NICTA

Let's build secure systems on a correct kernel

June Andronick

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Australian Government
Department of Broadband, Communications and the Digital Economy
Australian Research Council

NICTA Funding and Supporting Members and Partners

Credits

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Gerwin Klein

(part of) the Trustworthy Embedded Systems crowd

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Agenda

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Secure Systems "à la NICTA"

For 1 critical system:

- 1 desired security property P
- an interactive theorem prover
- a bit of patience

1. carefully design your system
2. prove that the design enforces P
3. prove correctness of the TCB
4. prove isolation

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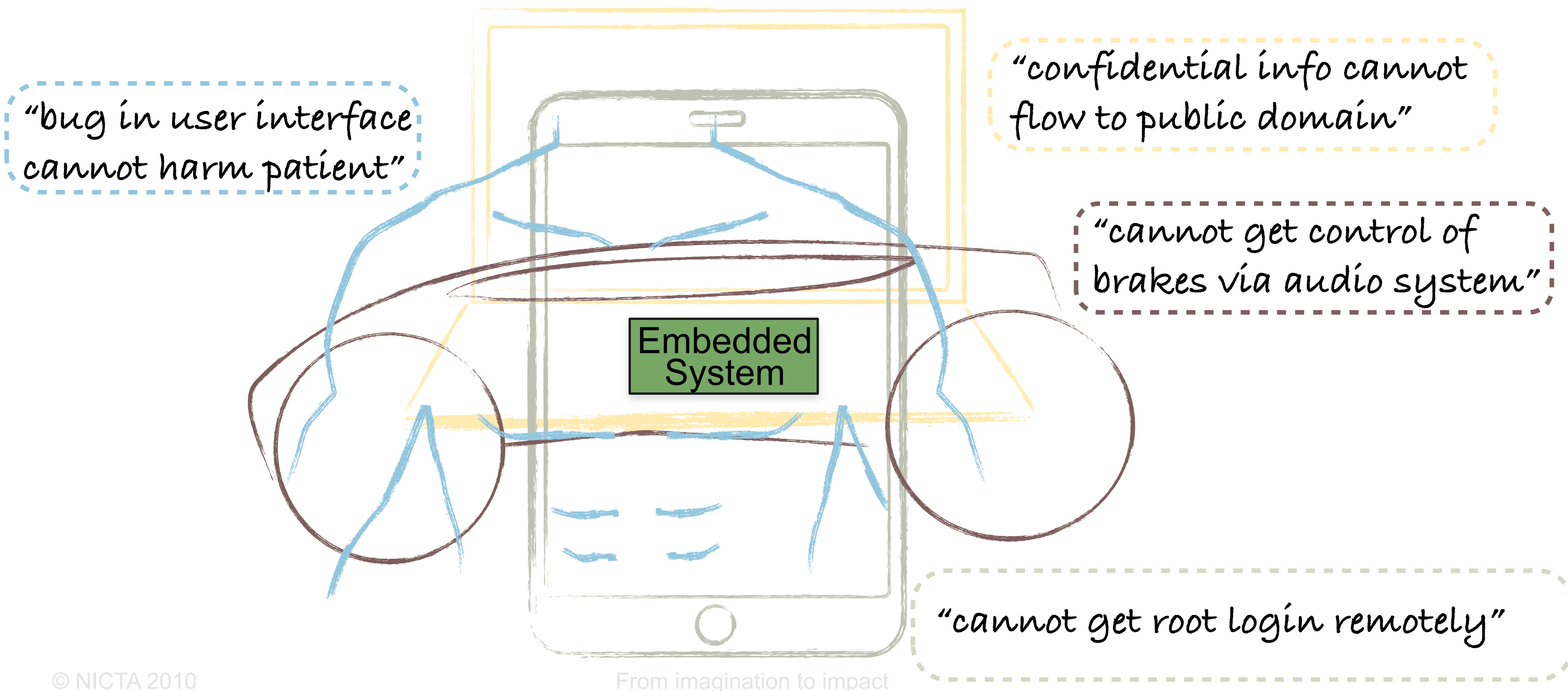
Motivation

Aim: Trustworthy Embedded Systems

Target: code-level guarantee at reasonable cost — real-world, usable systems (low-level, performant)



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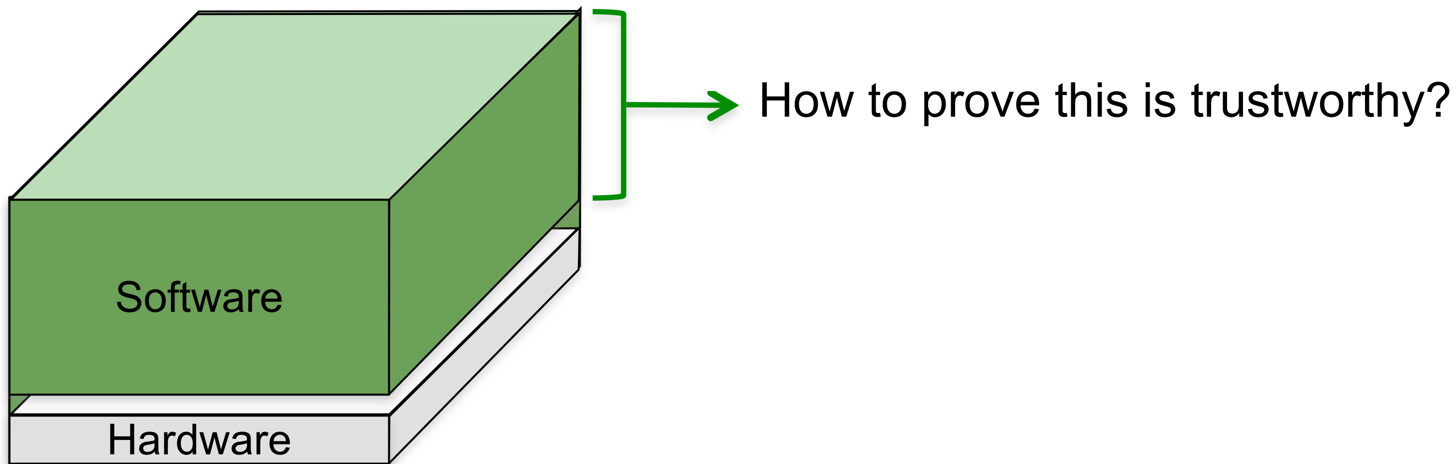
Approach



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Approach

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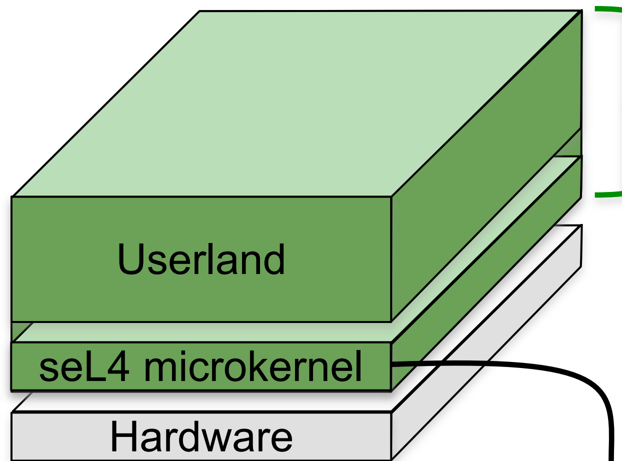

How to prove this is trustworthy?

