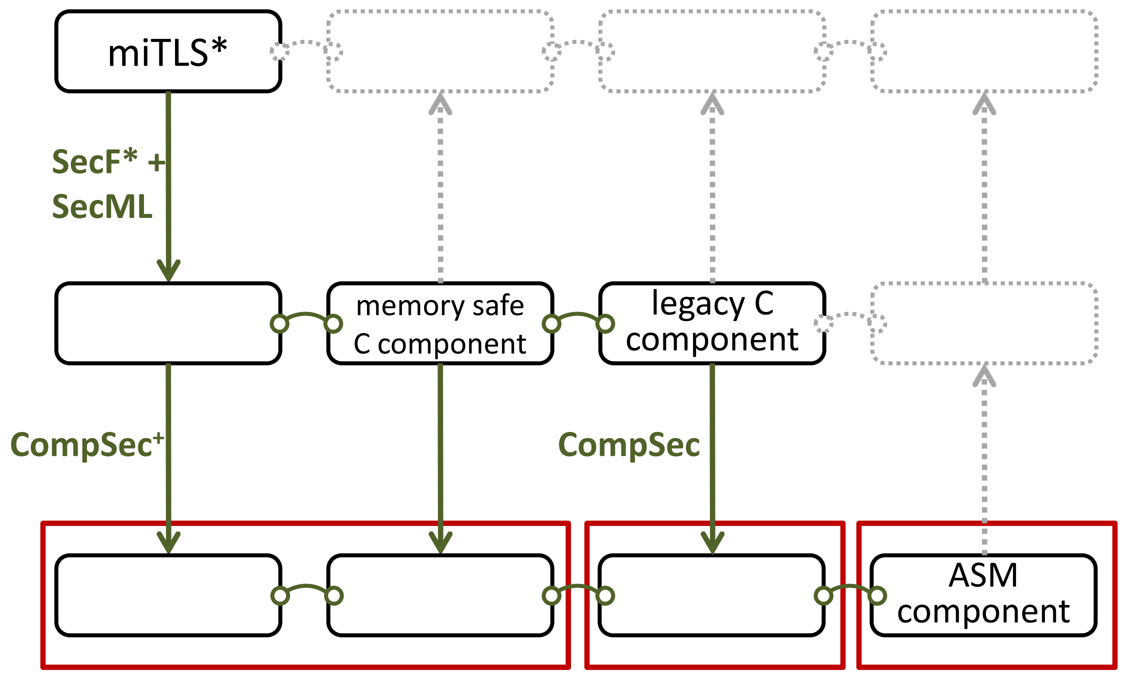

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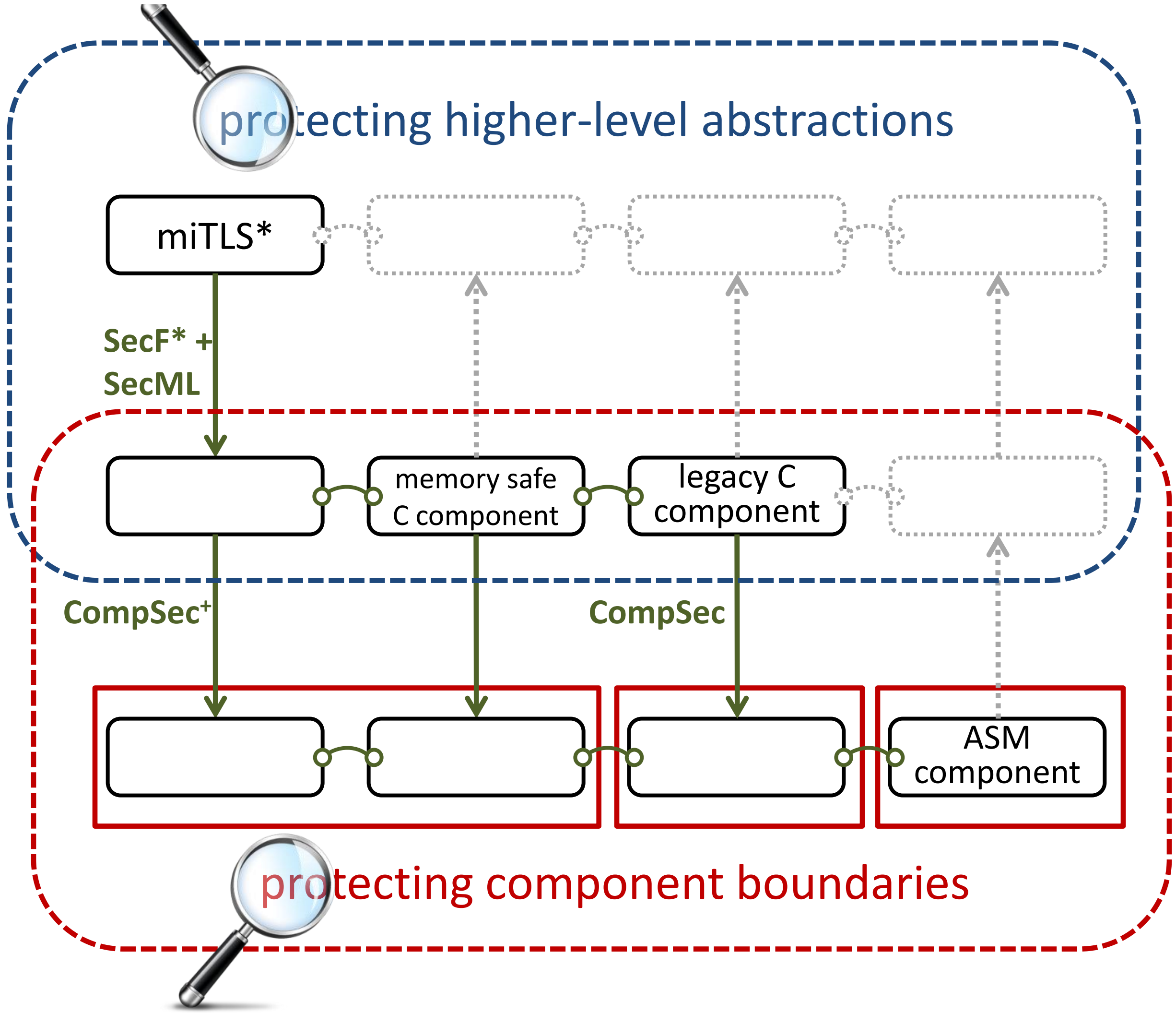

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Recent preliminary work, joint with Yannis Juglaret et al

