Compositional Verification of Security Properties for Embedded Execution Platforms

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Low and High Level System Security Bugs

'Dirty Cow' Linux vulnerability found after nine years

The 'Dirty Cow' bug was originally introduced nine years ago, and has been sitting unnoticed for much of that time

AFTER JEEP HACK, CHRYSLER RECALLS 1.4M VEHICLES FOR BUG FIX

Apple's App Store hit by the XCodeGhost of malware present

22 SEP 2015 4

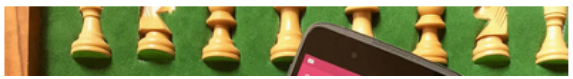
Apple, iOS, Malware, OS X, Vulnerability

'Quadrooter' flaws affect Android phones

All versions of Android are vulnerable to these fla until the September security release next month.

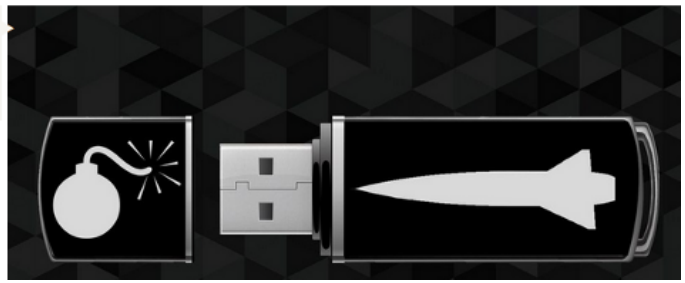
By Zack Whittaker for Zero Day | August 7, 2016 -- 22:00 GMT (23:00 BST) | Topic: Security

17 f 686 in 445



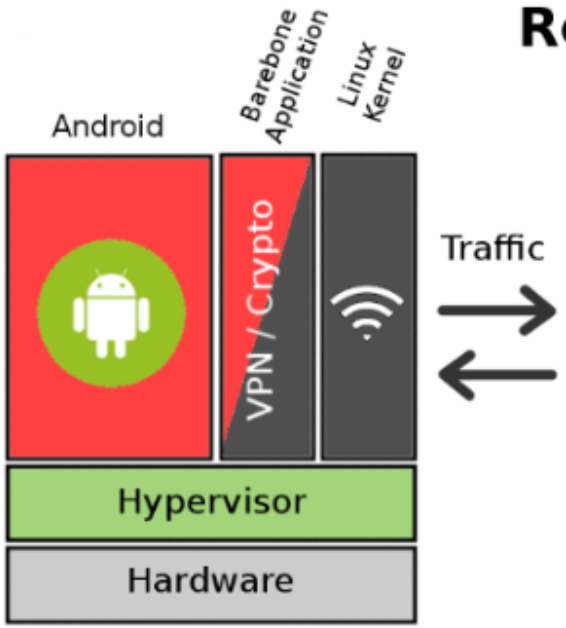
BadUSB Can Turn Thumb Drives Into Cyberweapons

2.9k SHARES 962 996 144 754 0 1



Tutus demonstrator

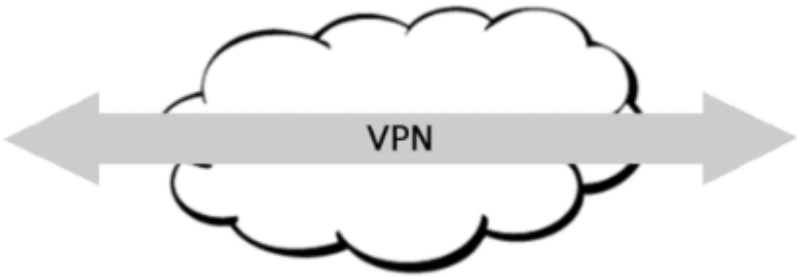
Red-black architecture



- Untrusted: Android and Linux Kernel
- Middle guest is trusted:
  - negotiates parameters for VPN
  - encrypts all outgoing traffic
  - decrypts all incoming traffic

System objectives:
- VPN is enforced under all conditions
- VPN parameters never compromised

FÄRIST MOBILE



FÄRIST VPN

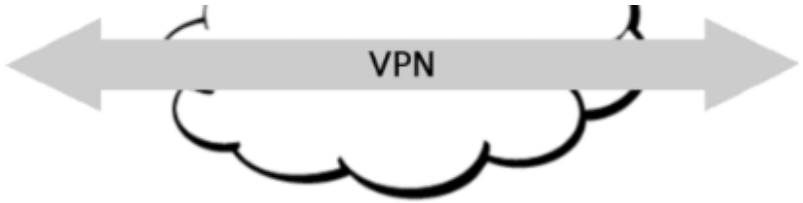
Tutus demonstrator

Red-black architecture

- Untrusted: Android and Linux Kernel

minimal COTS hypervisor for ARMv8:

- fixed #guests, fixed memory size
- cores and devices owned exclusively
- no device virtualization, except: GIC
- secure boot loader
- memory isolation through HW extensions & SMMUs
- communication only through pre-defined channels



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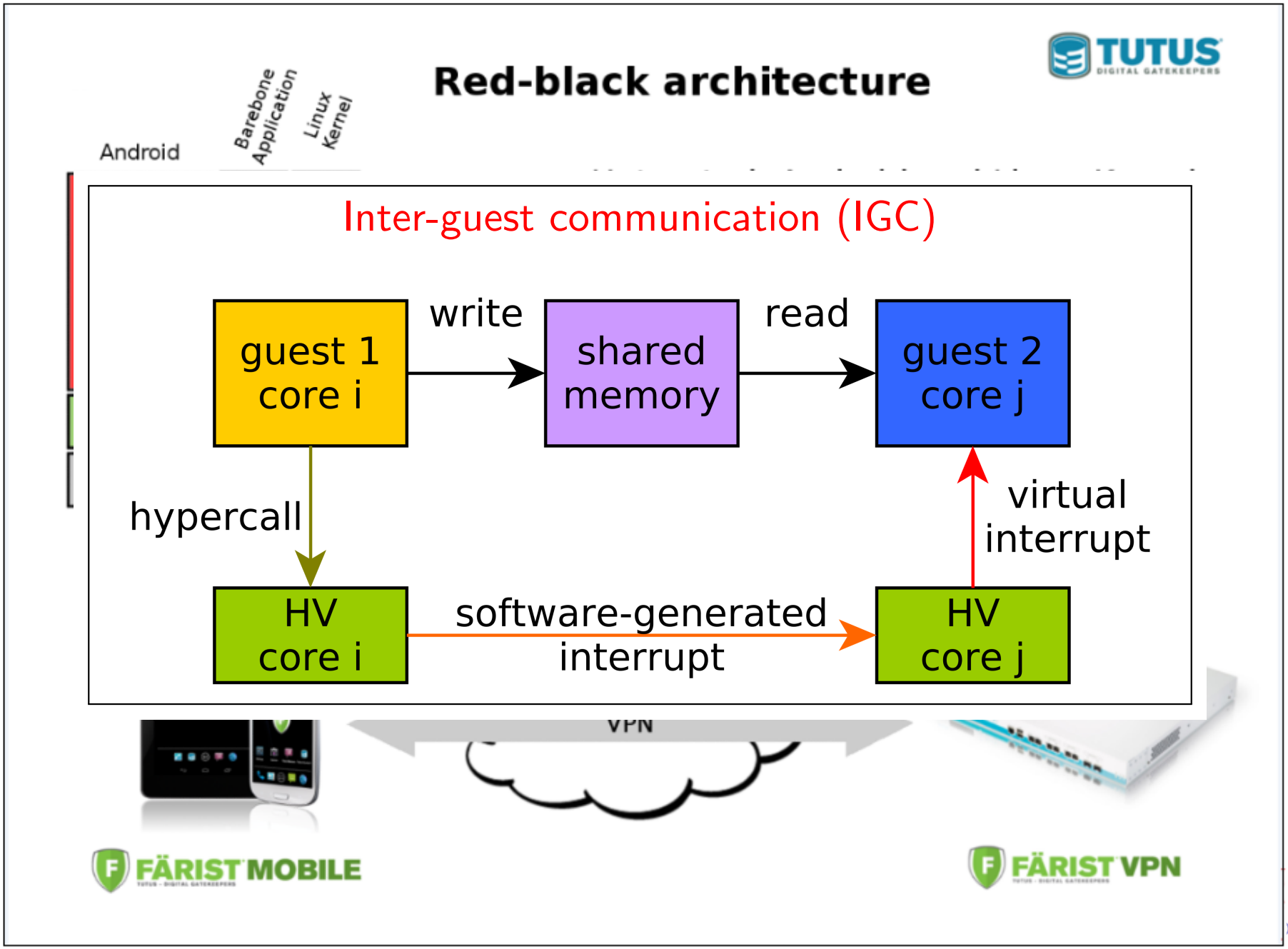
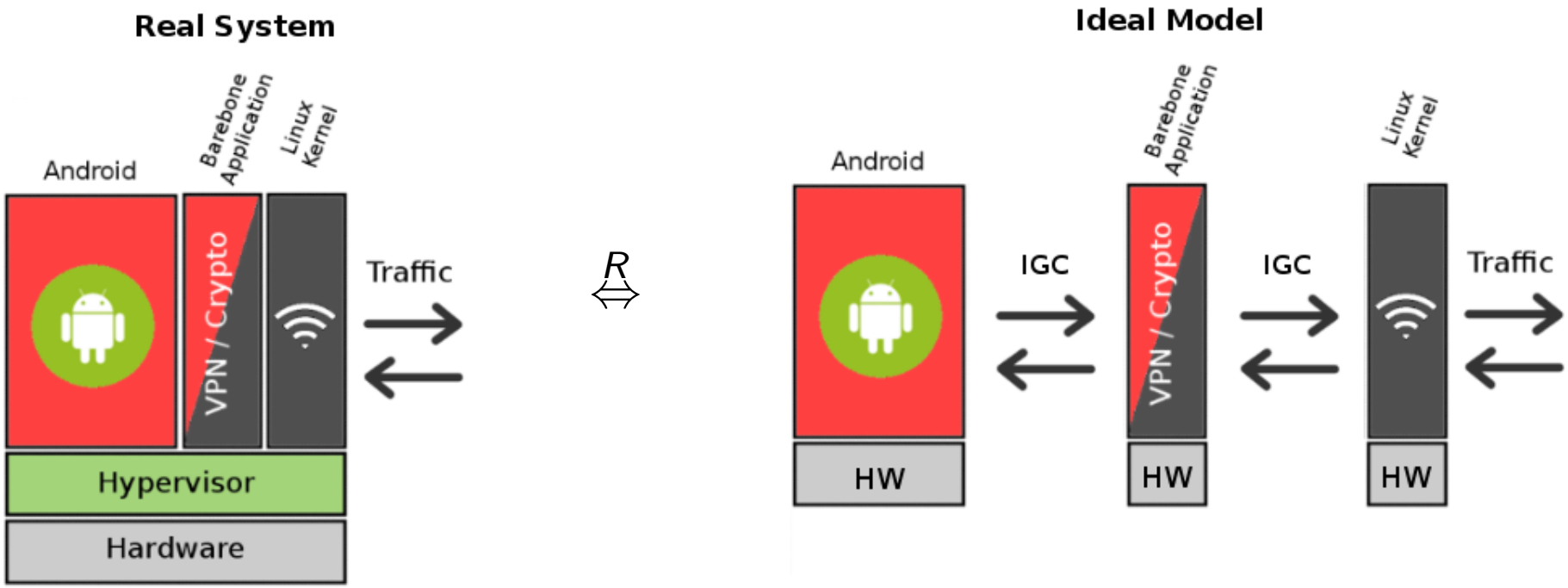
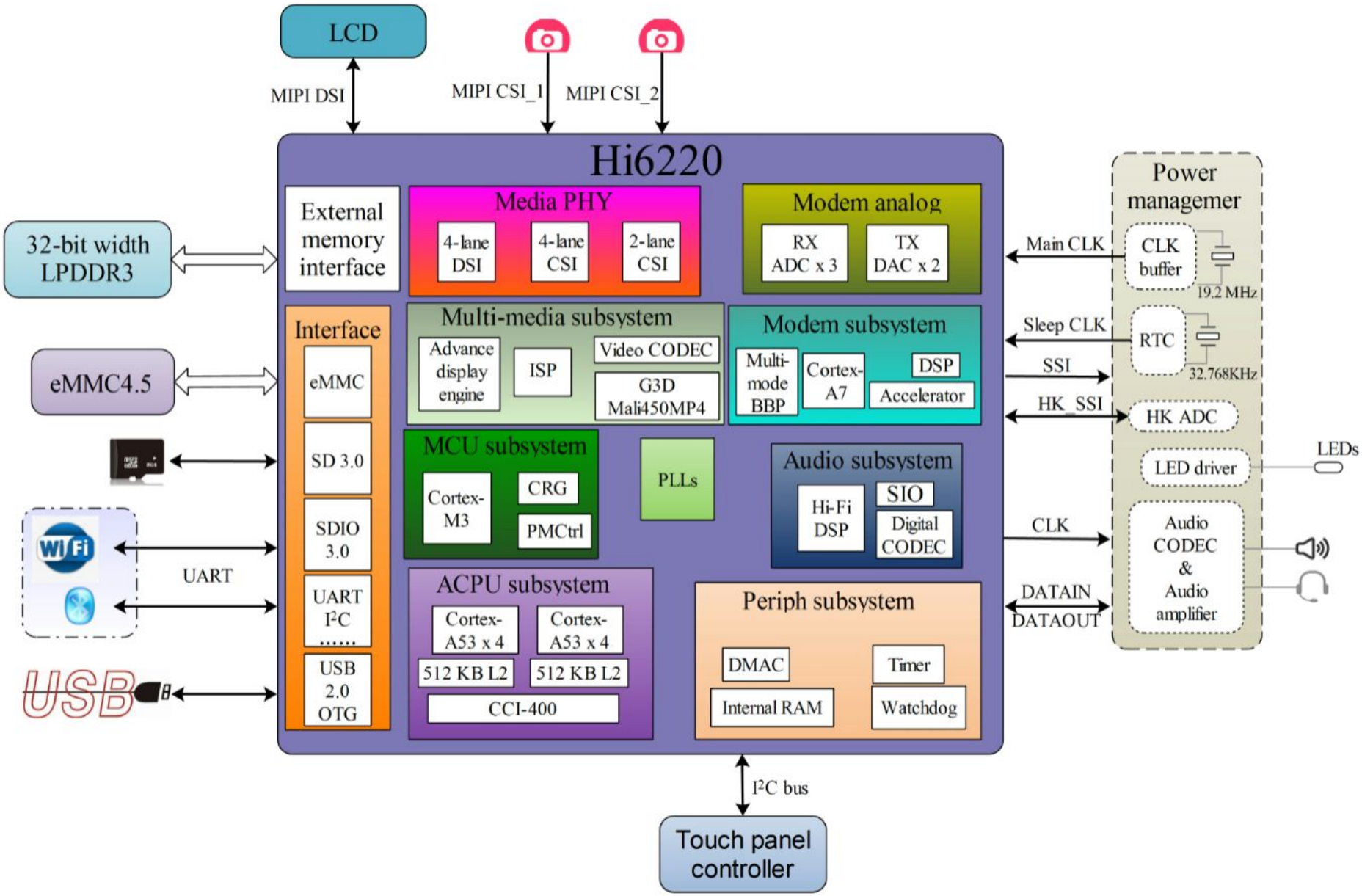