1. Trustworthy foundation → **seL4**

functional correctness for 10,000 loc

Formal functional spec

Formal proof of refinement

Code

L4.verified

Result: "Every behavior of the code is a behavior of the spec"

Corollary: "execution always defined" (no buffer overflows, …)

Assumptions:
- compiler + linker
- assembly code (600 loc)
- hardware (ARMv6)
- cache/TLB
- boot code (1,200 loc)

WORK IN PROGRESS

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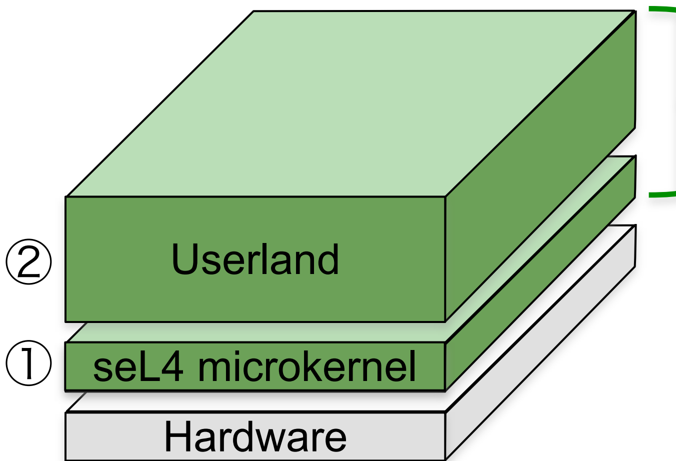
Approach



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   functional correctness for 10,000 loc

2. Strategic componentized security architecture

   formal guarantees for >1,000,000 loc

Idea: Strong *guarantees* about *whole system* without needing to reason about all of its code

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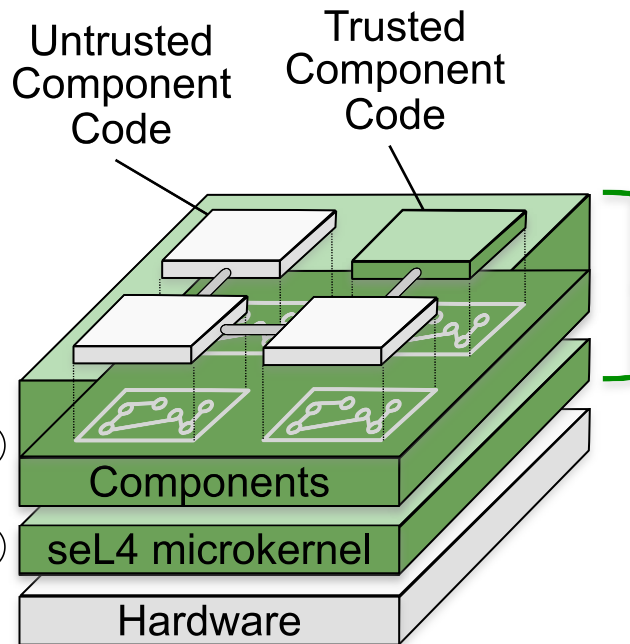
Approach



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   functional correctness for 10,000 loc

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   formal guarantees for >1,000,000 loc

Idea: Strong *guarantees* about *whole system* without needing to reason about all of its code

How: Using seL4's access control (*capabilities*)

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Approach

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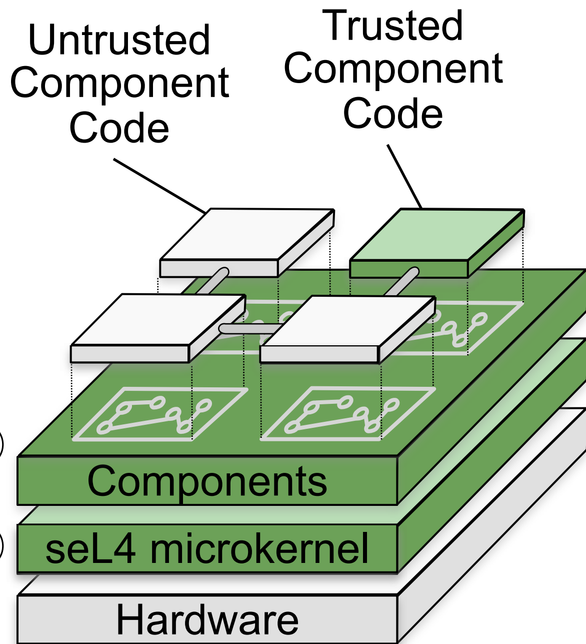

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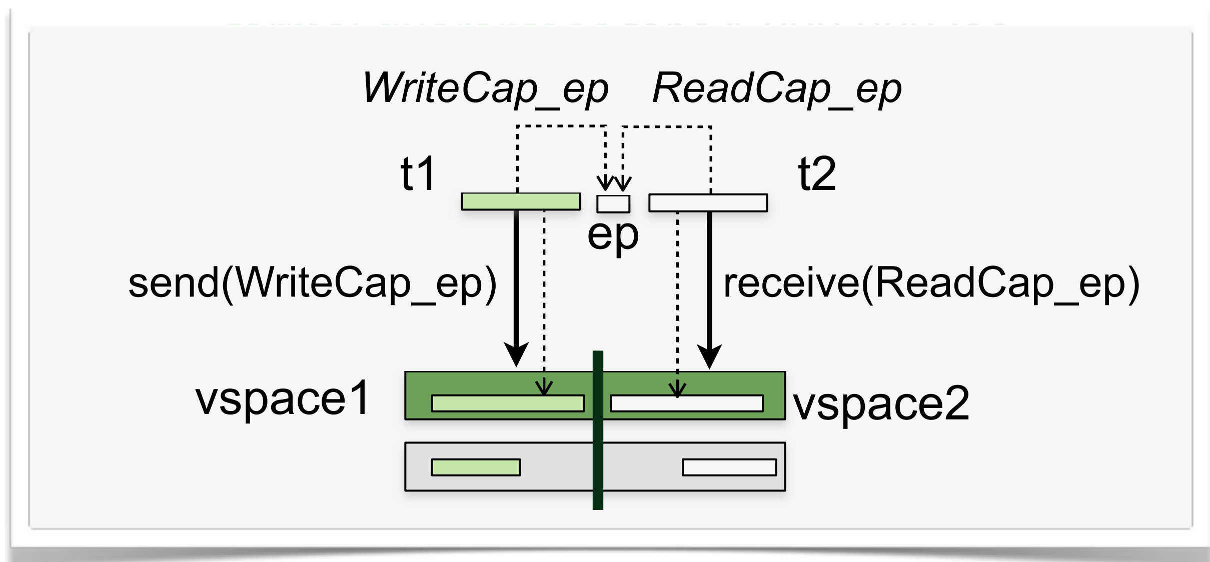

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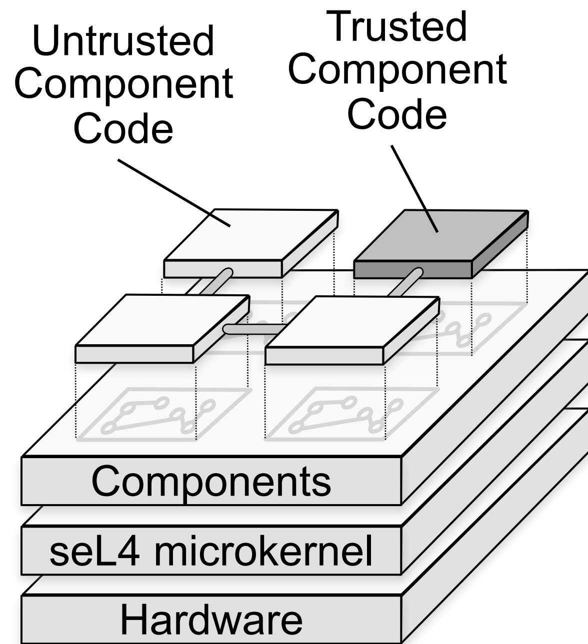
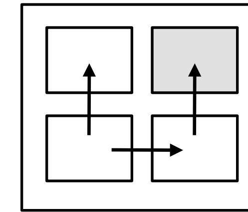
Careful design