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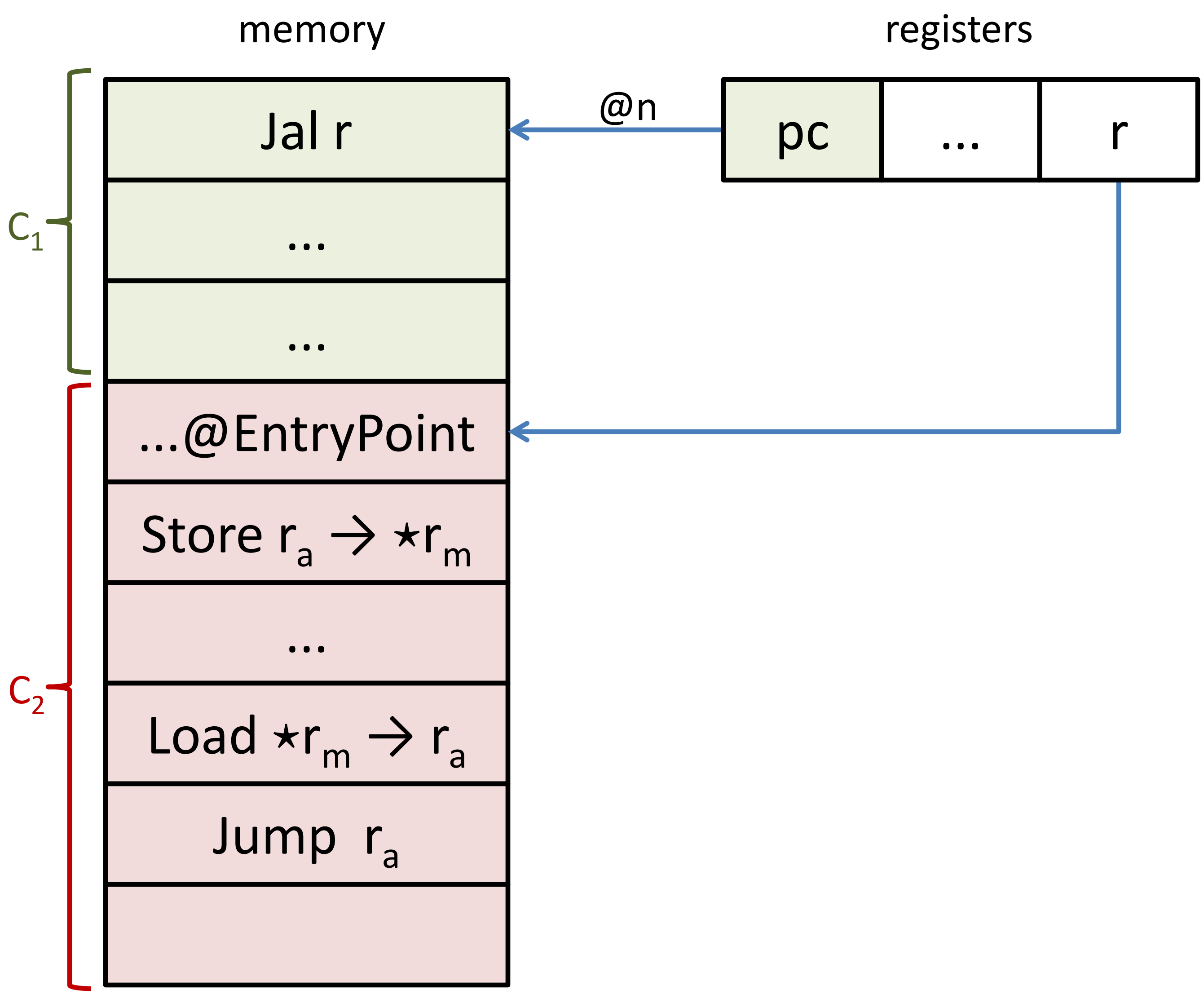

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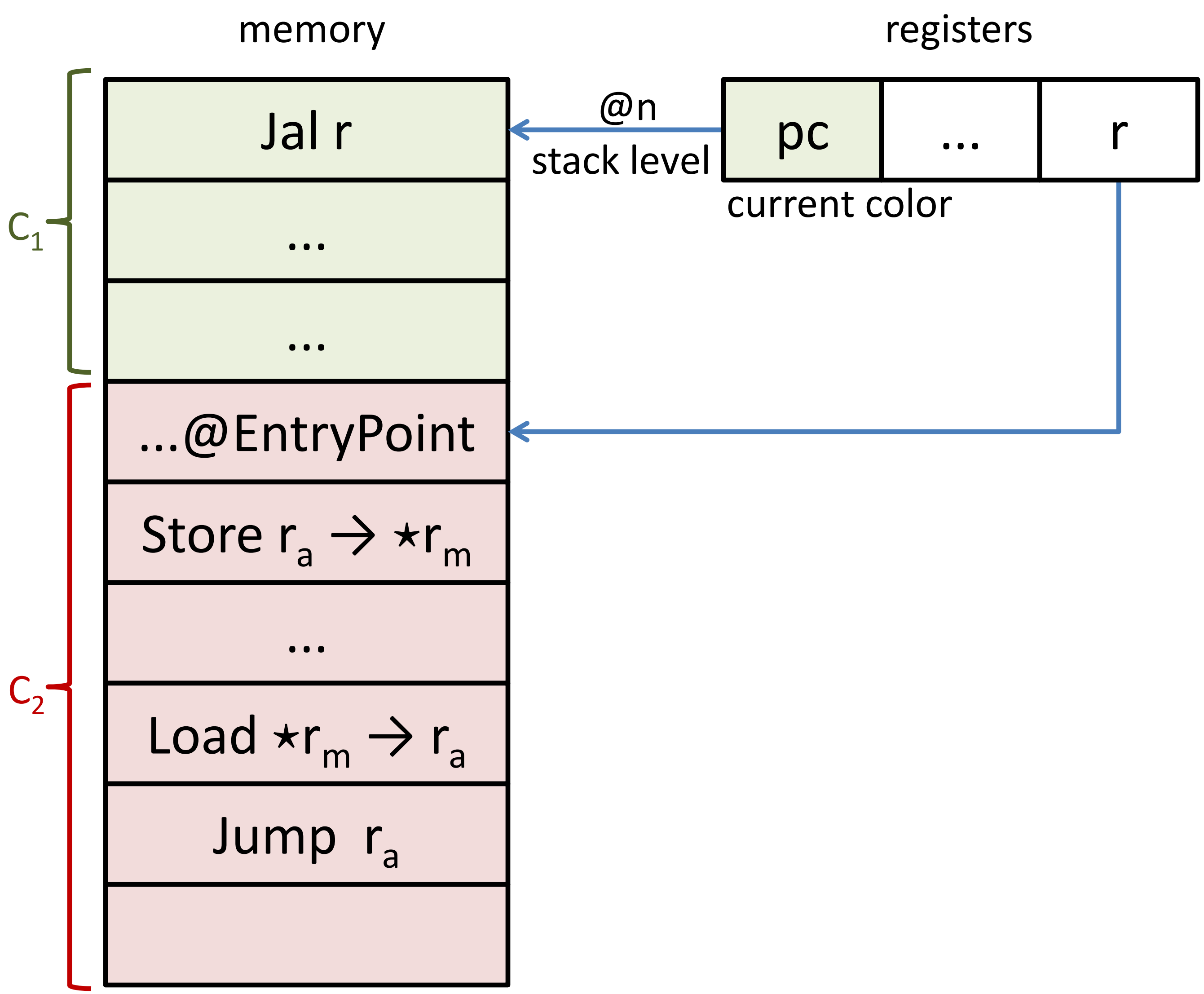