Goal: Bisimulation with Ideal Model



- ideal model: secure by construction
- bisimulation relation R: transfer information flow properties
- verification: focus on arbitrary guest steps here

SoCs complex / formal verification expensive



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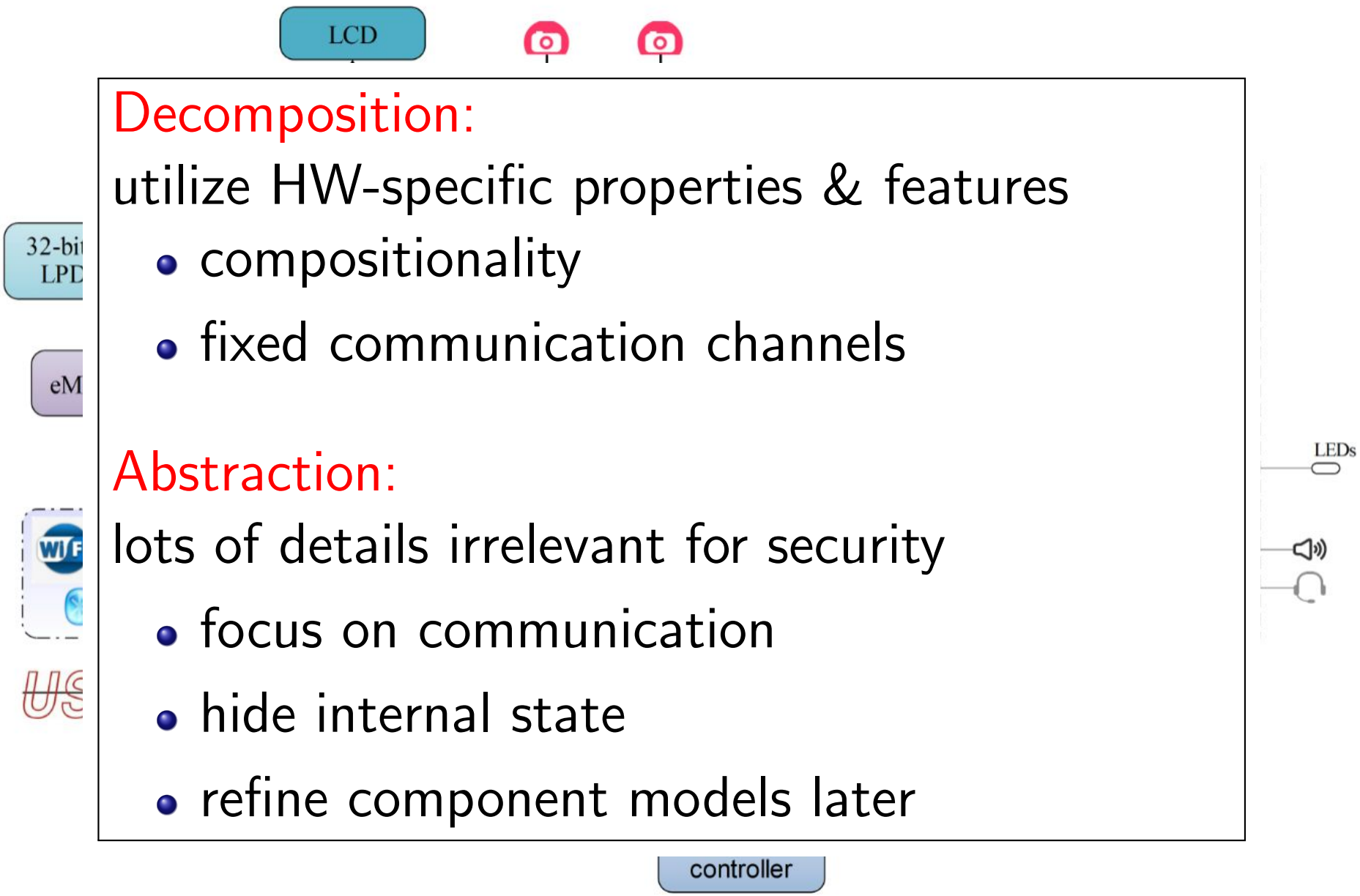


Decomposition:

utilize HW-specific properties & features

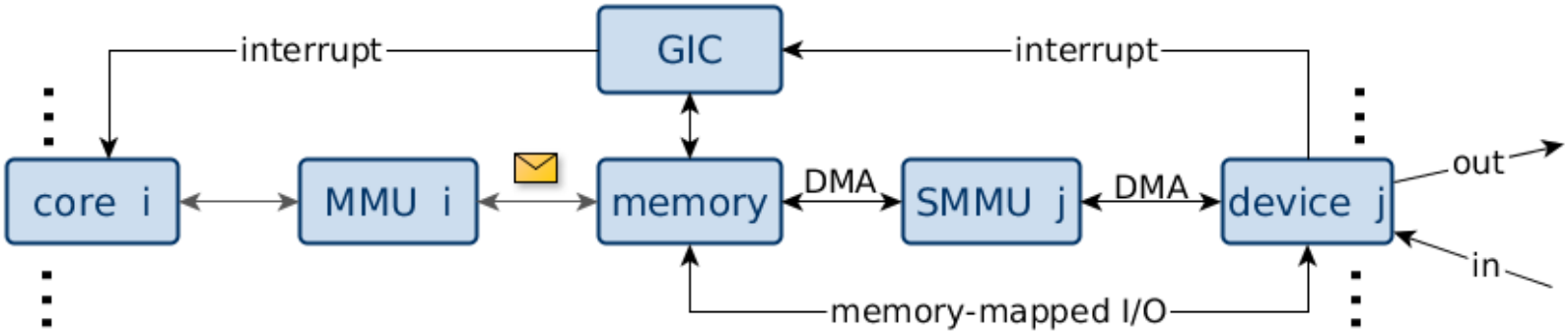
- compositionality
- fixed communication channels

Abstraction:

lots of details irrelevant for security

- focus on communication
- hide internal state
- refine component models later

ARMv8 platform model



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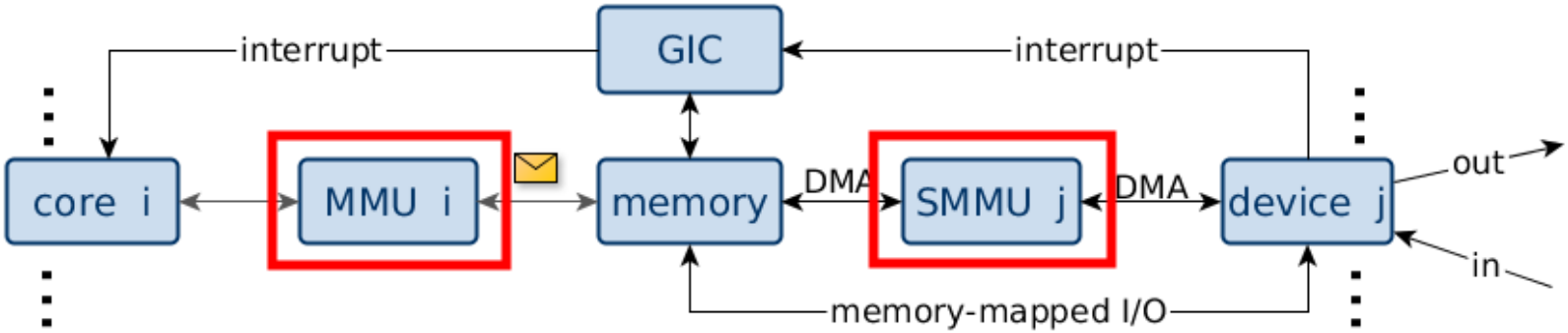

- (S)MMU: active?, page table base, current translations, mem requests

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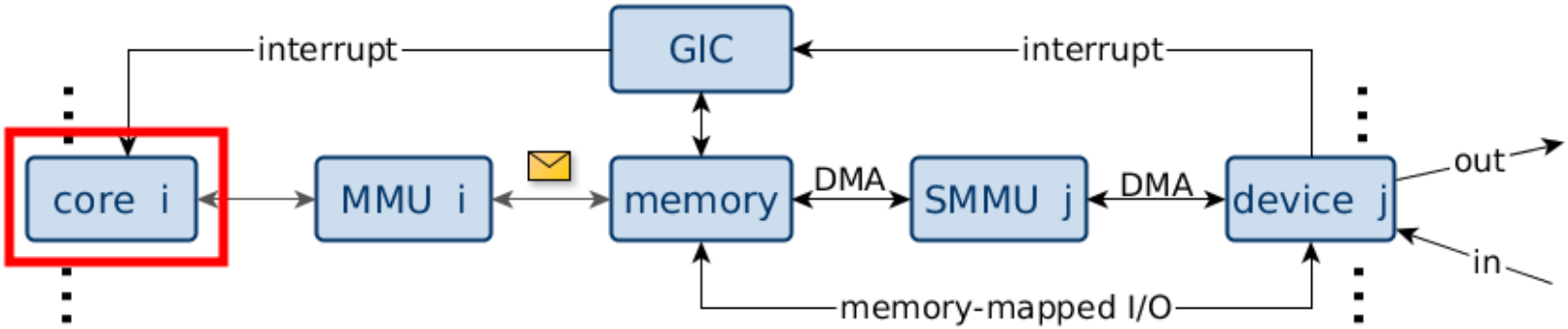

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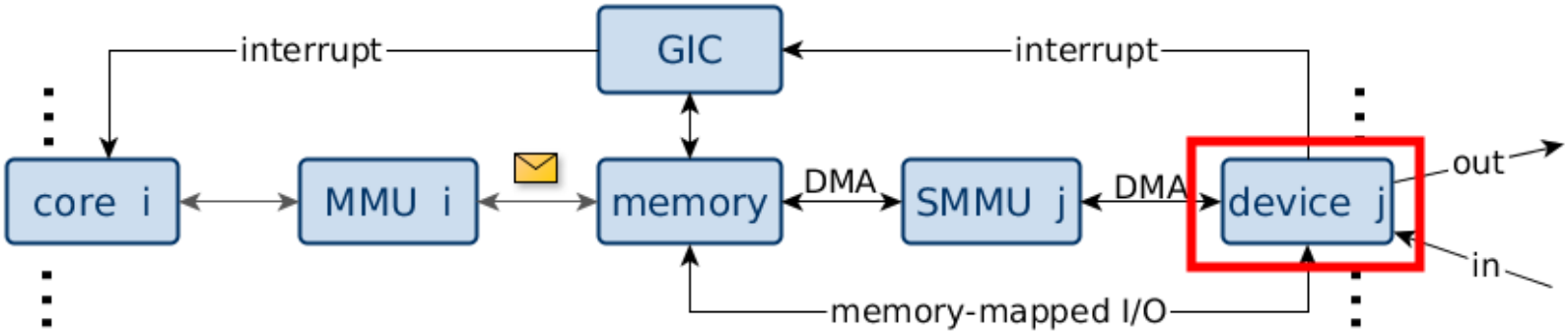