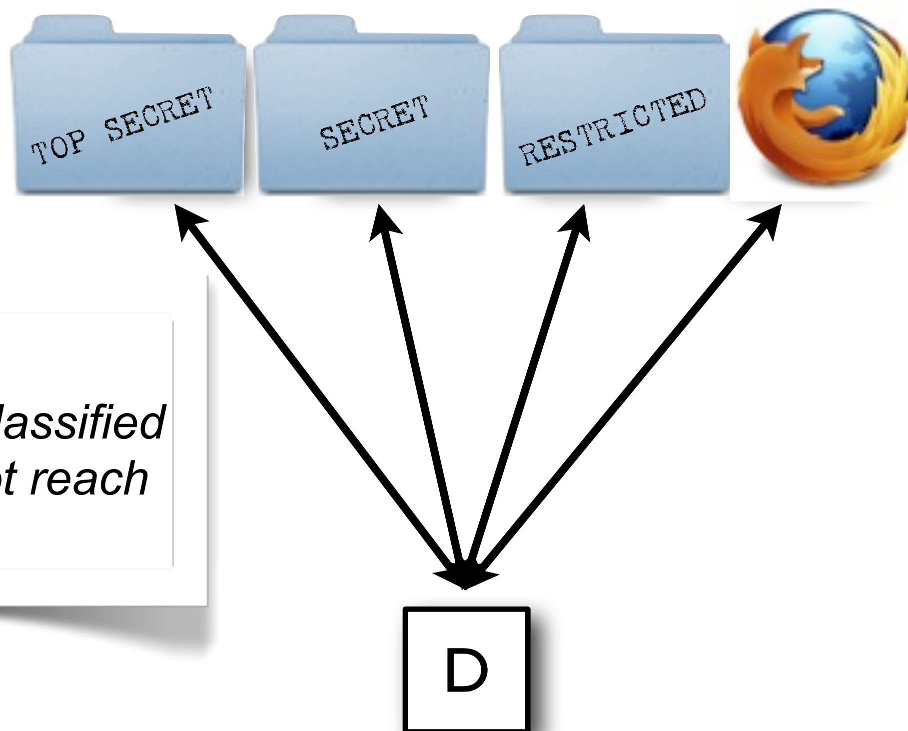
System Implementation

Security Architecture



1a. minimal Trusted Computing Base

Case-study



Goal:

Data from one classified network must not reach another

Secure Access Controller (SAC)

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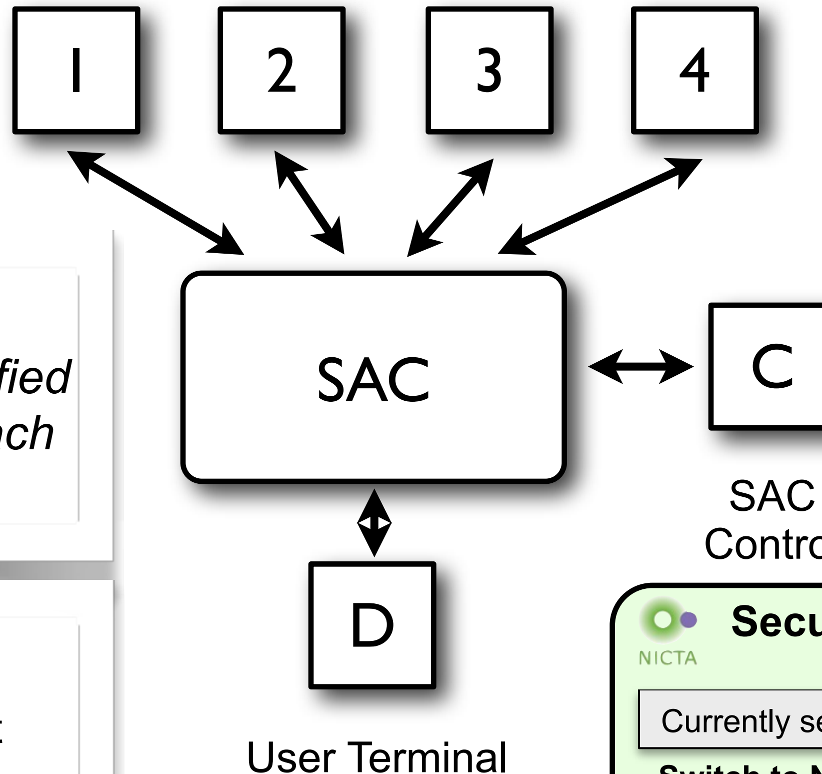
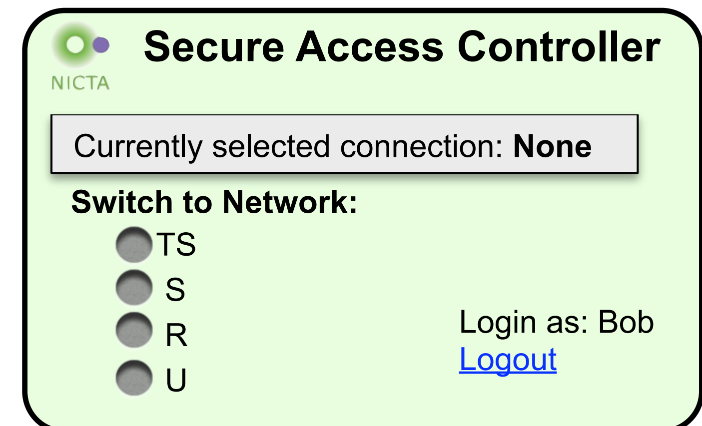
Goal:

Data from one classified network must not reach another

Assumptions:

- User terminal will not leak data
- All networks are otherwise malicious





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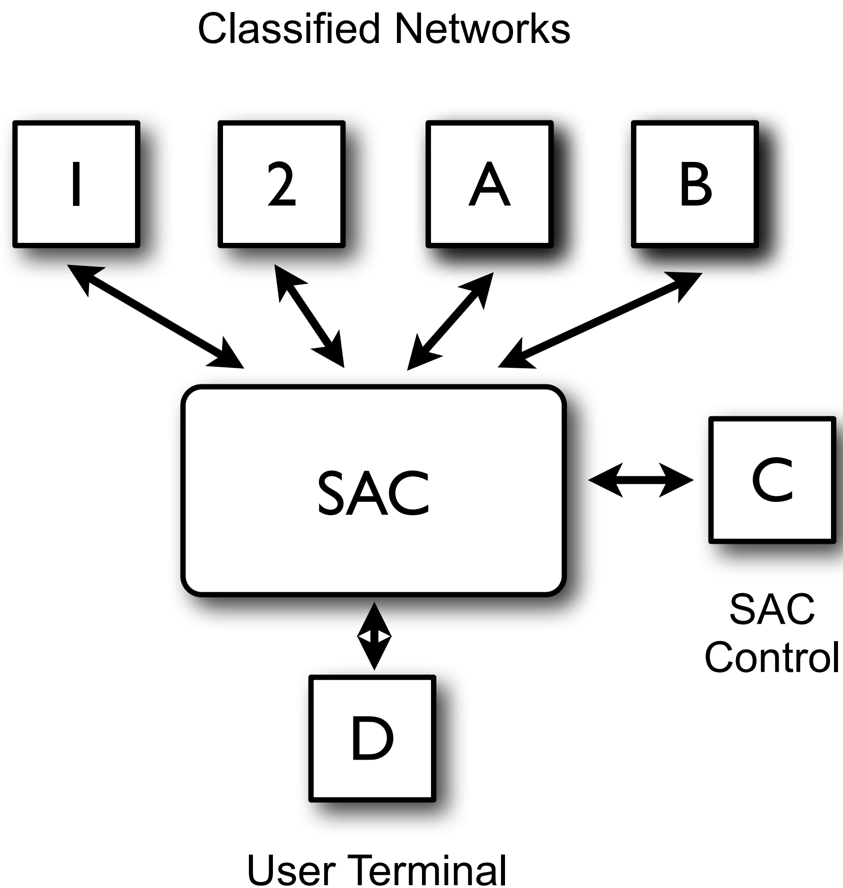
Design