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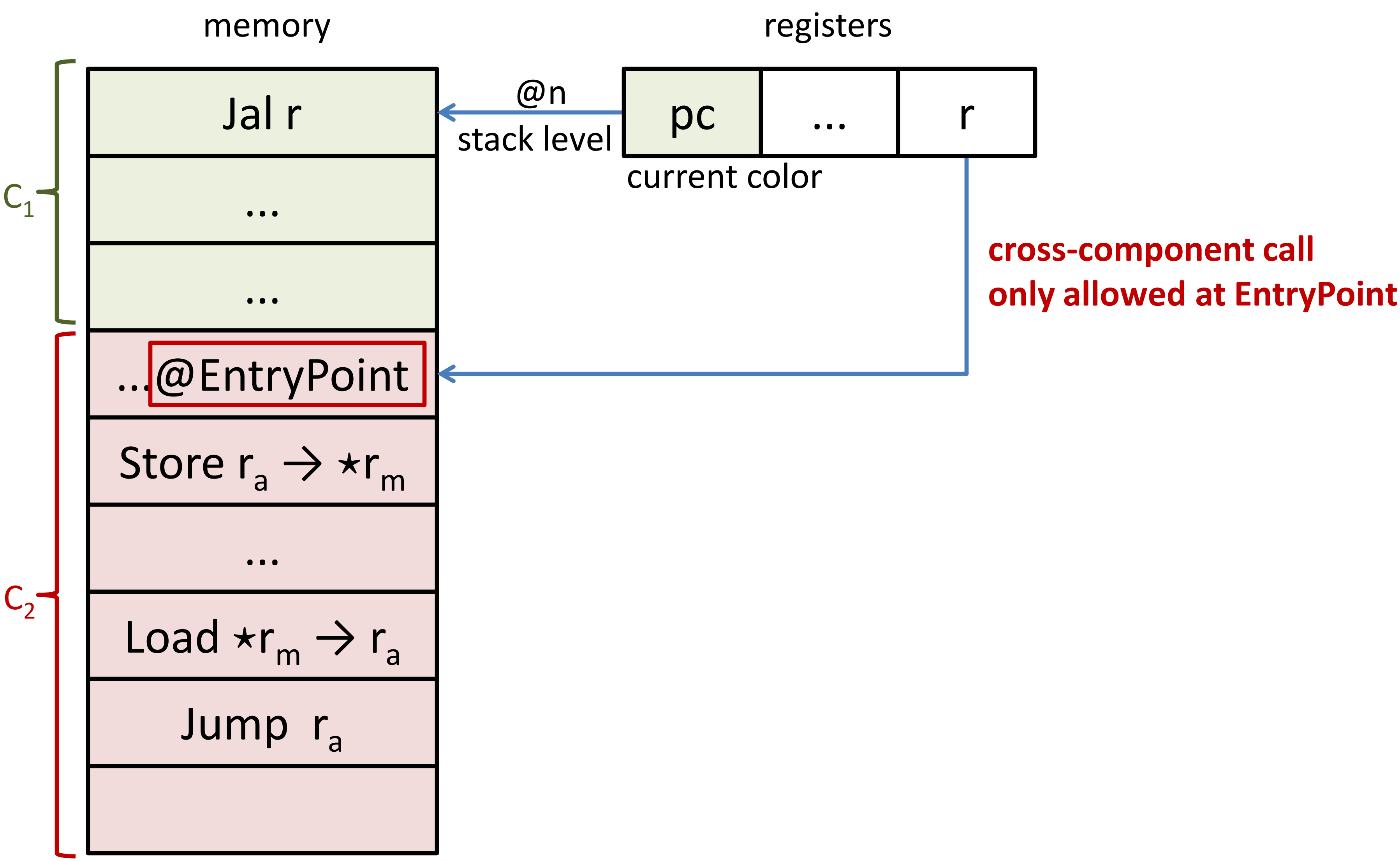

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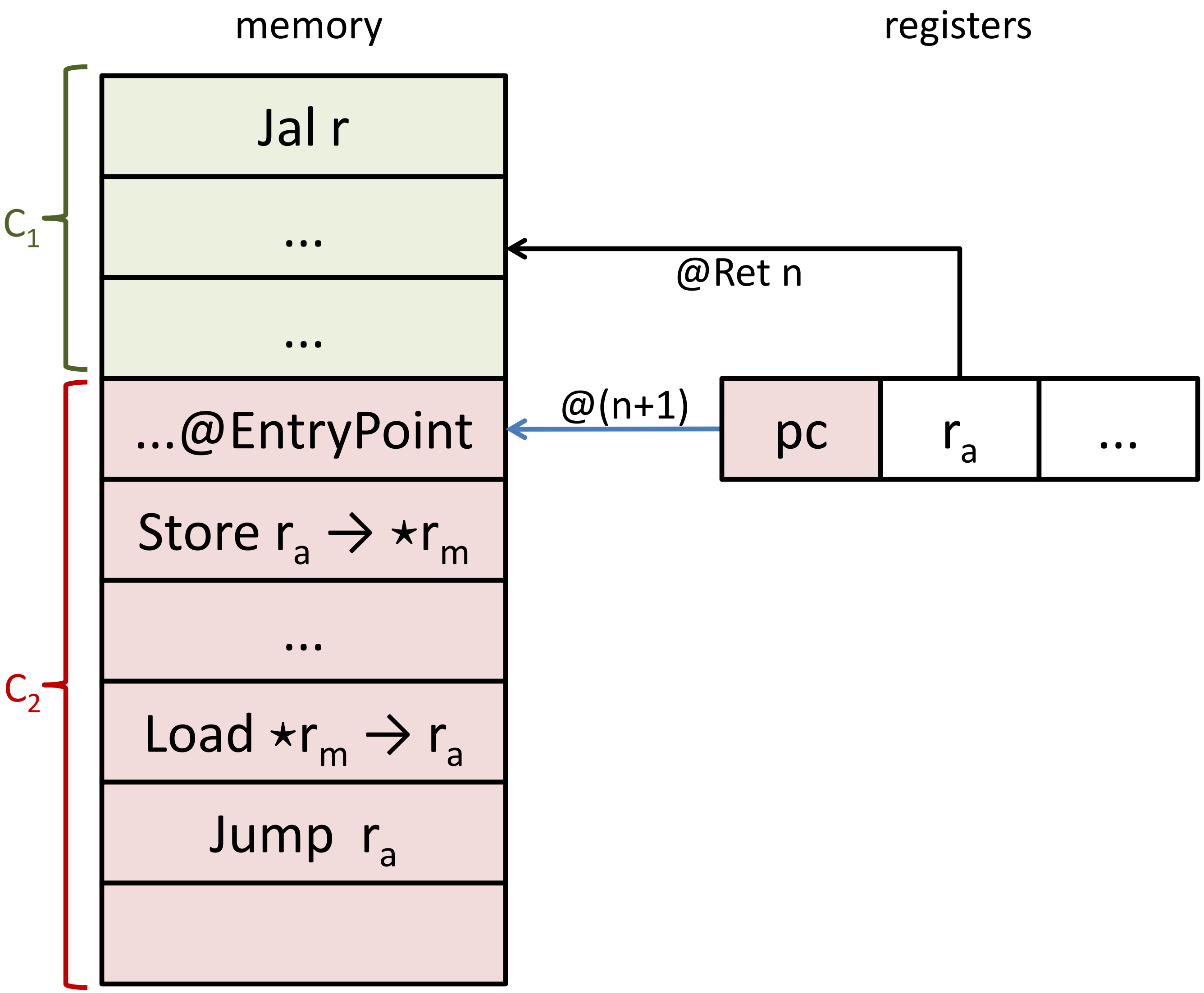