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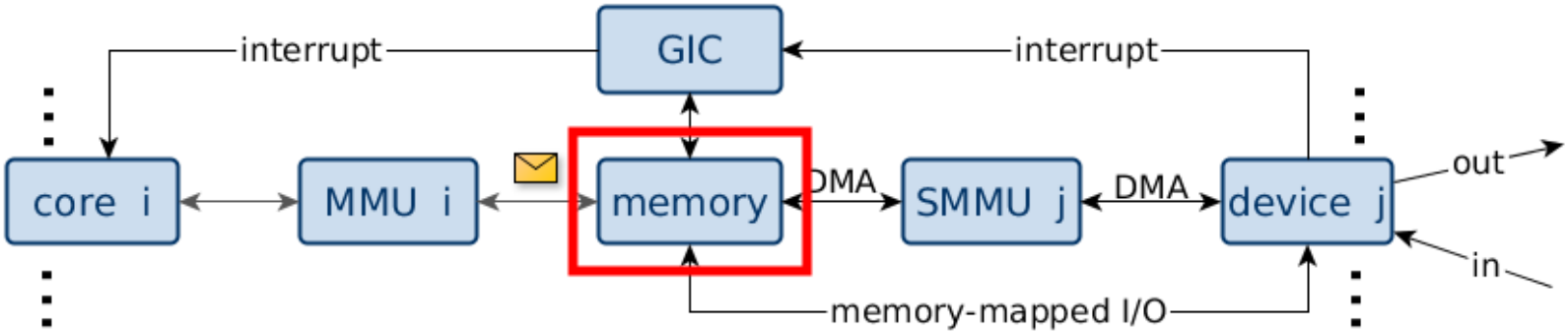

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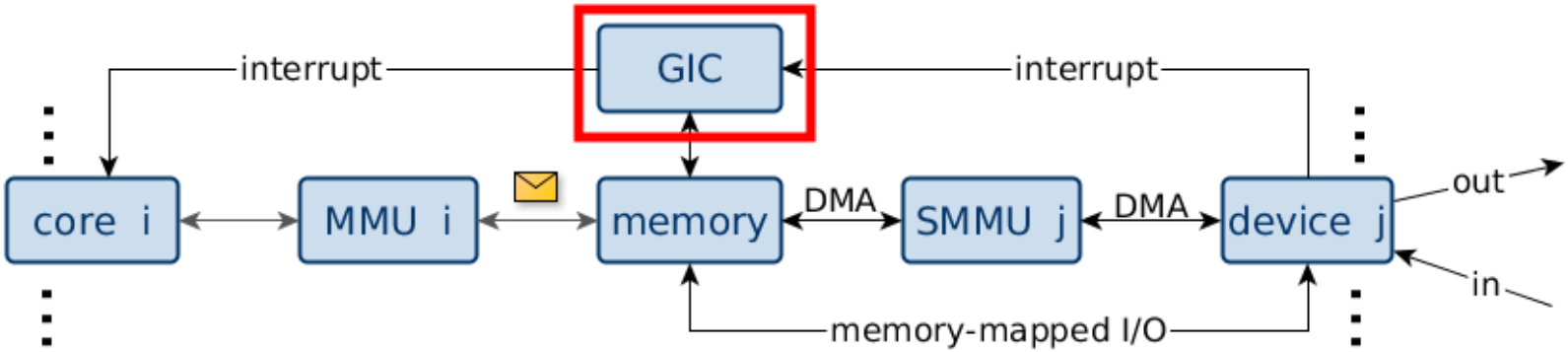

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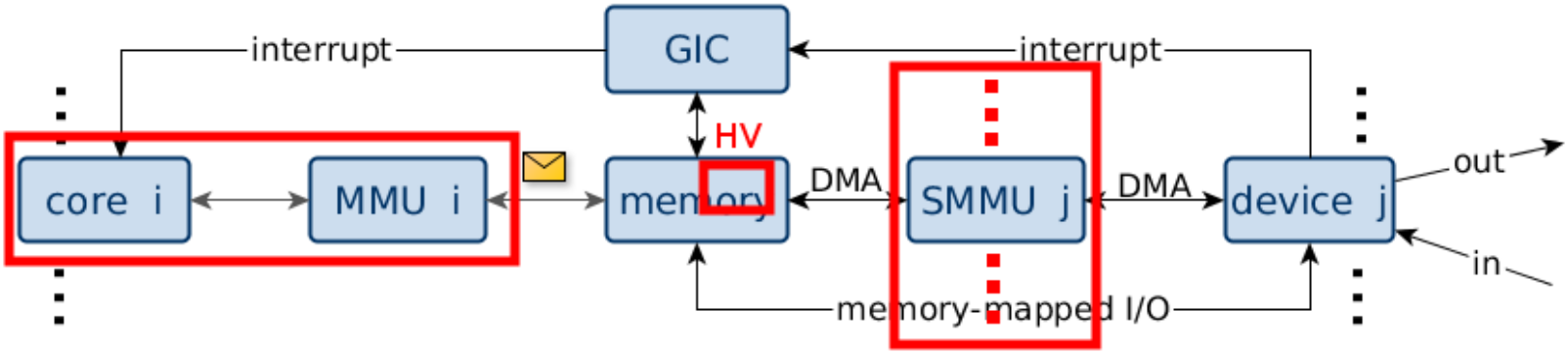

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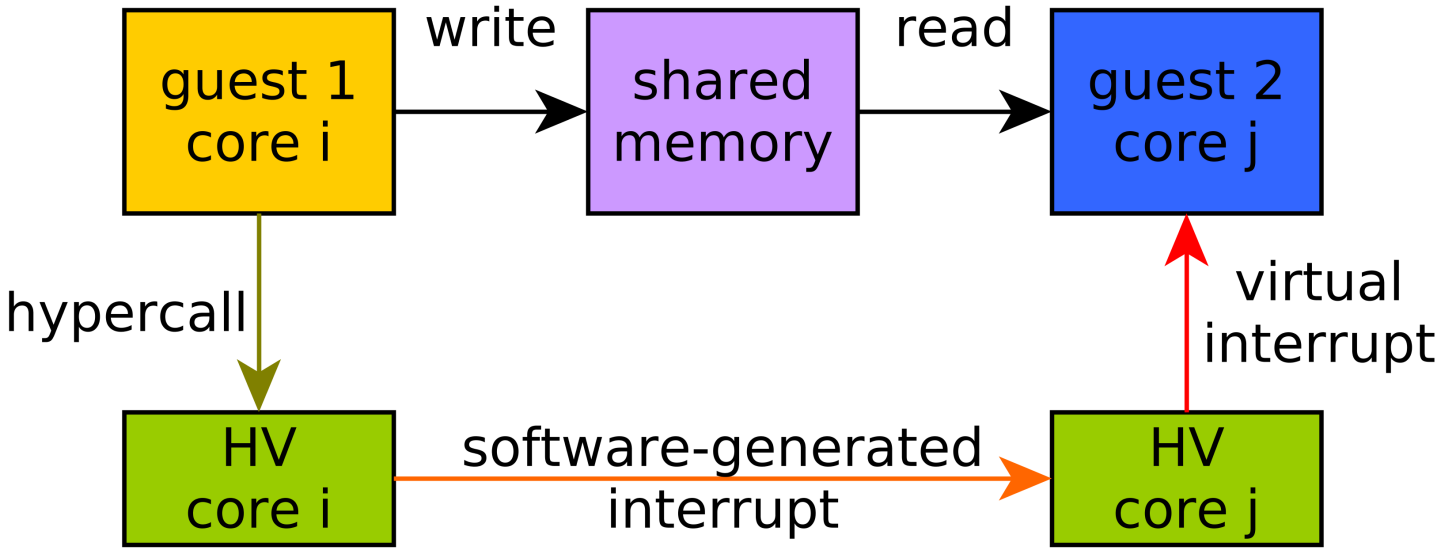
- hypervisor: fine-grained LTS, communication with GIC

Hypervisor LTS: IGC interrupt injection



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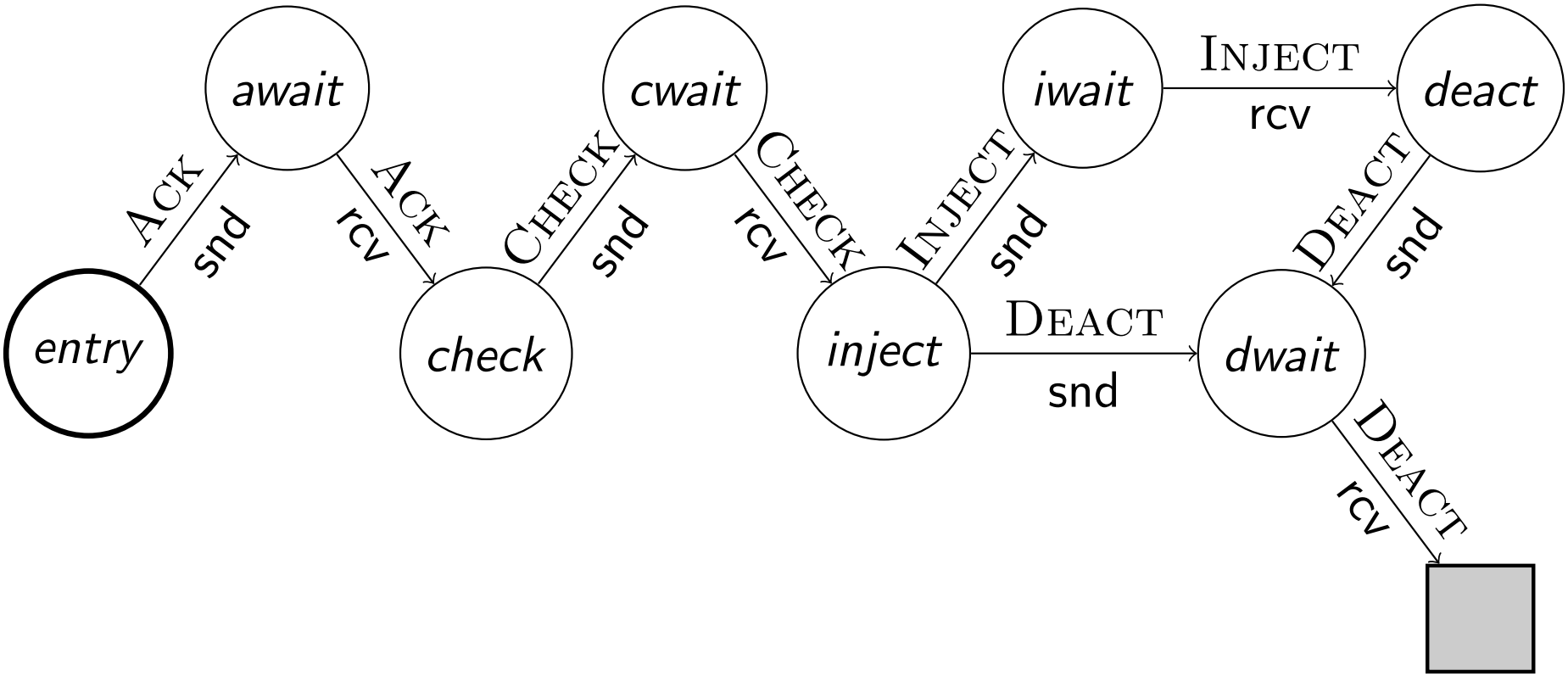

Verification: Platform Invariants

Component Constraints & HV configuration $\Rightarrow$ Invariant *Inv*:

- Messages & interrupts: preserve guest separation

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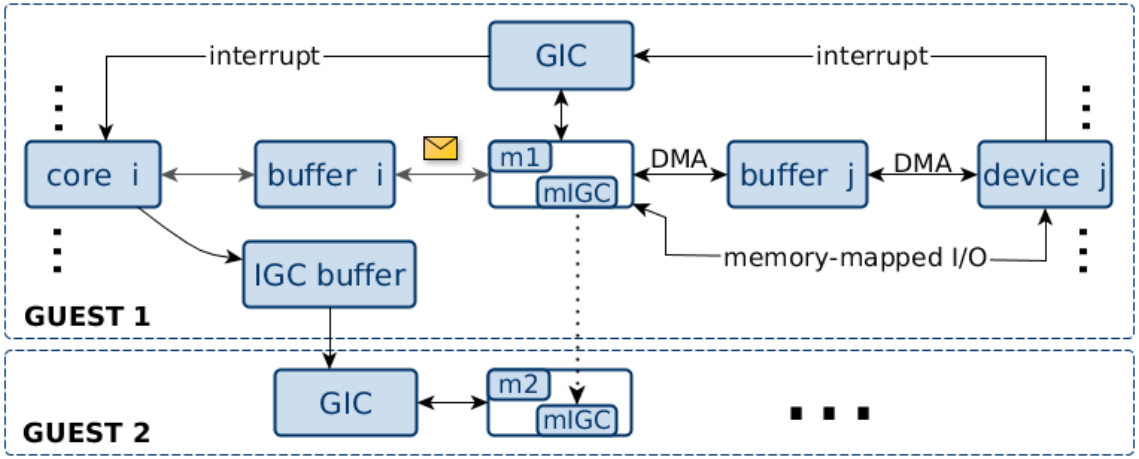