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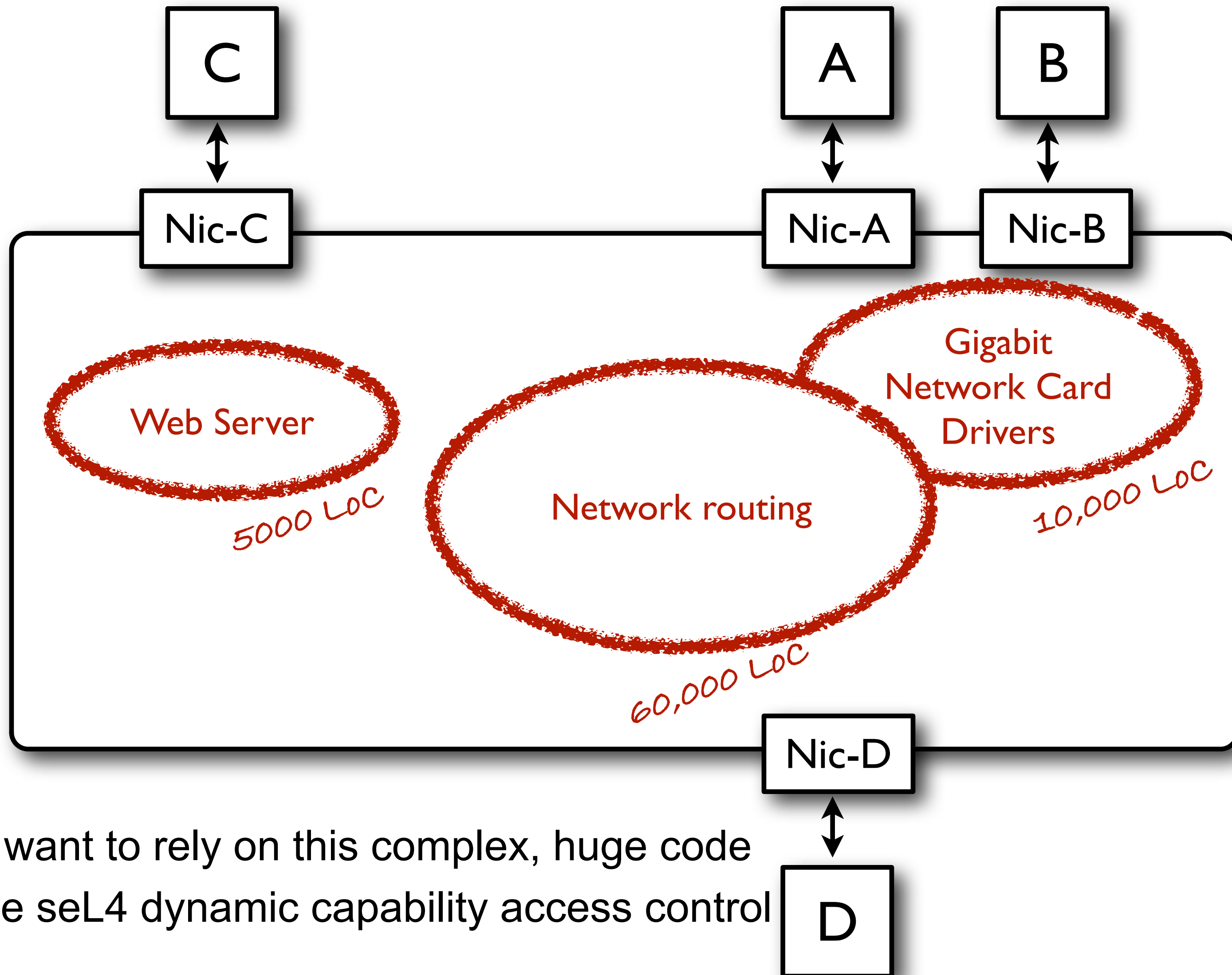
Minimal TCB



We don't want to rely on this complex, huge code

➜ We use seL4 dynamic capability access control

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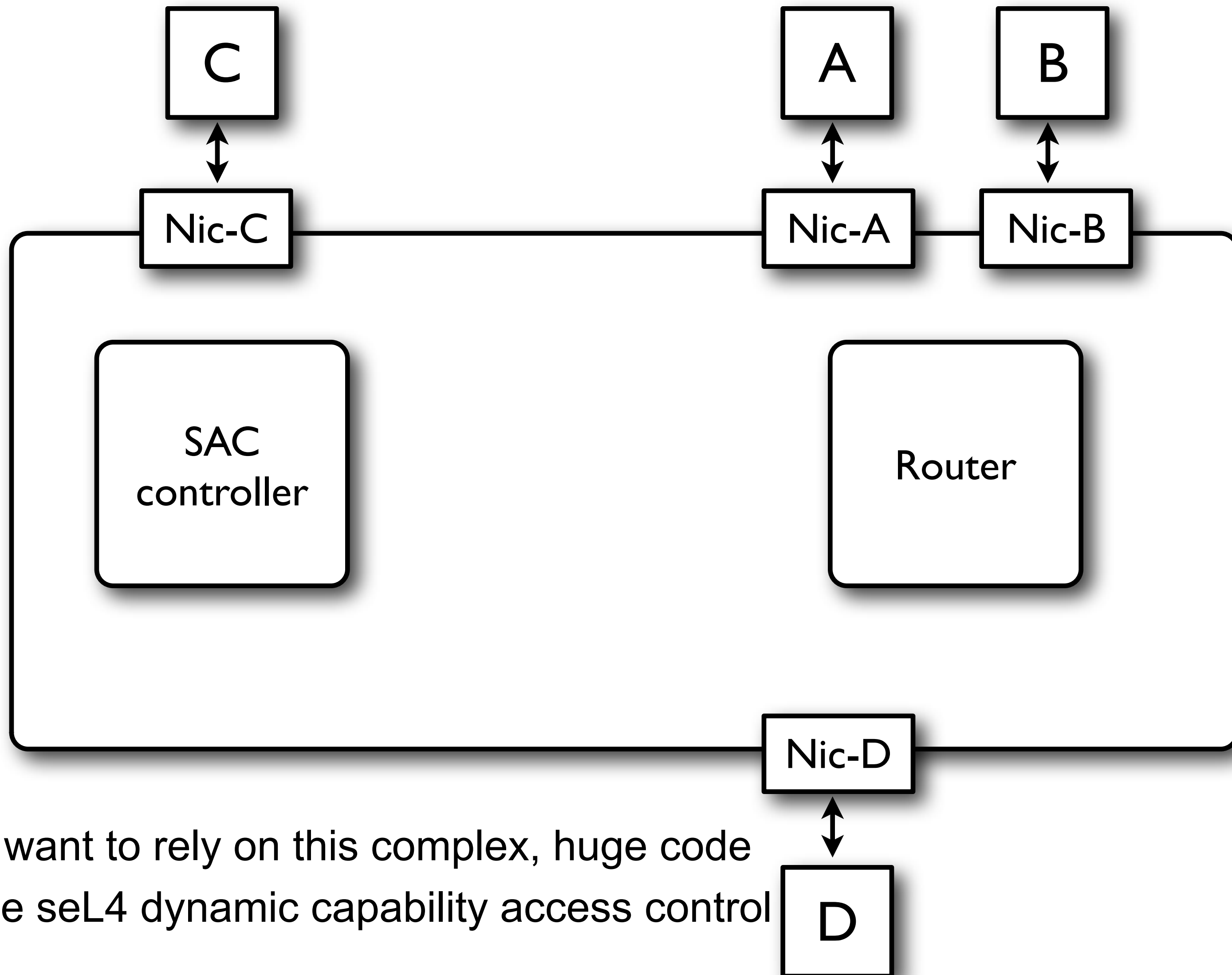
Minimal TCB