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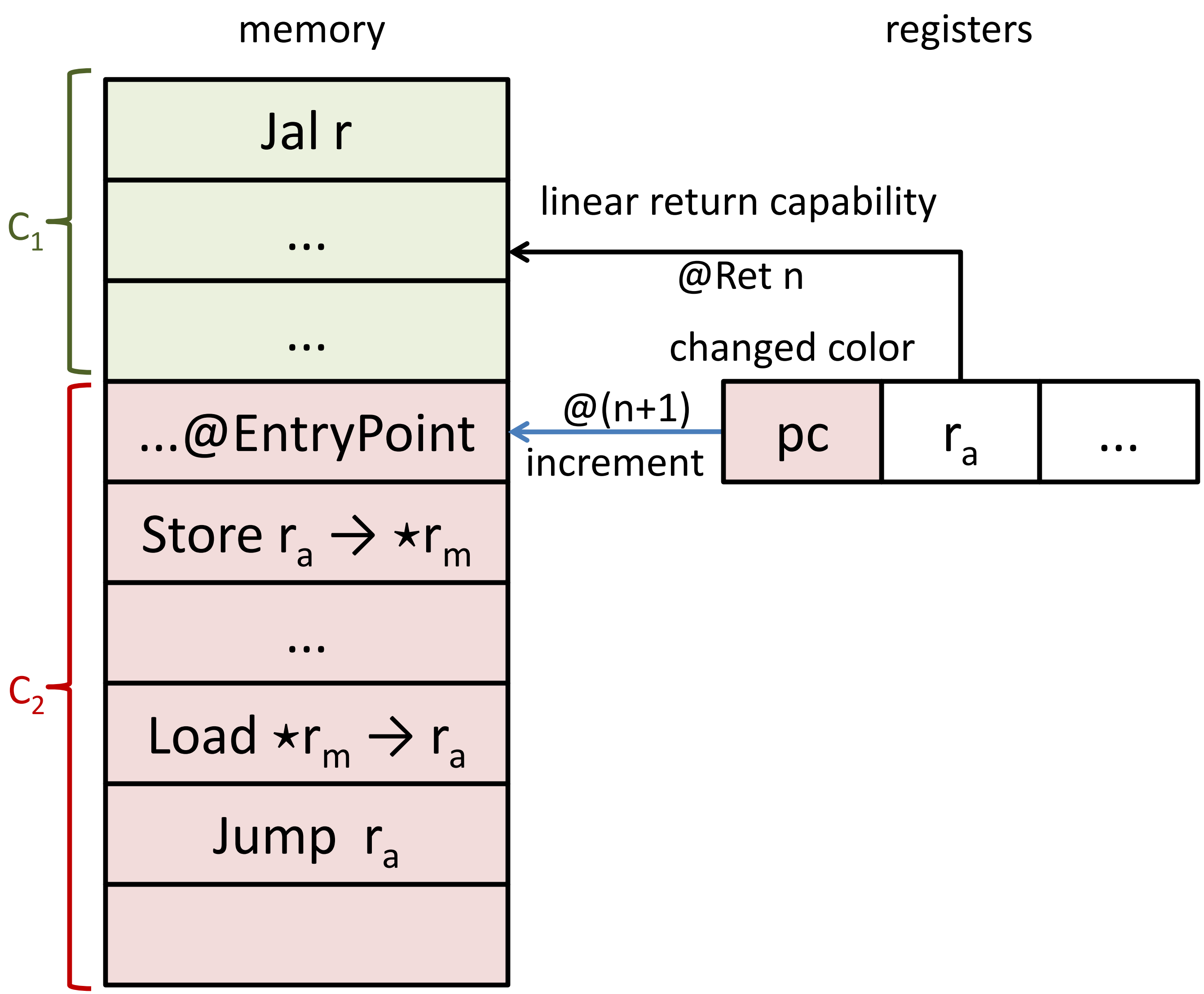

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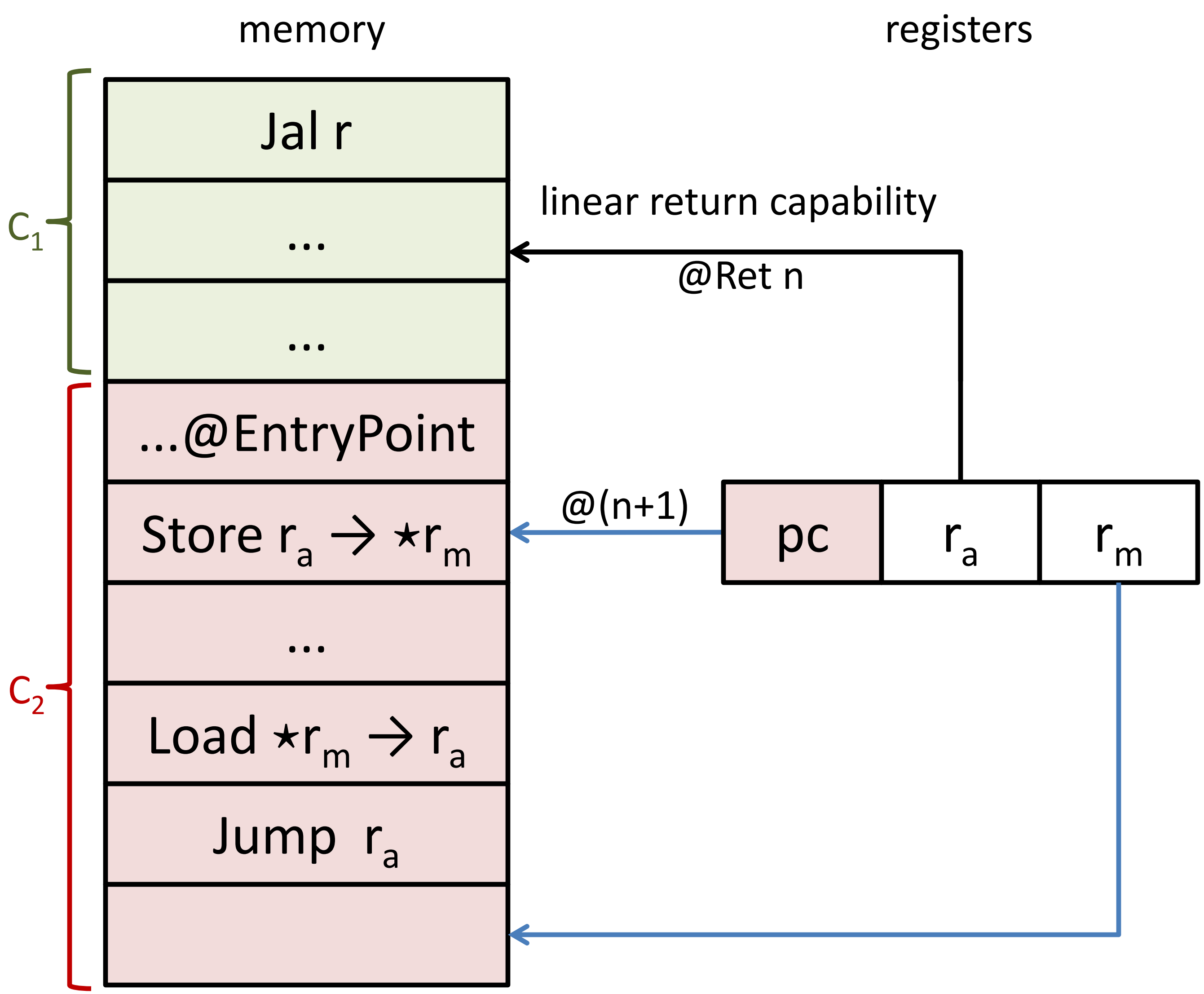