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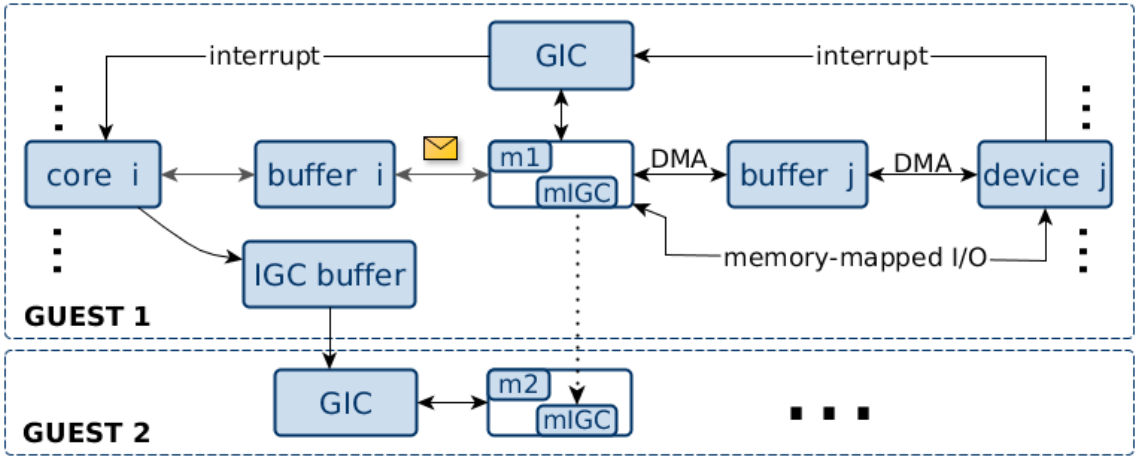

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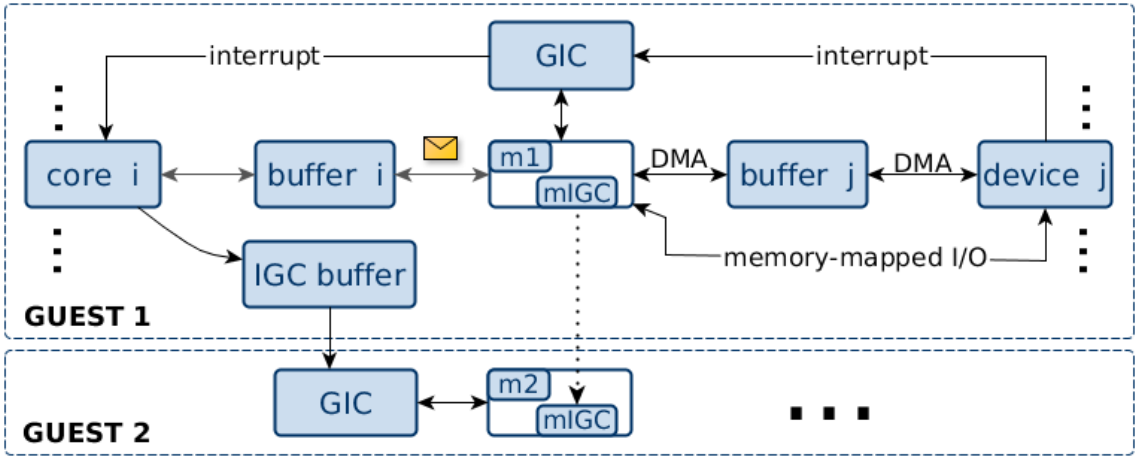

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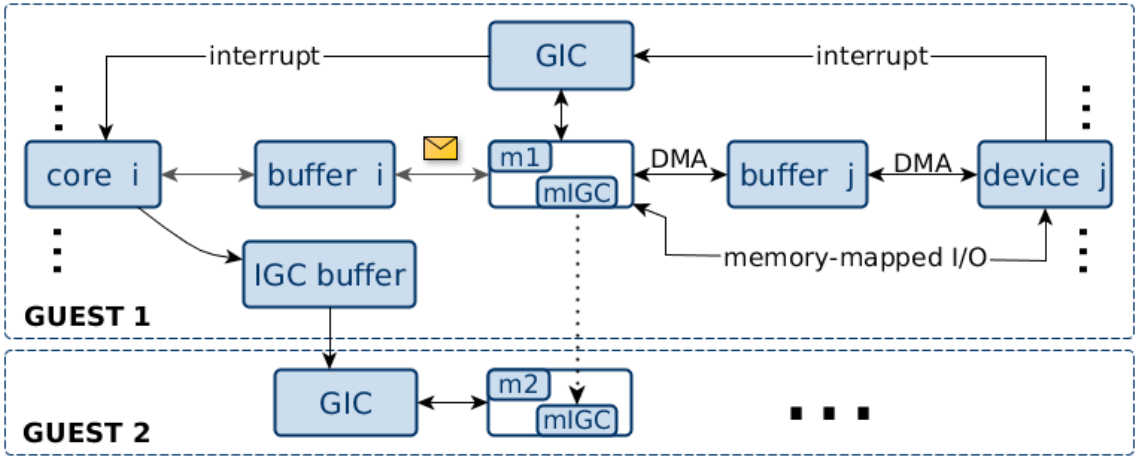

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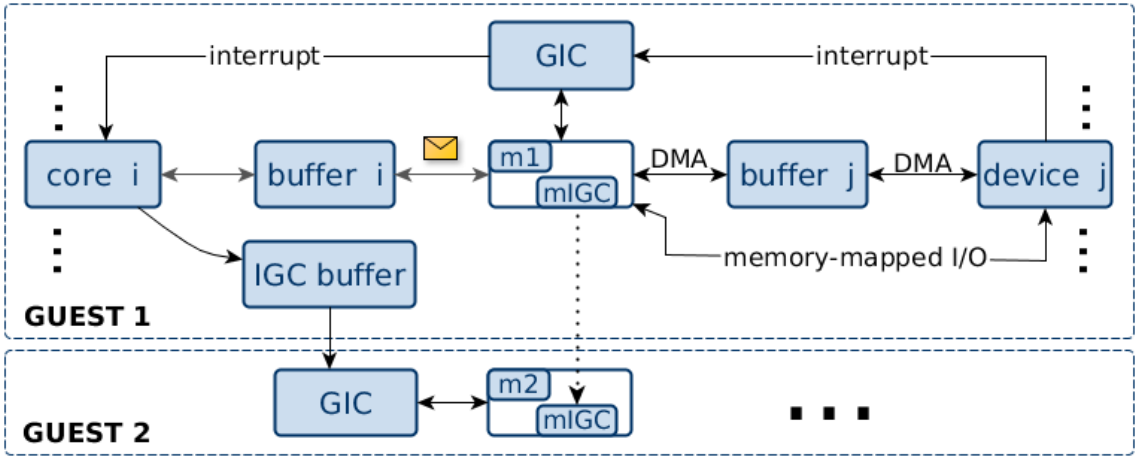

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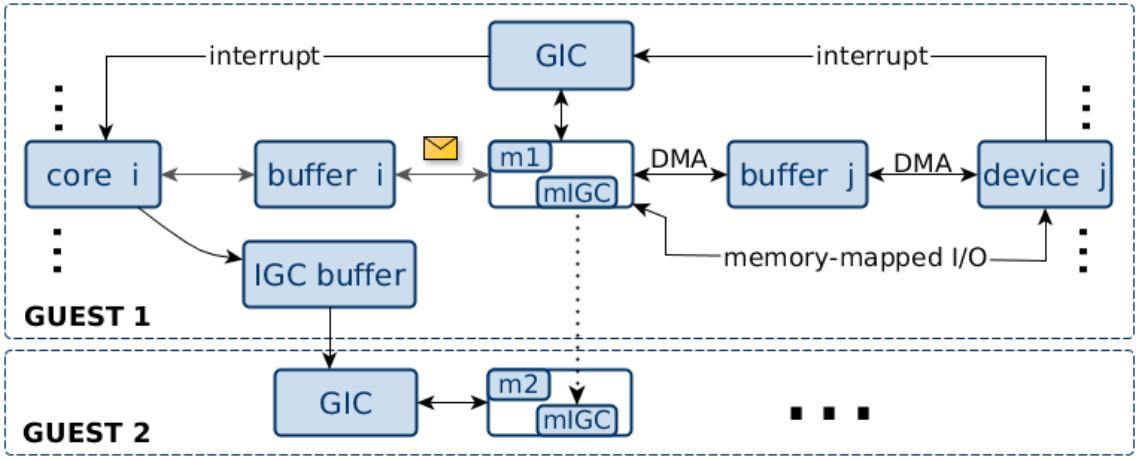

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- memory: only guest portion, intermediate physical addresses

Verification: Bisimulation Theorem

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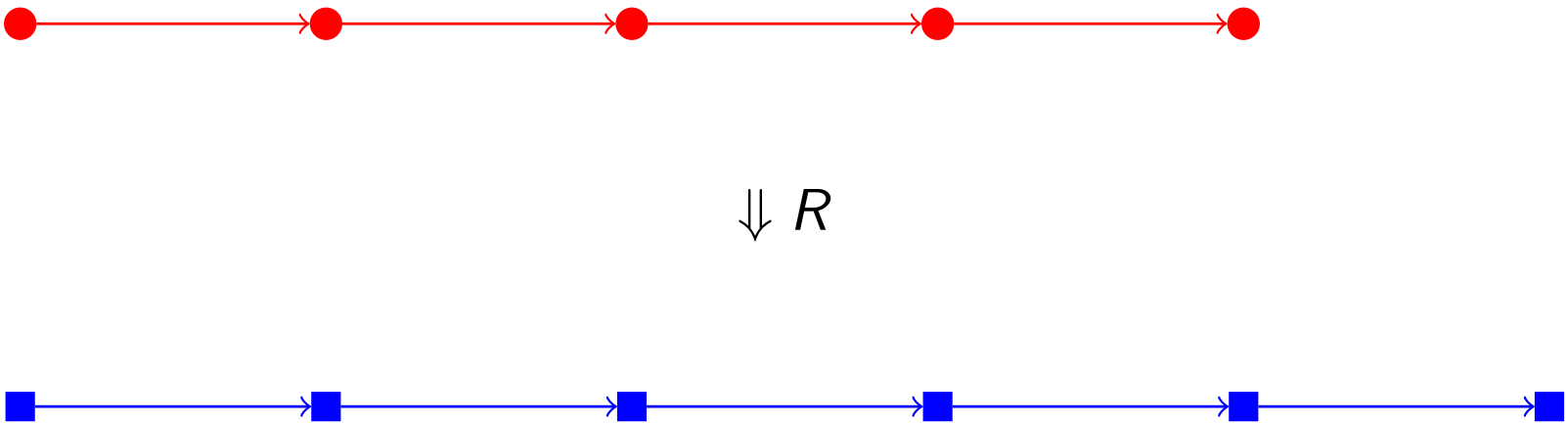

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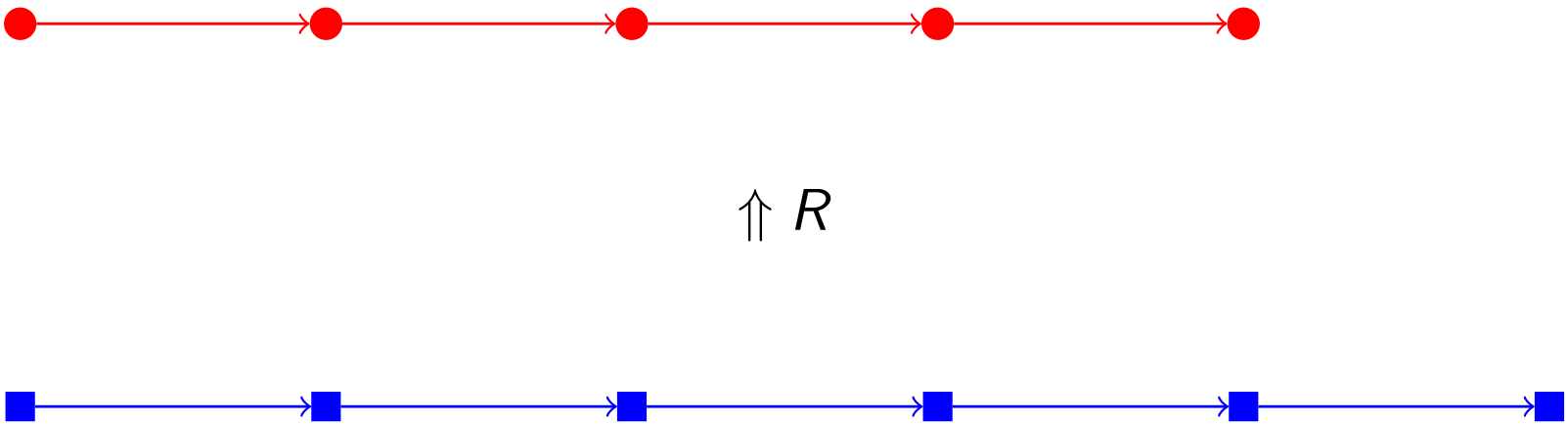