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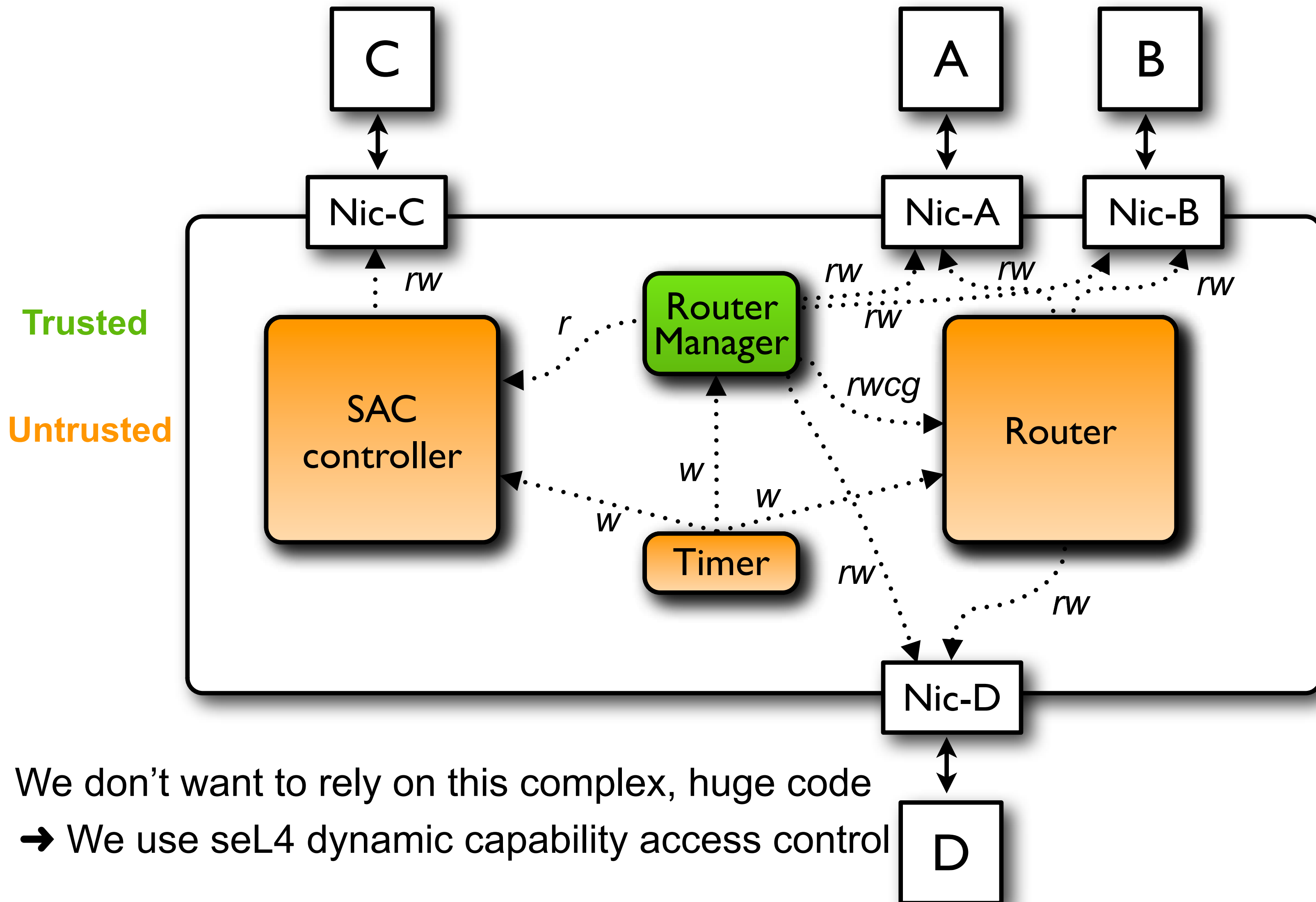
Minimal TCB



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Minimal TCB: Implementation

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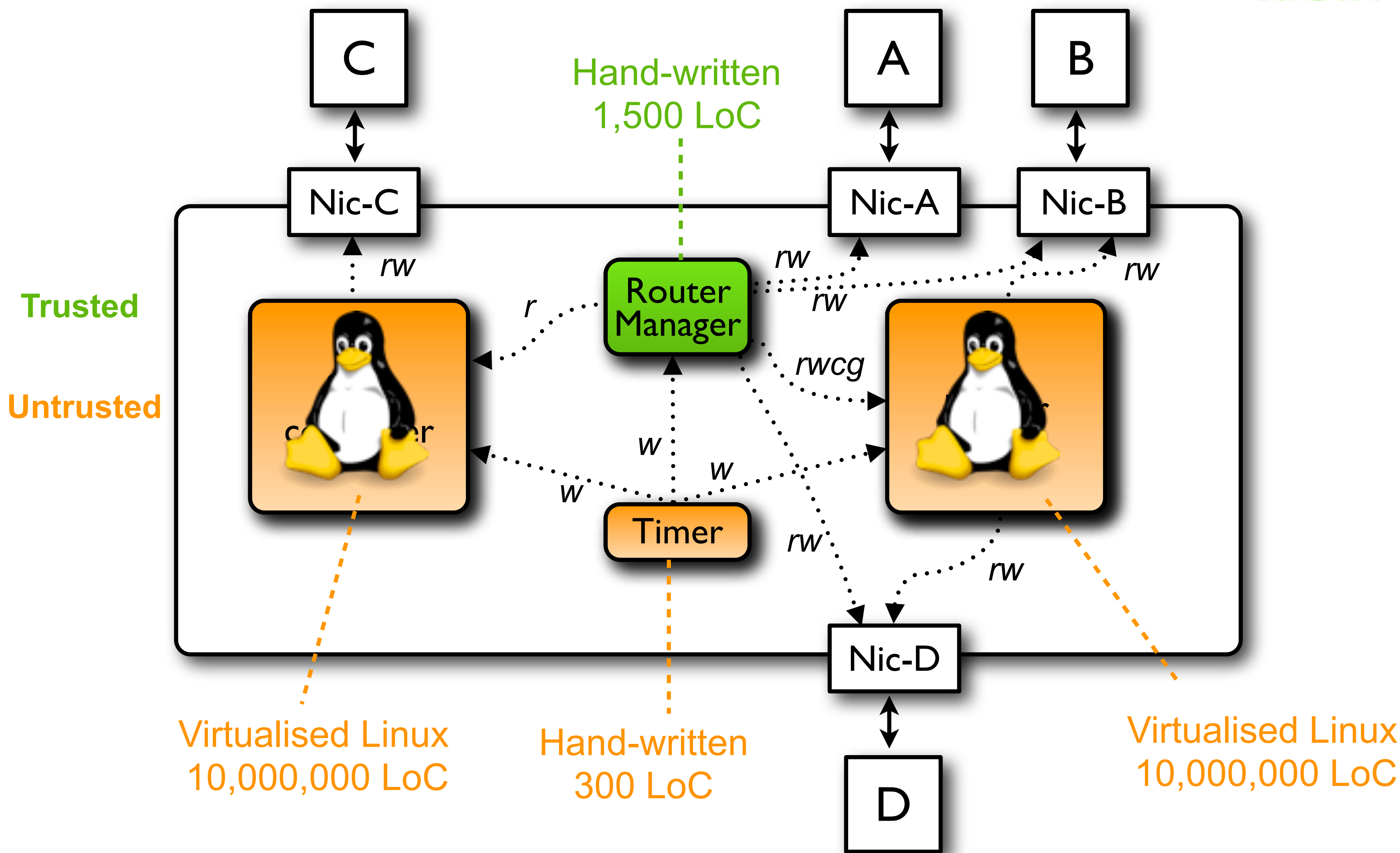