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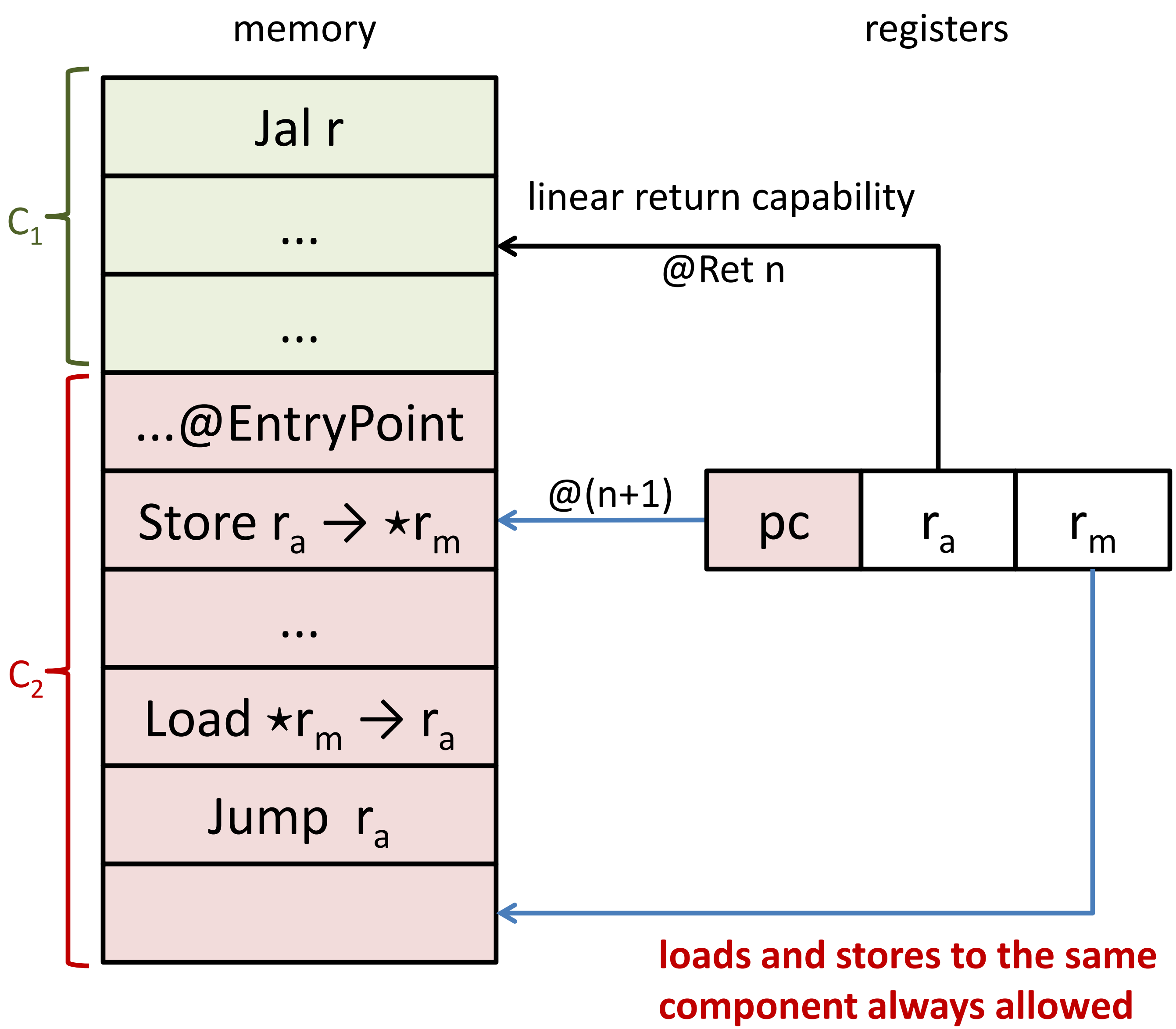

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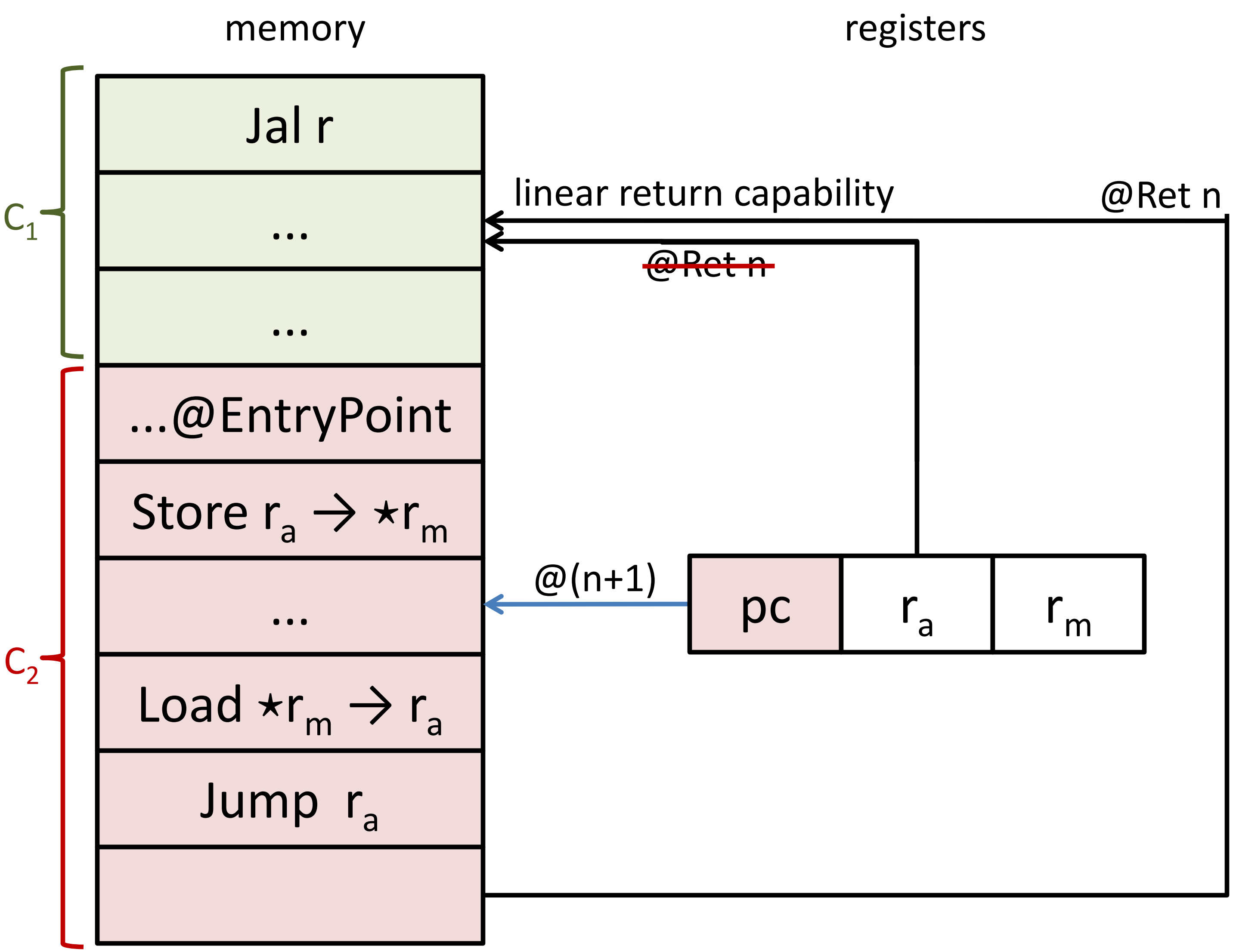