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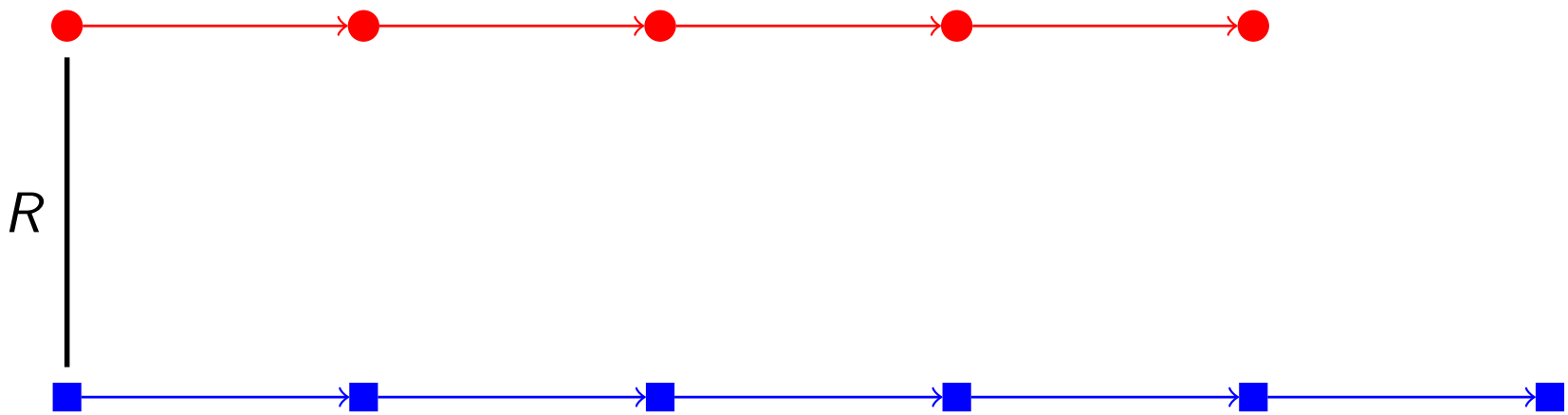

Proof by induction on transition sequence:

- for any initial state σ_P^0, $Inv(\sigma_P^0)$ and exists σ_I^0 such that $\sigma_P^0\ R\ \sigma_I^0$
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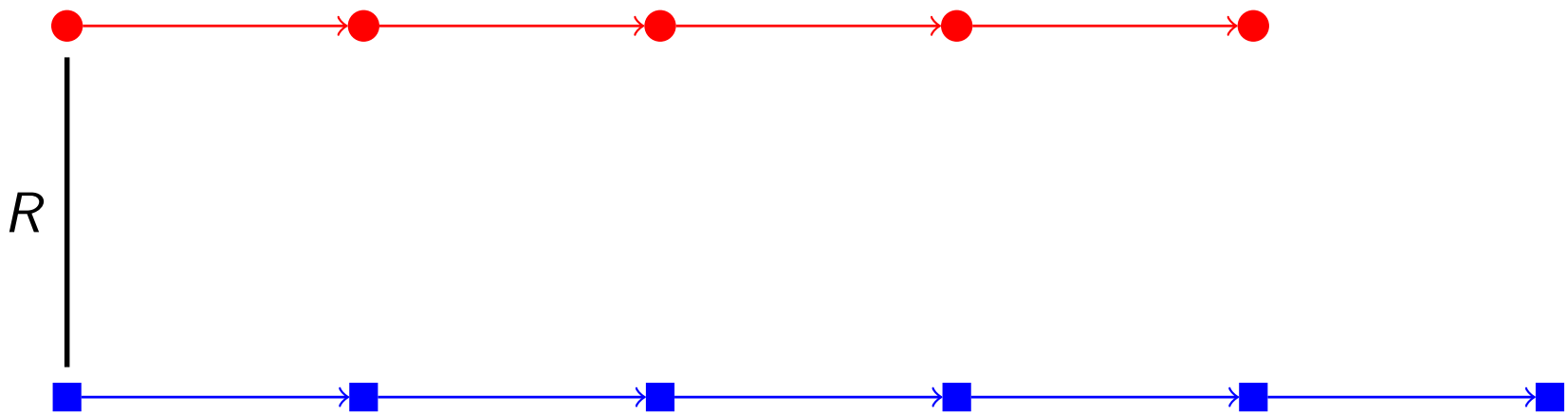

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- for σ_P and σ_I with $\sigma_P\ R\ \sigma_I$ and $Inv(\sigma_P)$:
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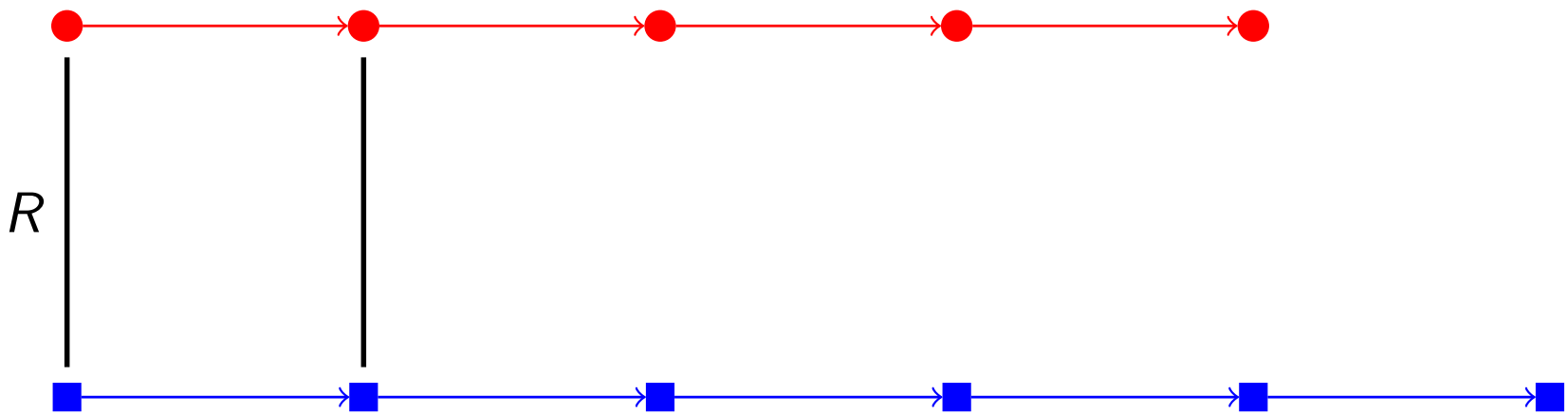

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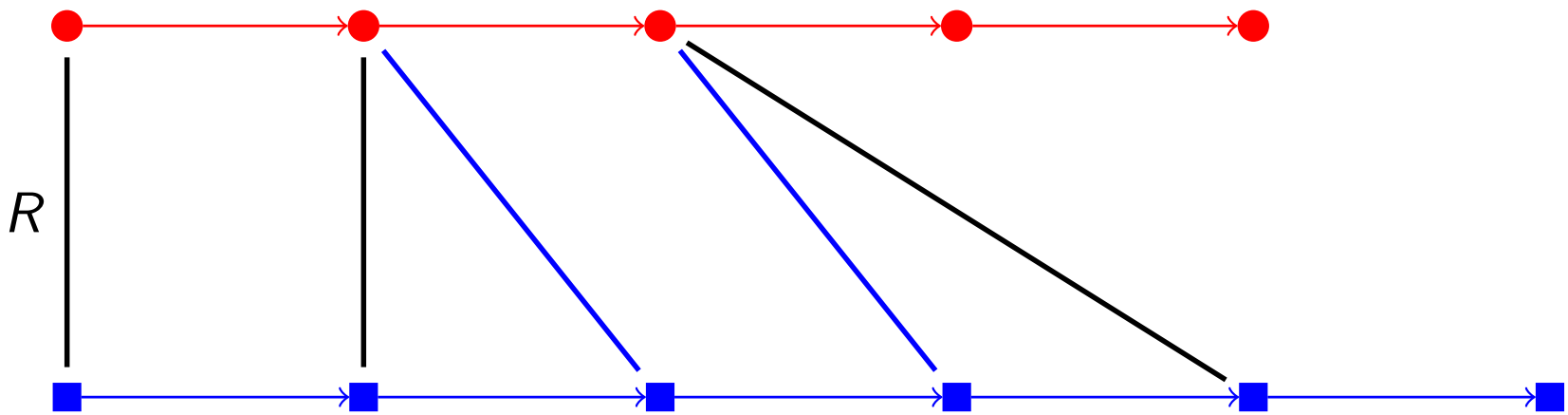

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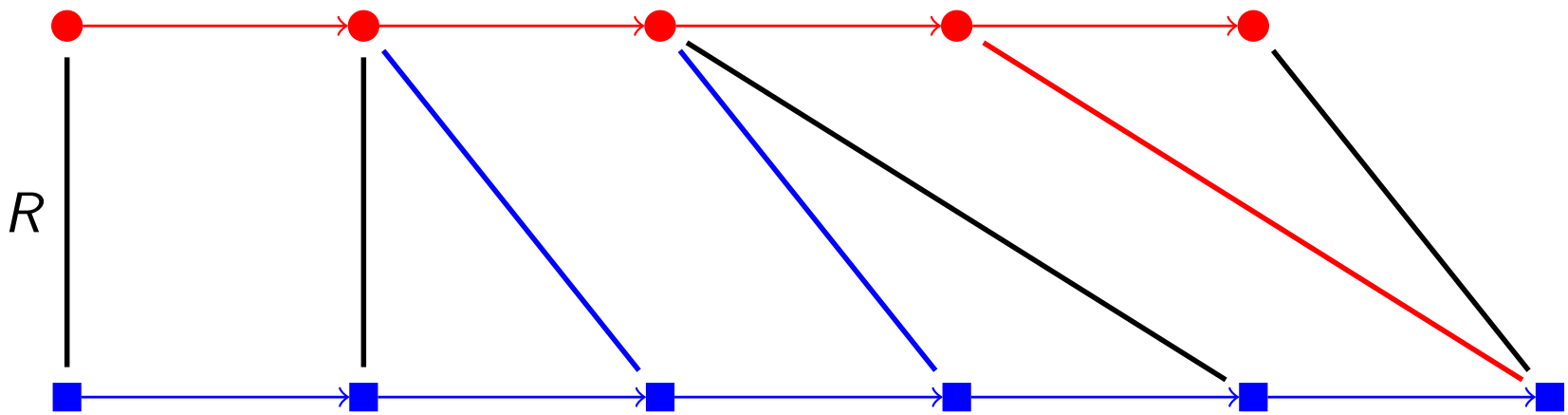