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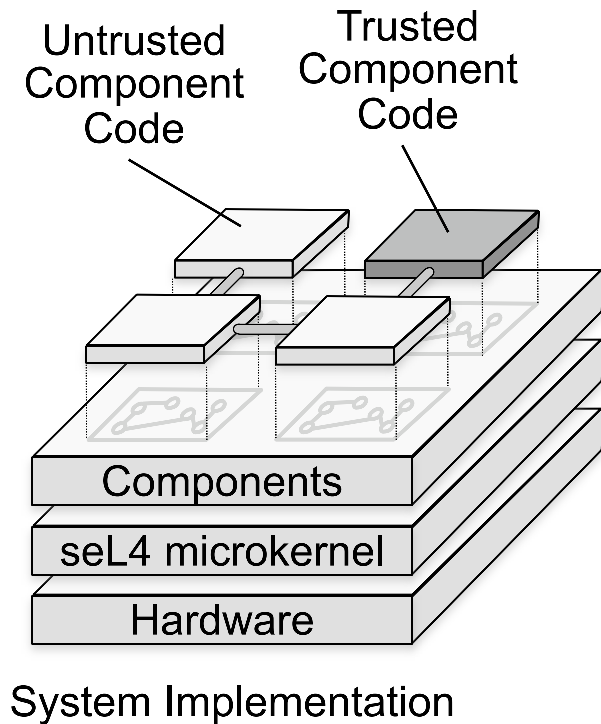
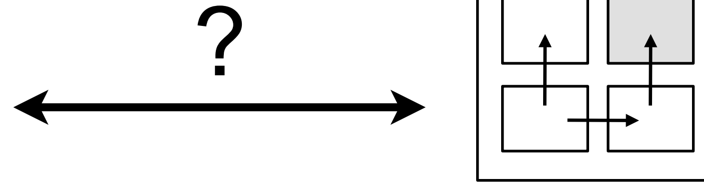
Back to the general picture



Security Architecture



1a. minimal Trusted Computing Base ✓

Now: how to set-up the system with this design?

Problem: reality is not that simple

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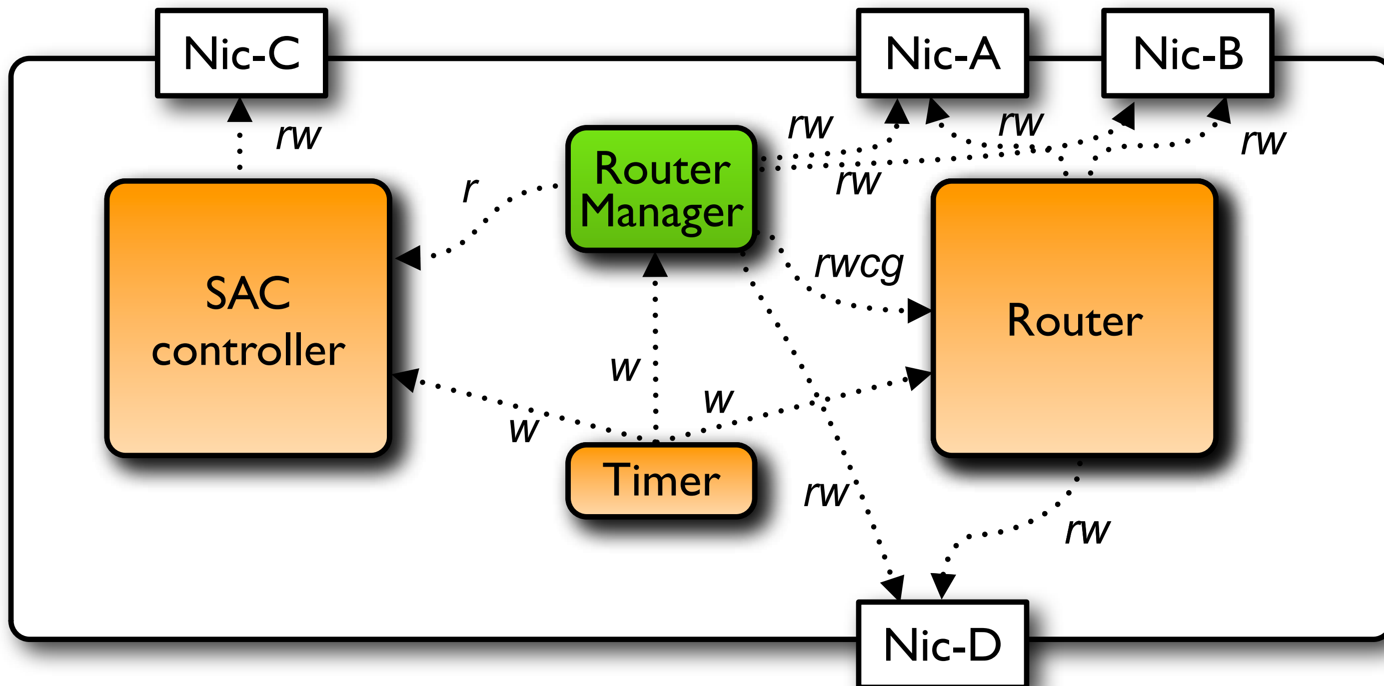
Back to the example

This is what we agree on the whiteboard

Now we need to implement this with actual kernel objects



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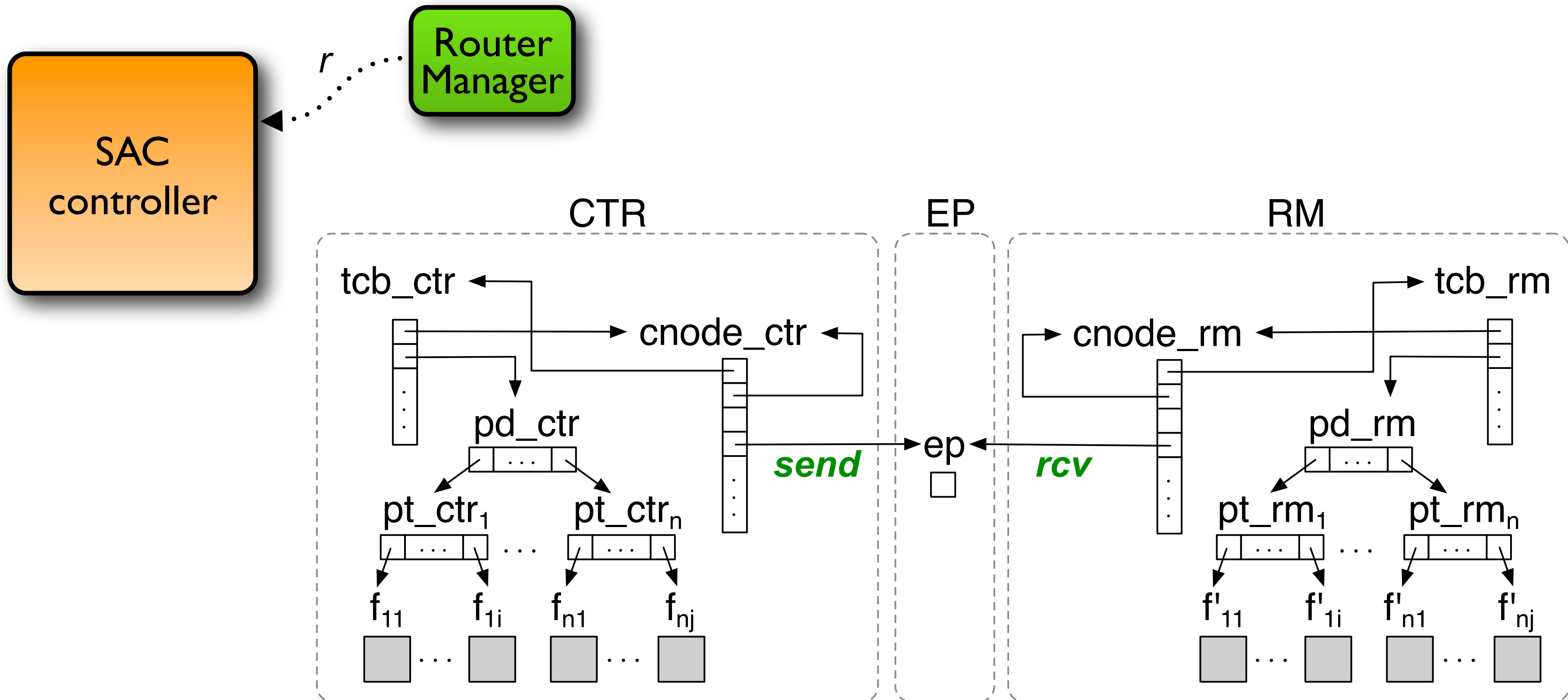

Every arrow is a capability!