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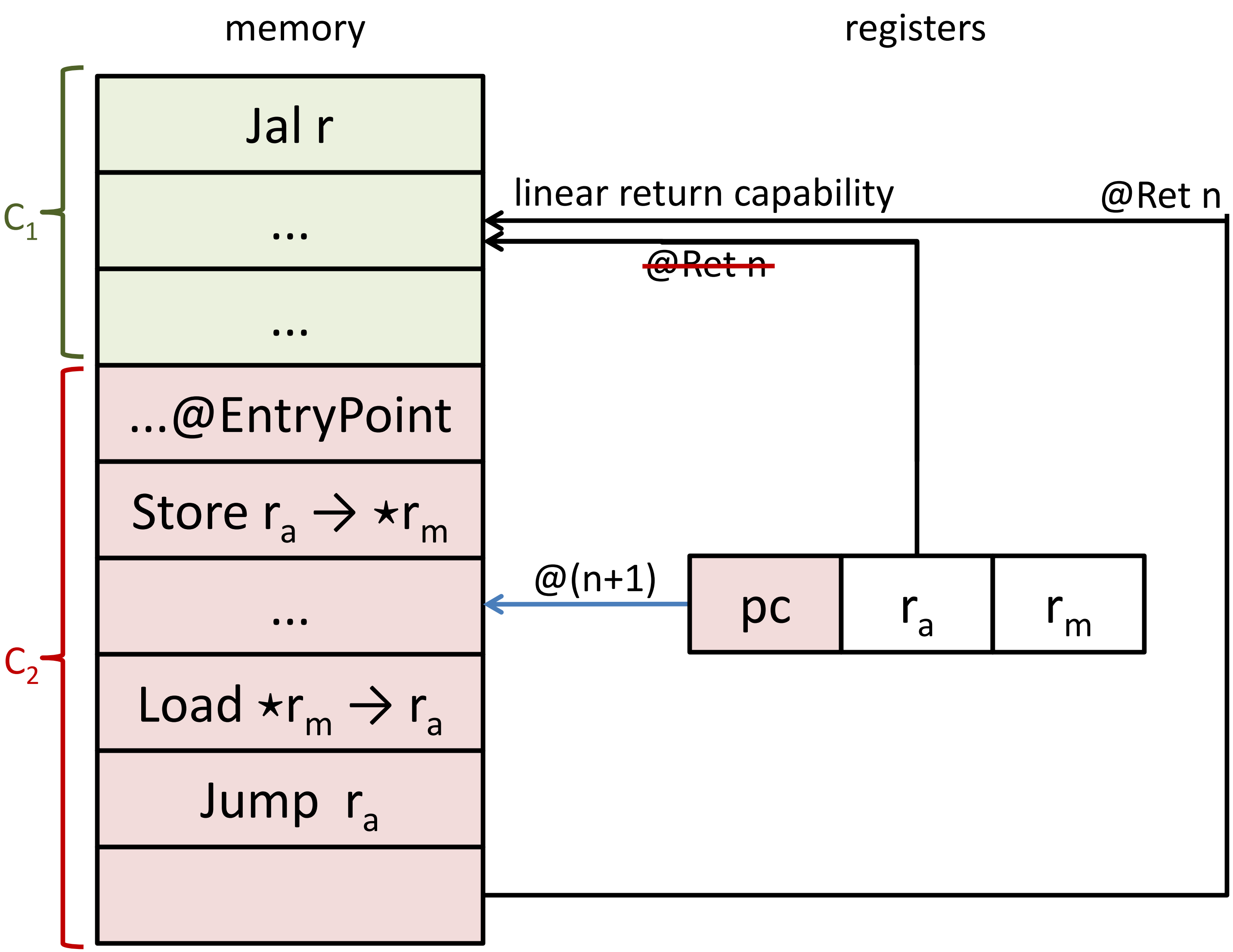
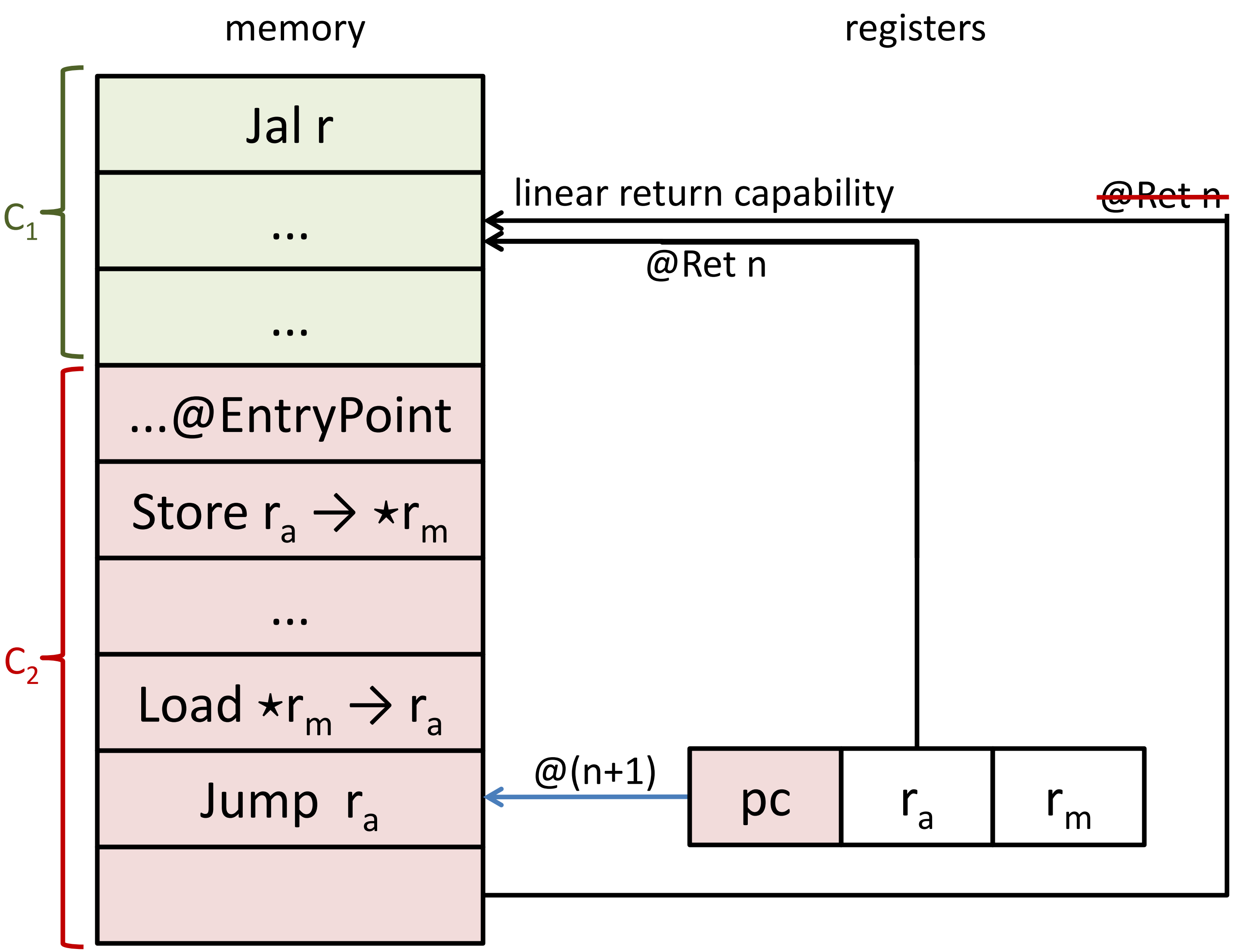