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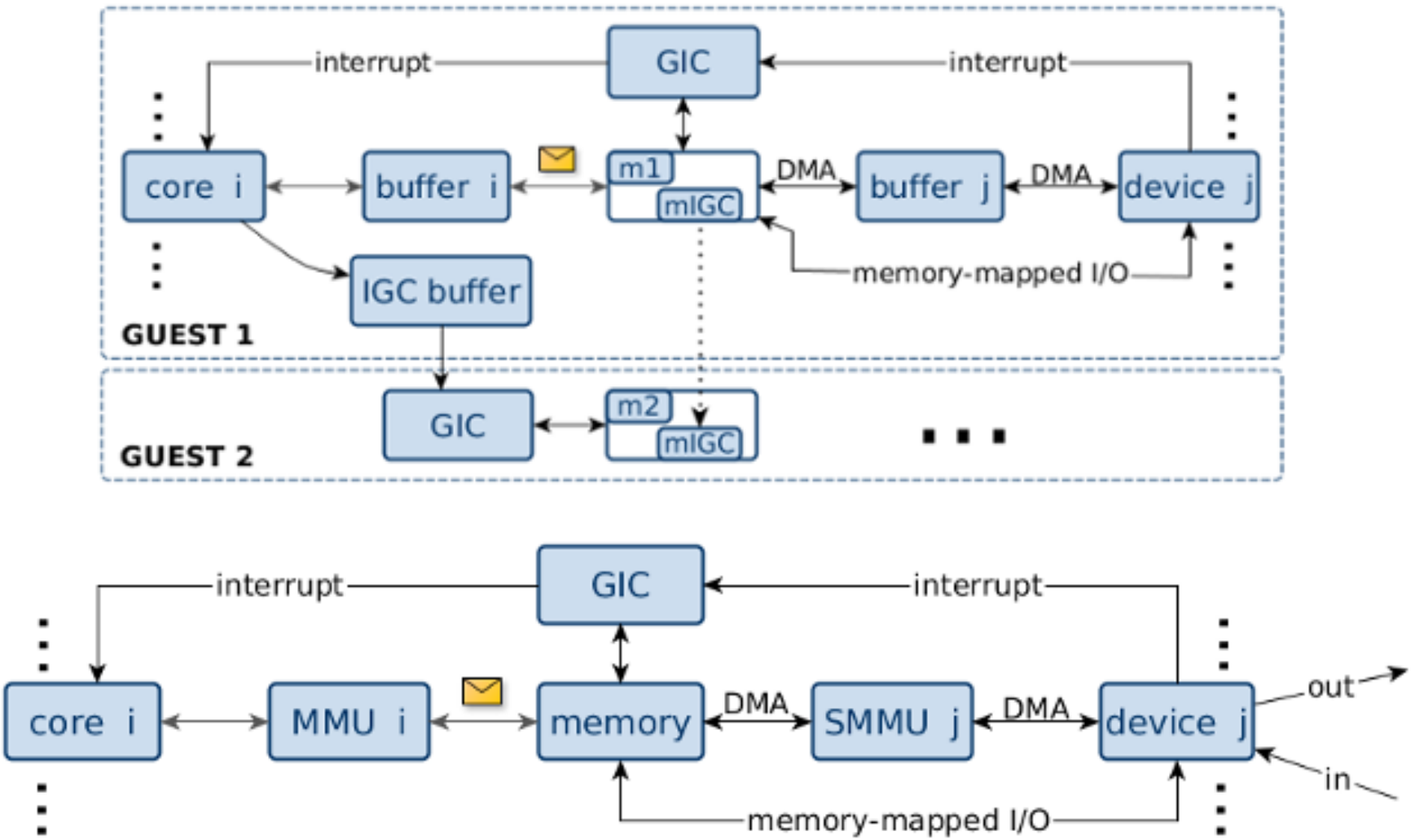
Verification: Bisimulation Relation



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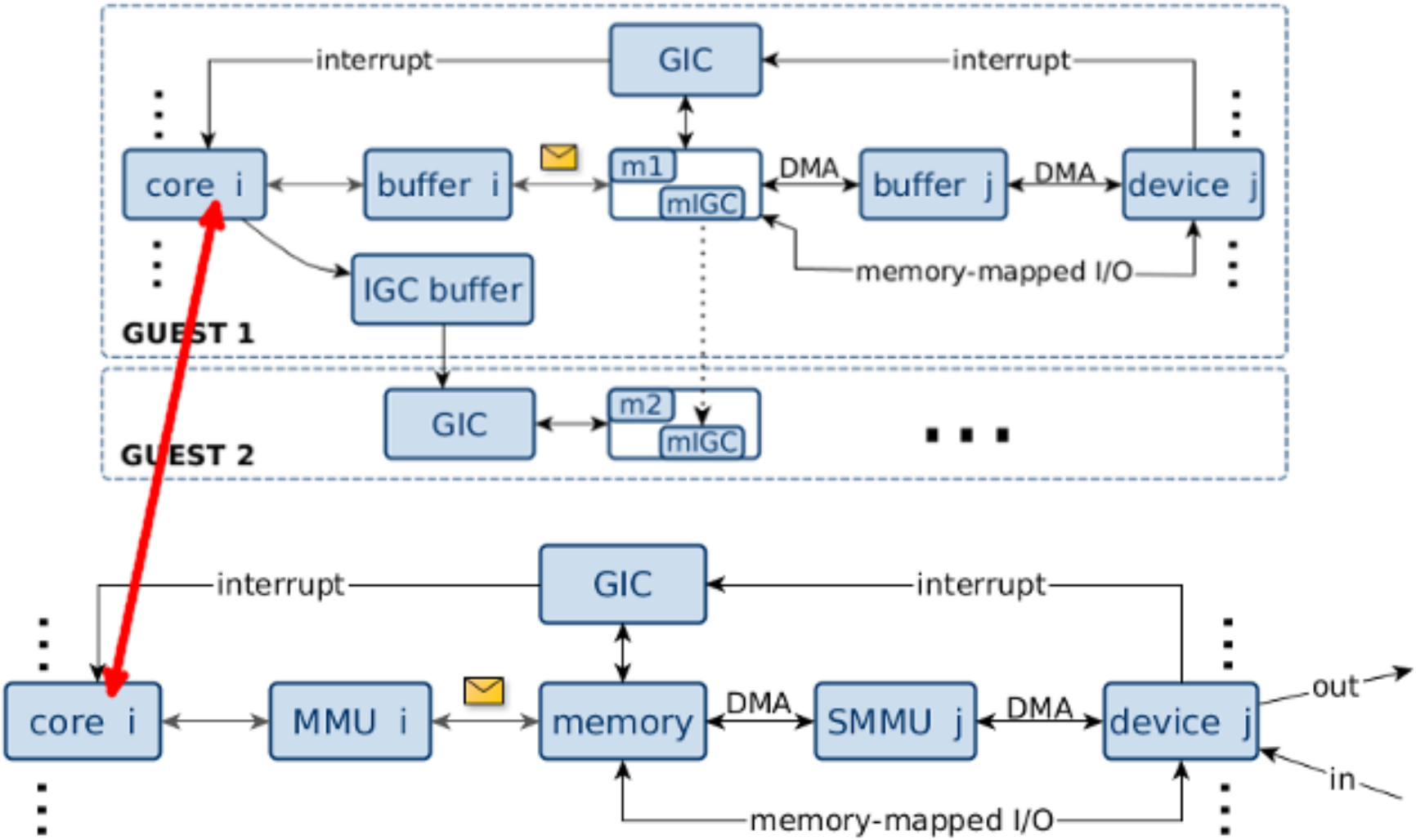

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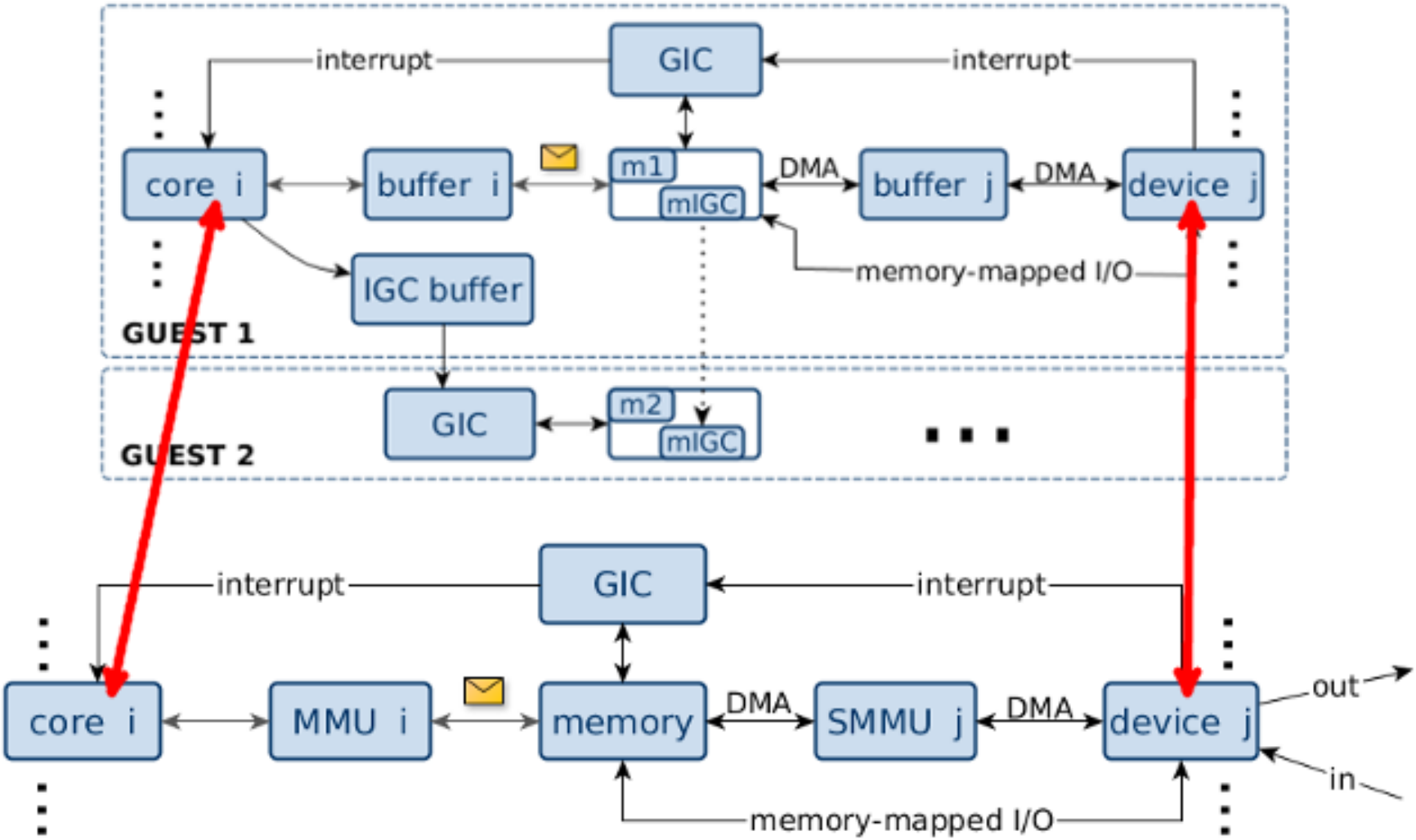

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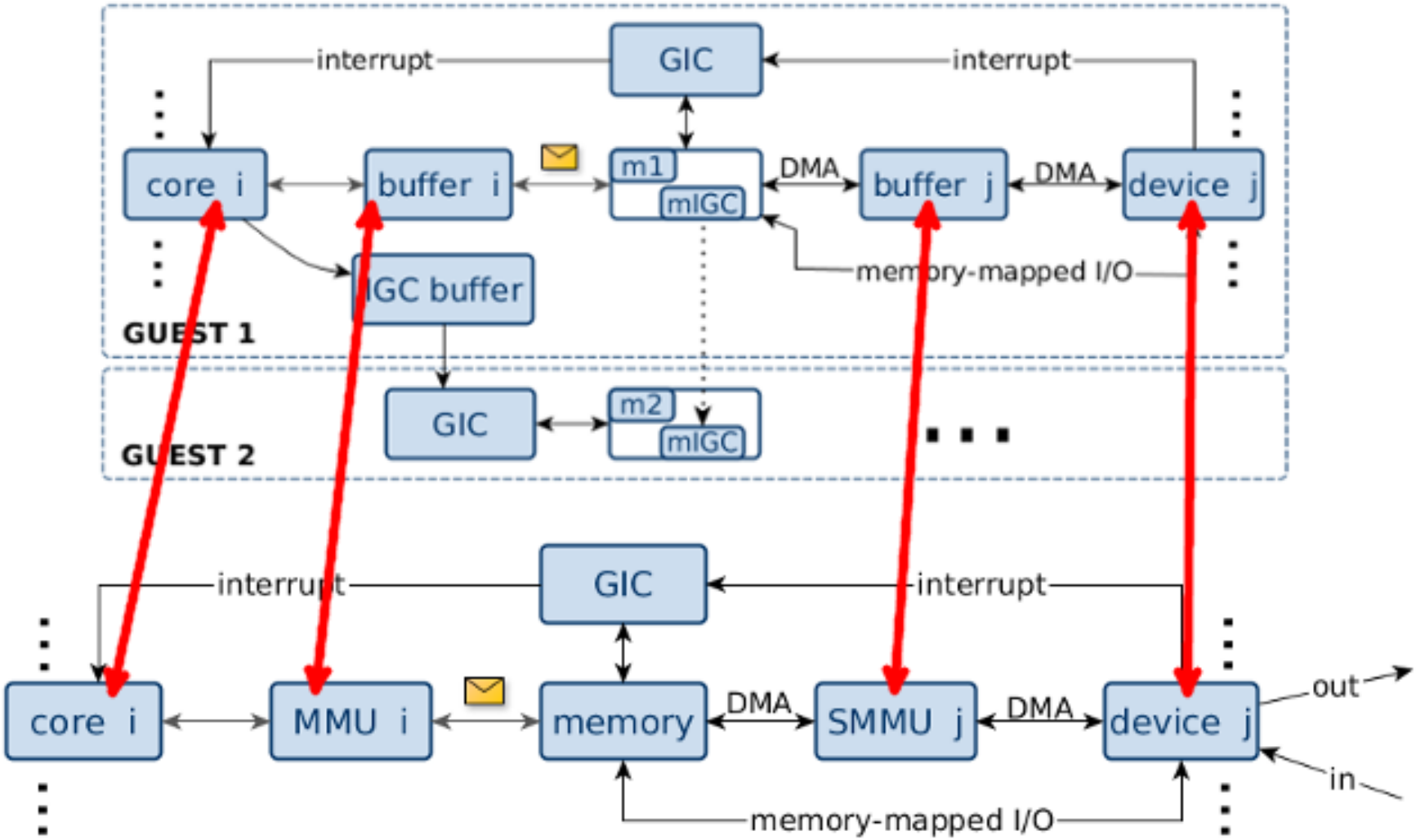