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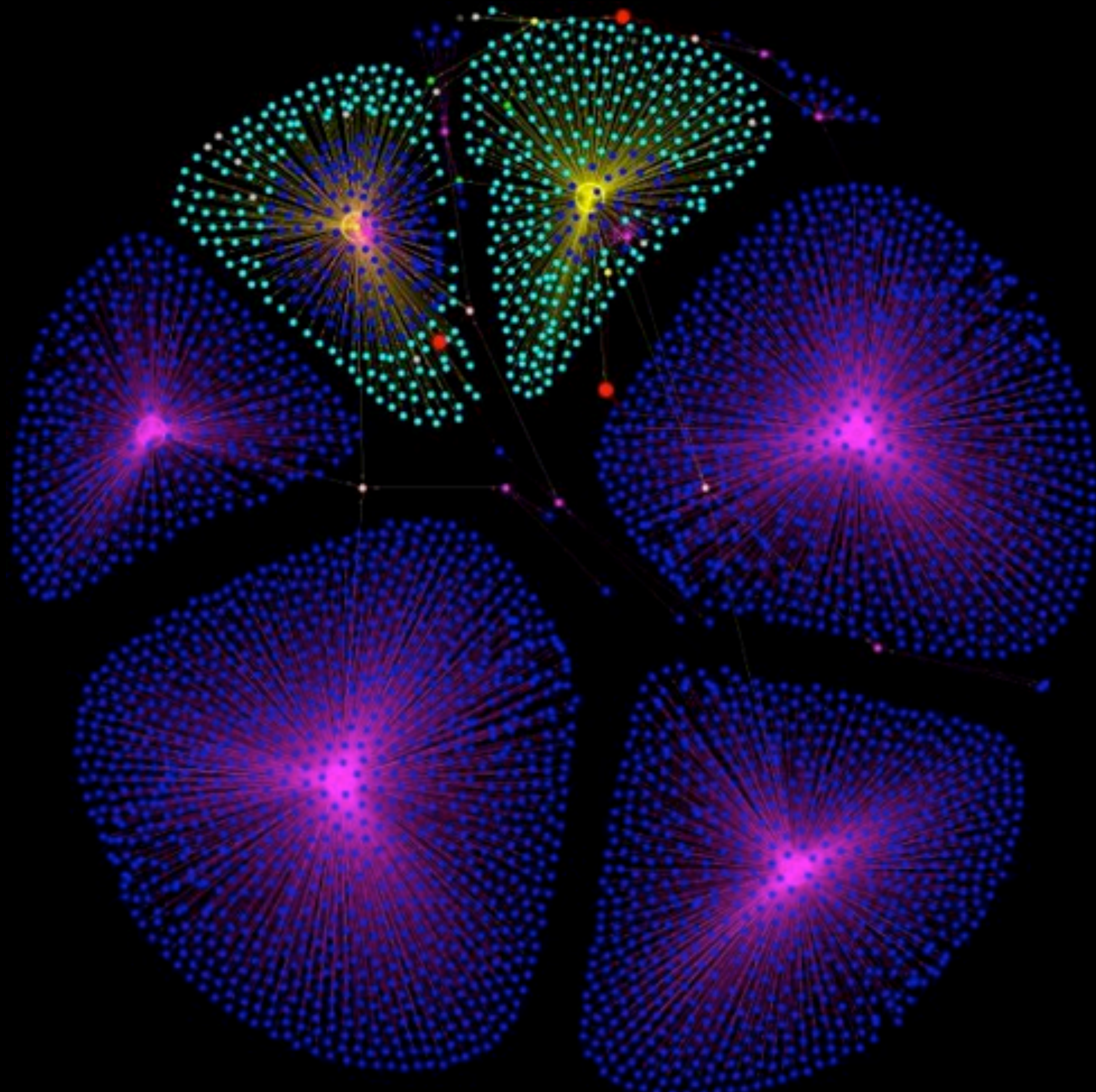
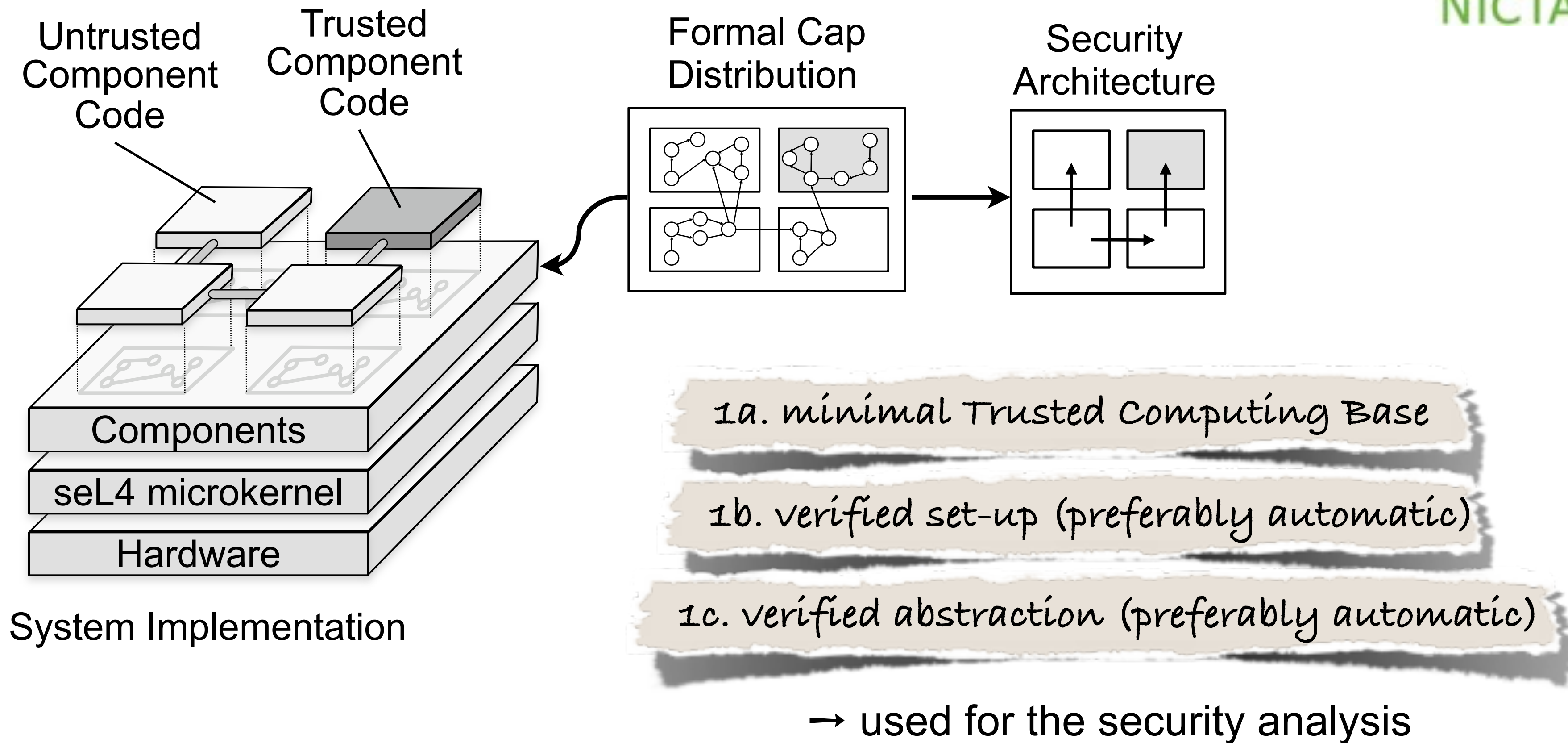


capability distribution

Back to the general picture



→ used for the security analysis

capDL: capability distribution language

Example:

$$obj1 \equiv Tcb[0 \mapsto CNodeCap\ 3, ...]$$
$$obj3 \equiv CNode[302 \mapsto CNodeCap\ 9 \quad Read \ \ , ...]$$