invariant:
at most one
return capability
per call stack level

Compartmentalization micro-policy



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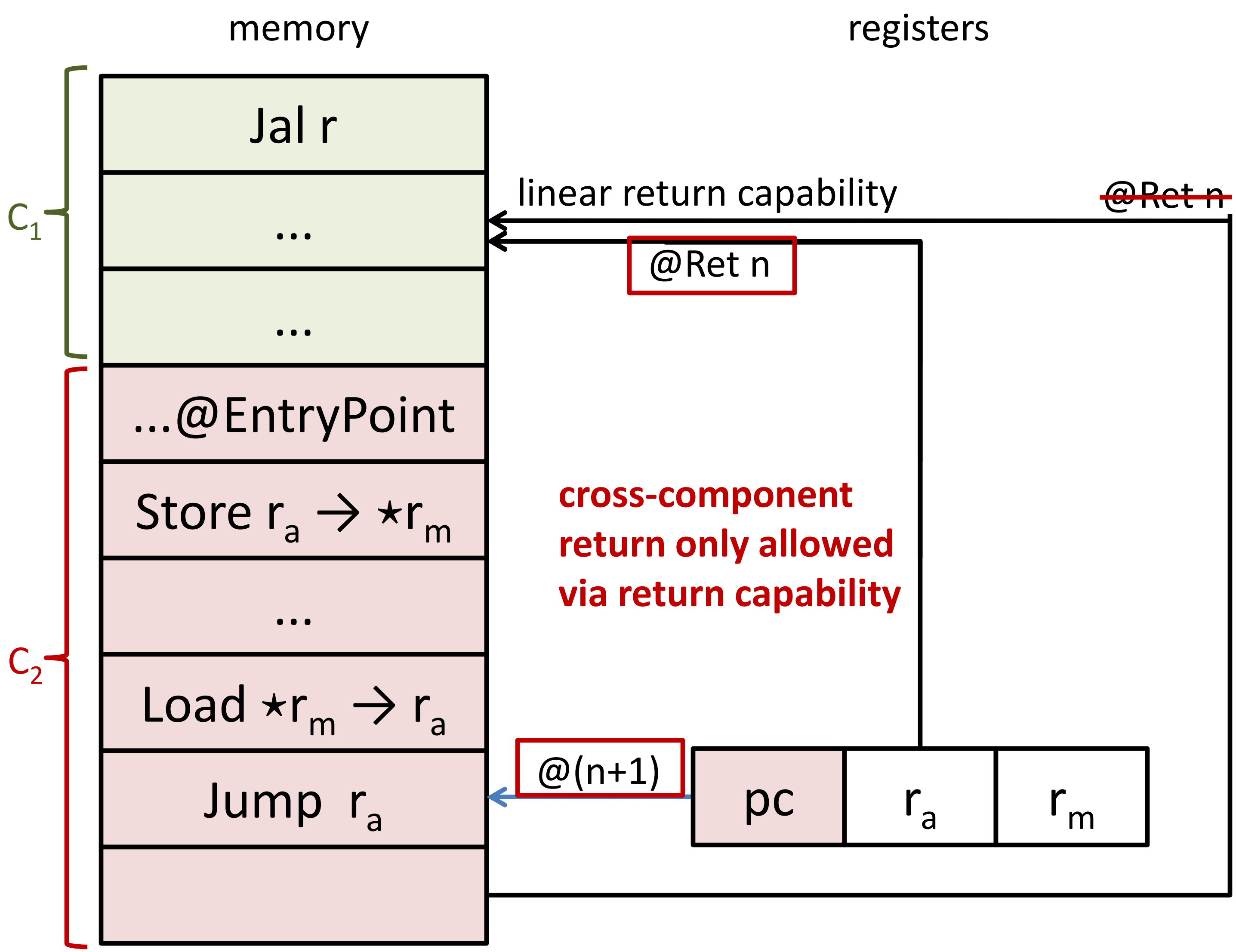

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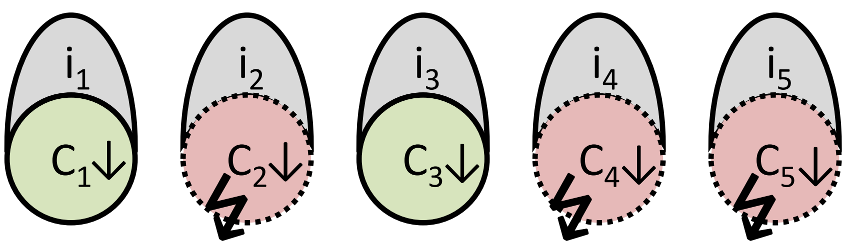
Secure compartmentalizing compilation (SCC)

∀compromise scenarios.



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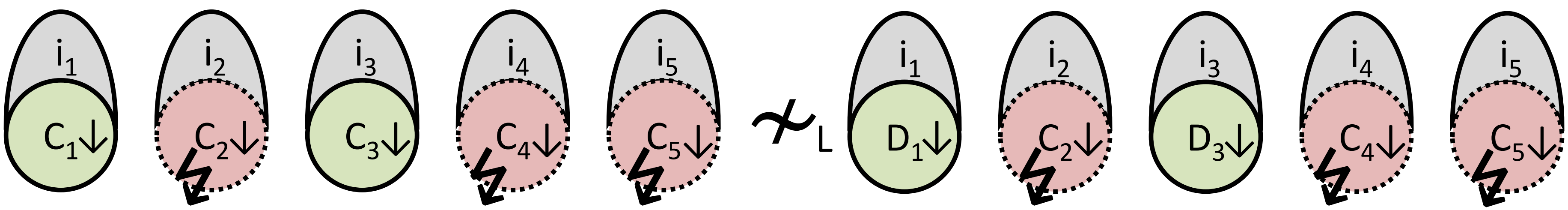