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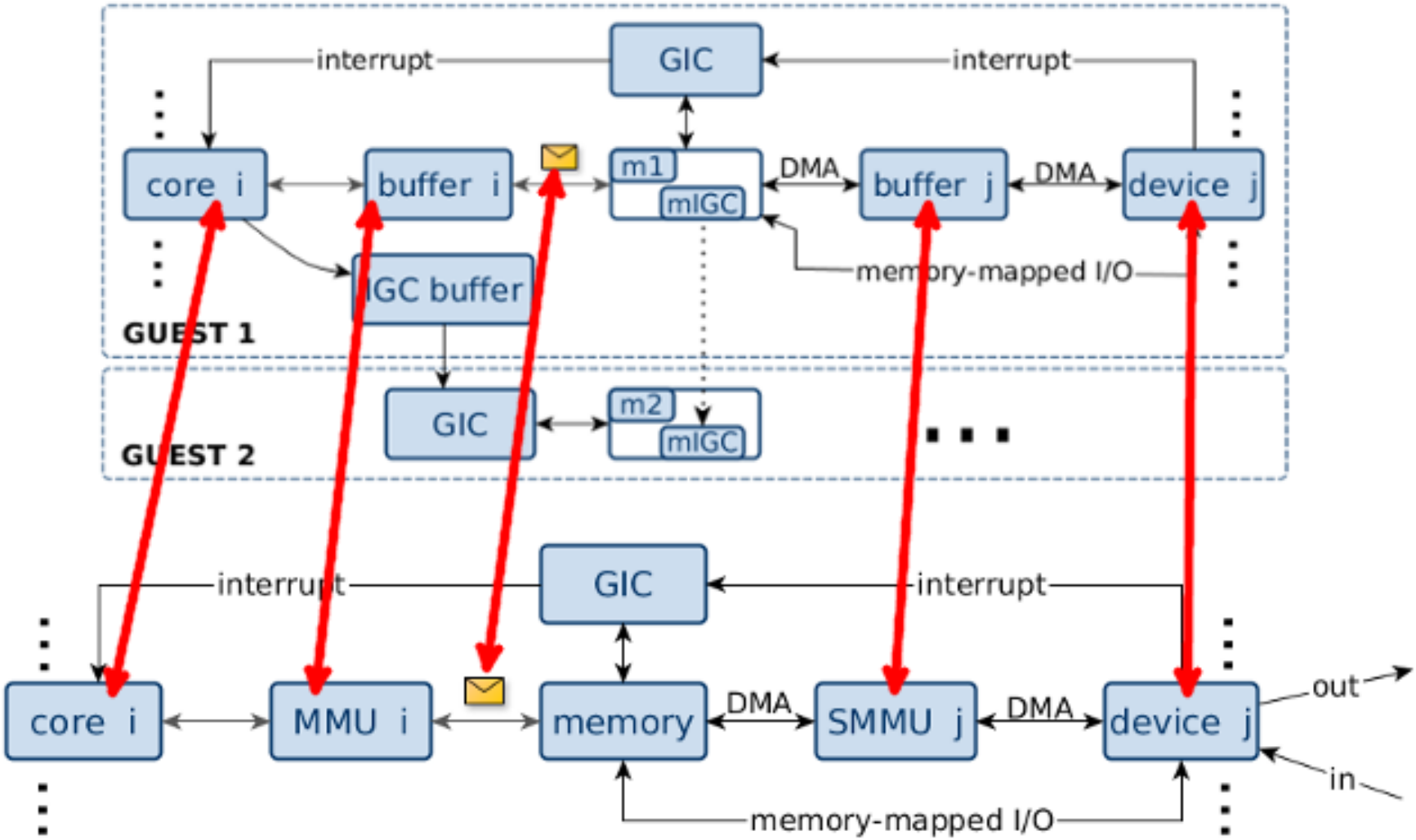

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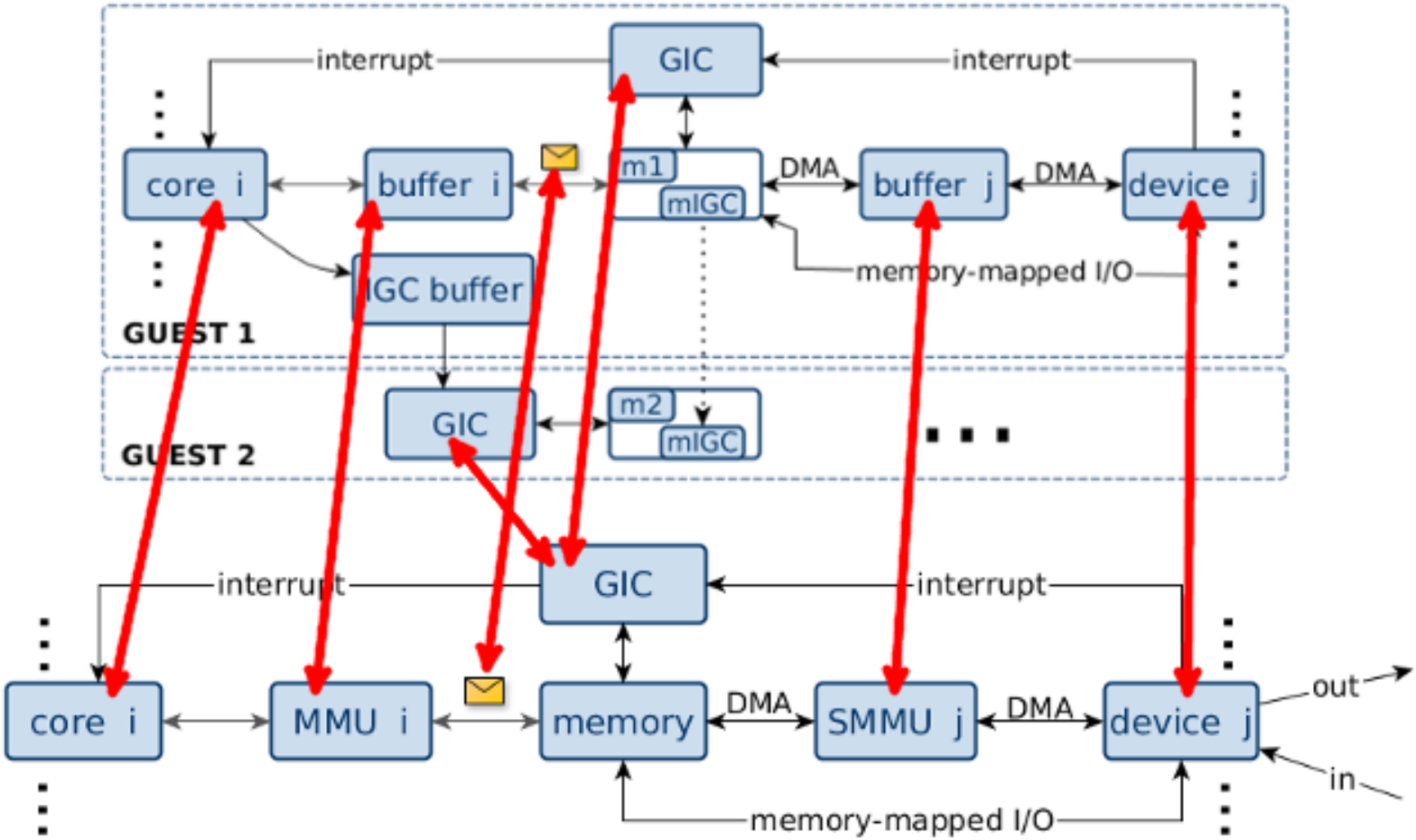

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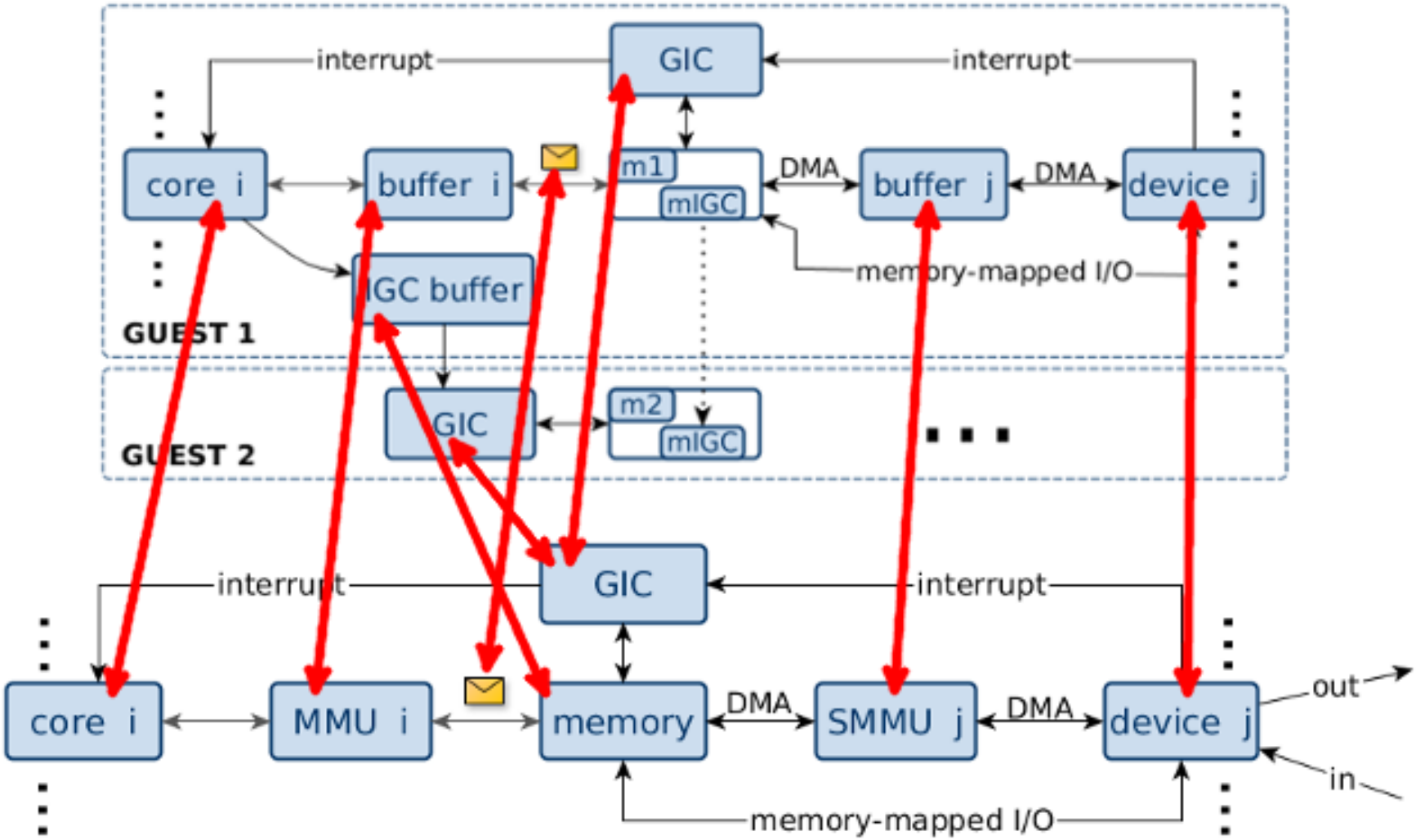

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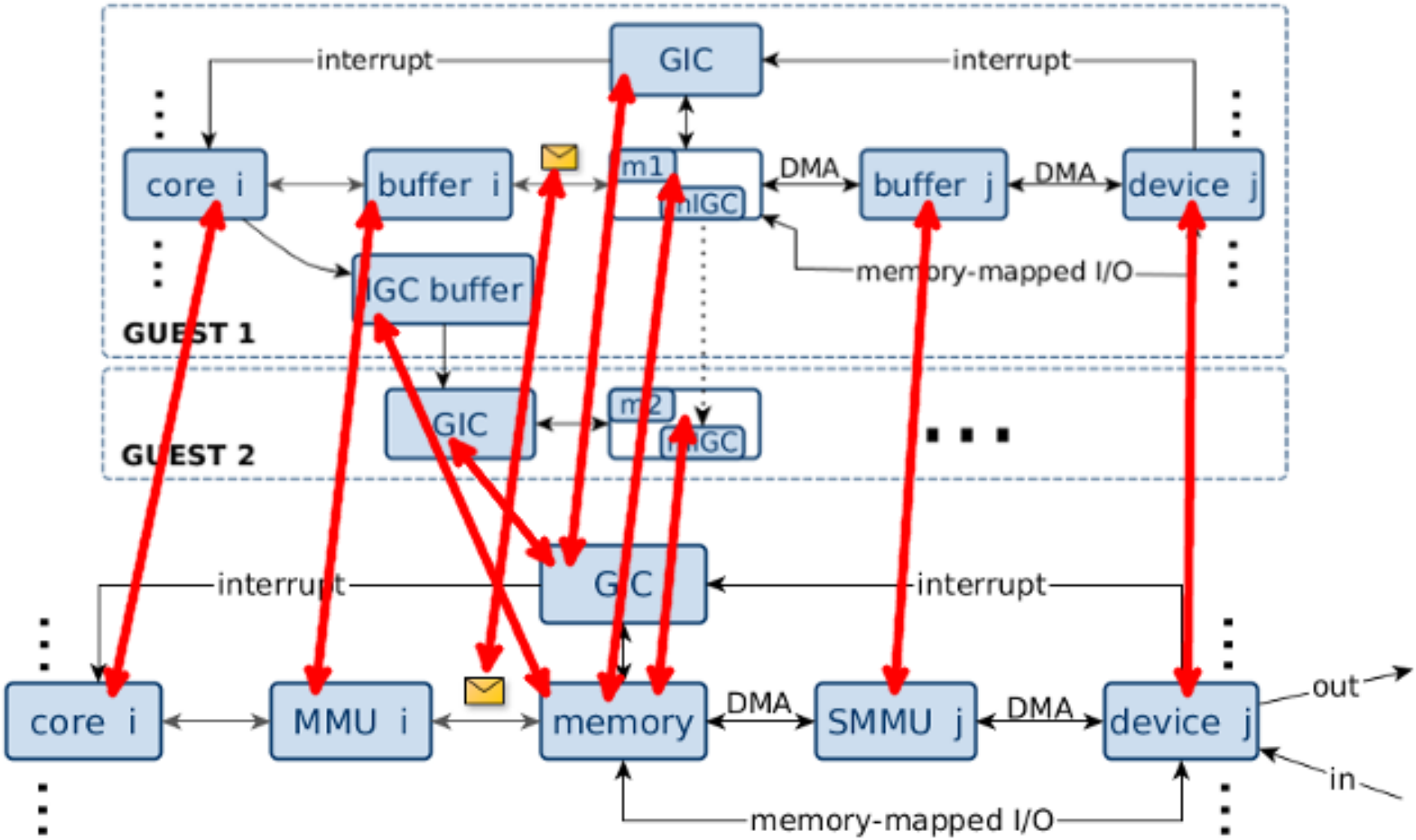
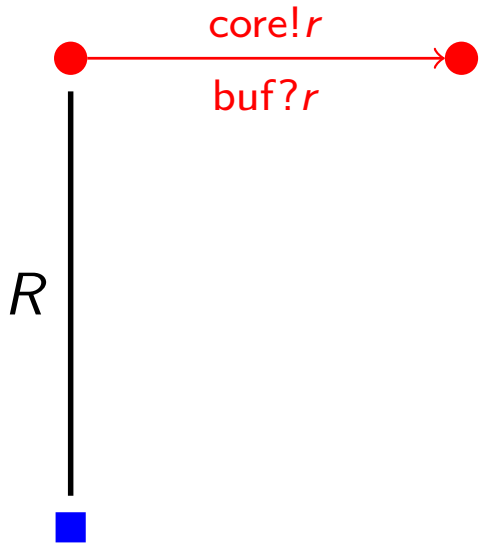
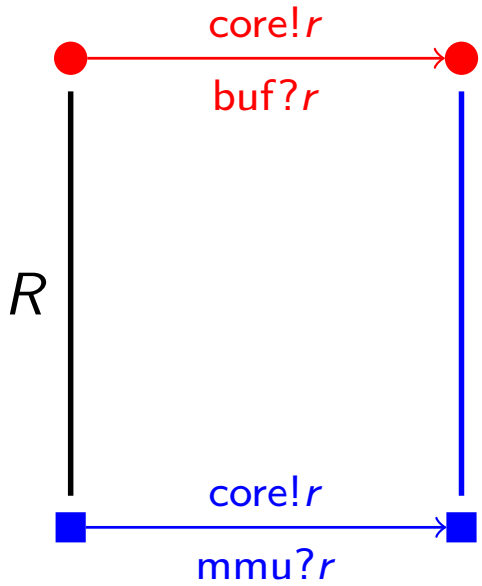


Verification: MMU steps



- ideal core sends memory request r to "MMU" buffer

Verification: MMU steps



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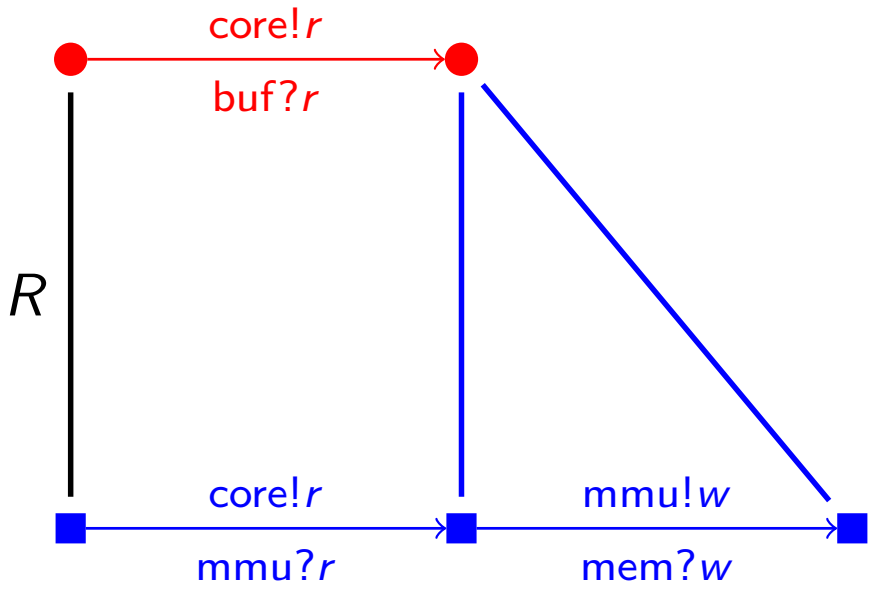

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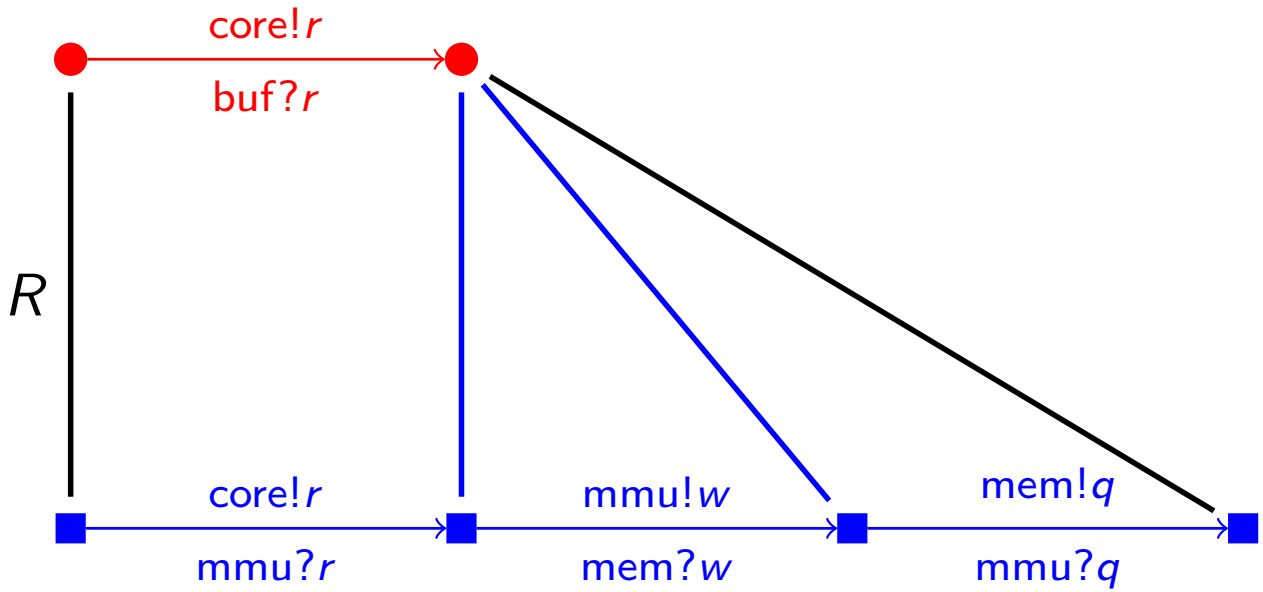

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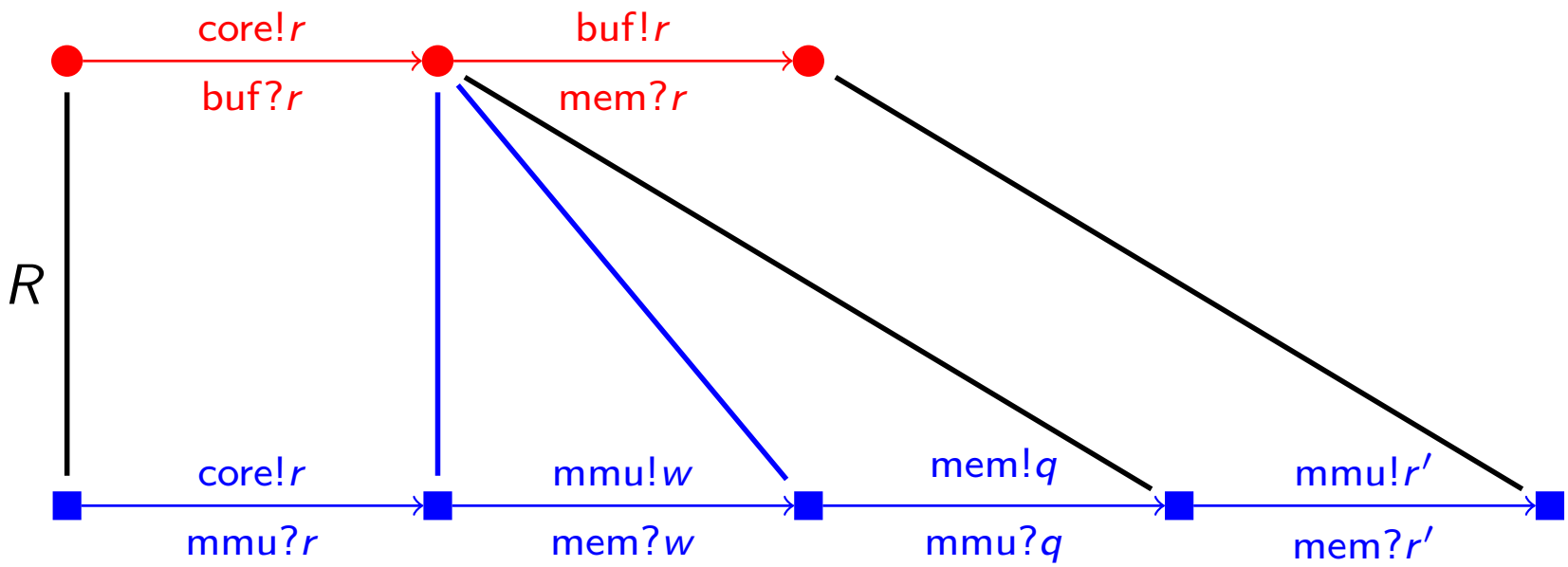

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- (translated) request forwarded to memory

Bisimulation Proof: Implementation

	basic	common	ideal	platform	hyperv.	bisim.	total
model specification	99	435	1,121	1,750	1,440	350	5,195
invariant specification	–	17	387	518	–	453	1,375
machinery	309	–	95	–	–	585	989
proofs	652	1,094	1,132	1,466	145	7,437	11,926
total	1,060	1,546	2,735	3,734	1,585	8,825	19,485

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- implemented in HOL4 theorem prover
- most important cases verified
- first steps towards automation
- simplifier and resolution solvers for trivial cases
- proofs robust against local changes
- lots of technical lemmas

Assumptions and Caveats

- flat memory model

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- one core memory request at a time

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- flat memory model
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Conclusion & Future work

Summary:

- compositonal approach to SoC modeling for security verification
- reusability of models, adaptability of proofs
- top-down approach, abstraction and late refinement
- early identification of invariants and proof obligations
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TODOs:

- generalized formal framework, DSLs
- more automation
- advanced hardware features
- refinement of components
- property transfer

THANKS!

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