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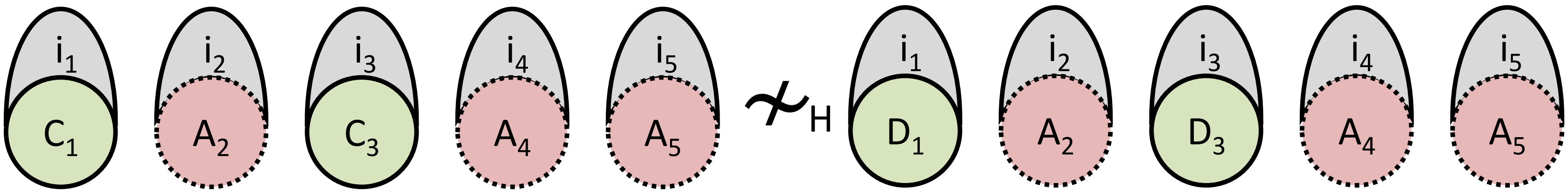
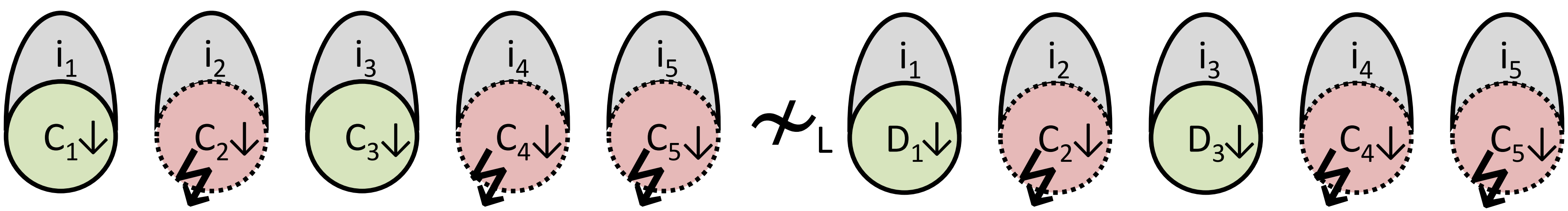


∀ low-level attack from compromised $C_2\downarrow$, $C_4\downarrow$, $C_5\downarrow$

∃ high-level attack from some fully defined A_2, A_4, A_5



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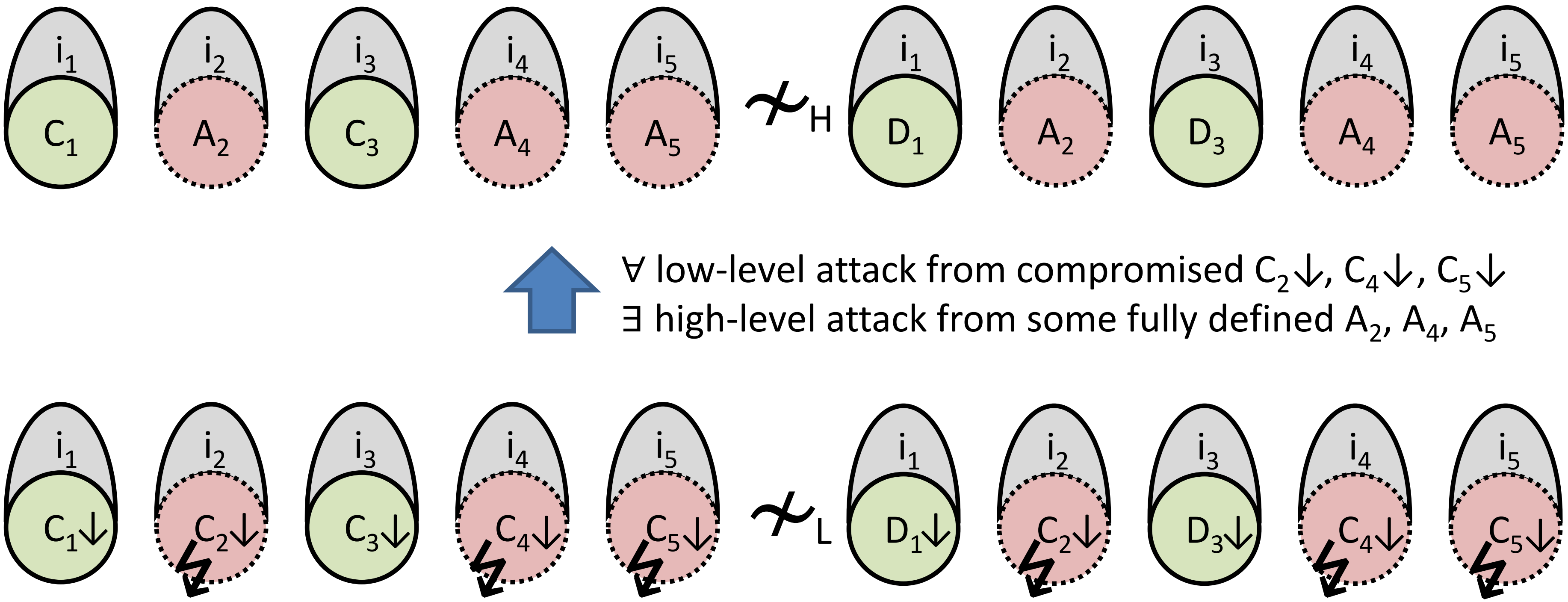

follows from "structured full abstraction for unsafe languages" + "separate compilation"

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

Protecting higher-level abstractions

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  - **push these limits further and combine with static analysis**

SECOMP focused on dynamic enforcement
but static analysis could help too

- **Improving efficiency**
  - removing spurious checks
  - just that by using micro-policies our compilers add few explicit checks
  - e.g. turn off memory safety checking for a statically memory safe component that never sends or receives pointers

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- **Improving transparency**
  - allowing more safe behaviors
  - e.g. we could statically detect which copy of the linear return capability the code will use to return (in this case static analysis untrusted)

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remaining fundamental challenges

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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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- **Orthogonal properties**:
  - memory safety (enforcing CompCert memory model)

What secure compilation adds over compositional compiler correctness

- **mapping back arbitrary low-level contexts**
- **preserving integrity properties**
  - robust compilation phrased in terms of this
- **preserving confidentiality properties**
  - full abstraction and preservation of hyper-safety phrased in terms of this
- **stronger notion of components and interfaces**
  - secure compartmentalizing compilation adds this

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- **Problems not just with effort/scale**
  - devising good **proof techniques** for full abstraction is a hot research topic of it's own

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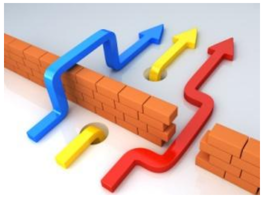

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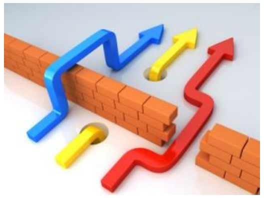

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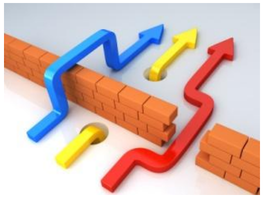

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  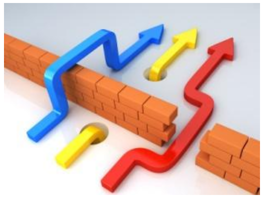
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- **Achieving strong security properties like full abstraction**
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- **Measuring & lowering the cost of secure compilation**
  
- Most of this is **vaporware** at this point but ...
  
  – building a community, looking for collaborators, and hiring
  ... **in order to try to make some of this real**

- Looking for excellent **interns**, **PhD students**, **PostDocs**, **starting researchers**, and **engineers**
- Prosecco can also support outstanding candidates in the **CR2 competition**

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- **Secure compilation meetings (very informal)**
  - 1st at INRIA Paris on August 2016
  - 2nd in Paris on 15(?) January 2017 ... maybe at UPMC
  - **build larger research community, identify open problems,**
    bring together communities (hardware, systems, security,
    languages, verification, ...)

Questions for Gallium

- What do you think? Is this plan outrageous?
- Would CompCert be a good base for some of this?
- Is there any plan for a RISC-V backend for CompCert?
- Is anyone from Gallium interested in working on secure compilation?