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Agenda

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<u>Secure Systems</u> "à la NICTA"

For 1 critical system:

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- an interactive theorem prover
- a bit of patience

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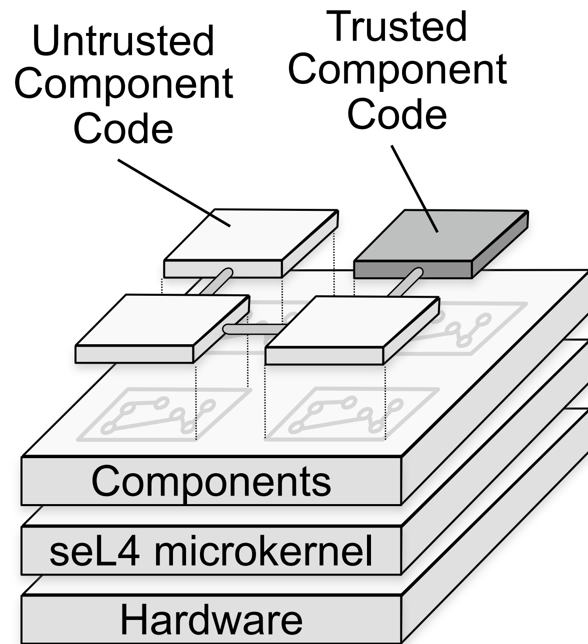
Security Proof



System Implementation

Theorem: $s_0 \xrightarrow{*} s \Rightarrow \mathcal{P}(s)$

```
lemma sacSecurity:
  (SAC-startup →* s) ⇒
   ¬ is_contaminated s NicA
```

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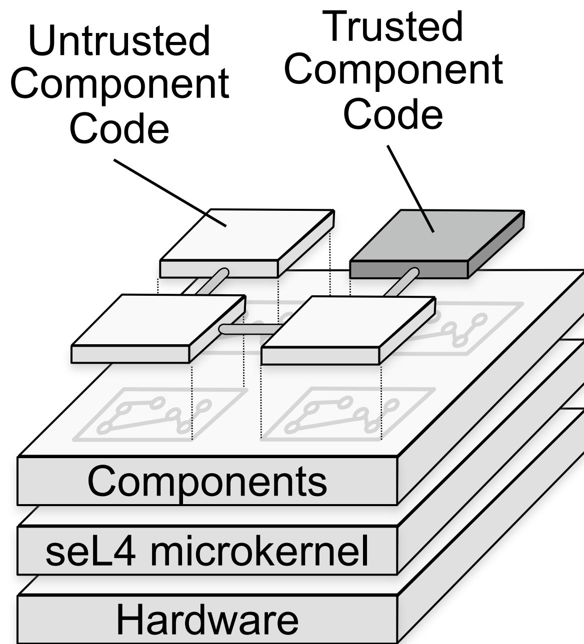
Security Proof



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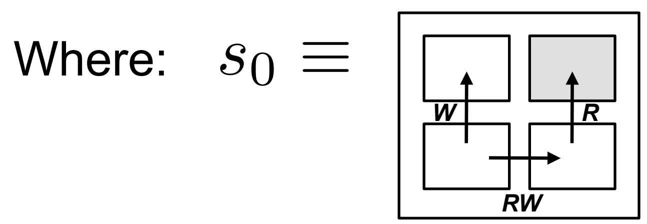
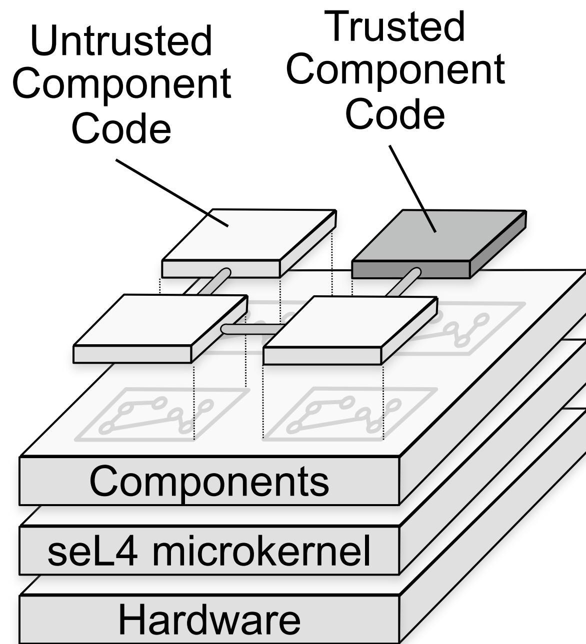
Theorem: $s_0 \xrightarrow{*} s \Rightarrow \mathcal{P}(s)$

Where: $s_0 \equiv$




```
RM_id      -> Some ({cap_r_to_SAC_C, ...}, not_contaminated)
SAC_C_id   -> Some ({cap_rw_to_NIC_C, ...}, not_contaminated)
NIC_A_id   -> Some ({}, not_contaminated)
NIC_B_id   -> Some ({}, contaminated)
```

Security Proof



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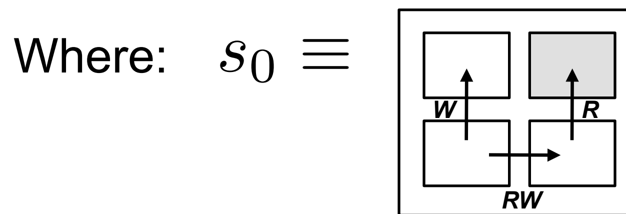
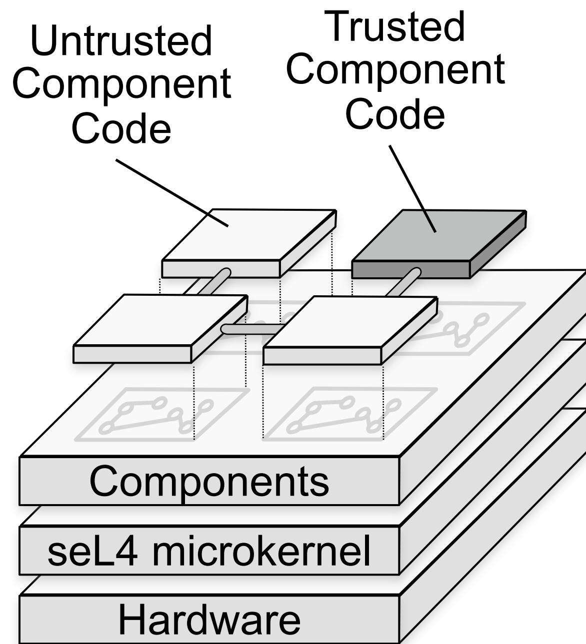


$$s \rightarrow s' \equiv s \xrightarrow{t} s' \vee s \xrightarrow{u} s'$$

$$\begin{aligned} s \xrightarrow{t} s' \equiv\ & let\ tc \in trusted_component(s)\ in \\ & let\ prg = program(tc)\ in \\ & let\ pc = program_counter(c, s)\ in \\ & let\ i = inst(prg, pc)\ in \\ & step(tc, s, i, s') \end{aligned}$$

```
RM_prg ≡
  [ SysOp (SysRead cap_r_to_SAC_C),
    SysOp (SysRemoveAll cap_C_to_R),
    SysOp (SysDelete cap_C_to_R),
    ...  ]
```

Security Proof



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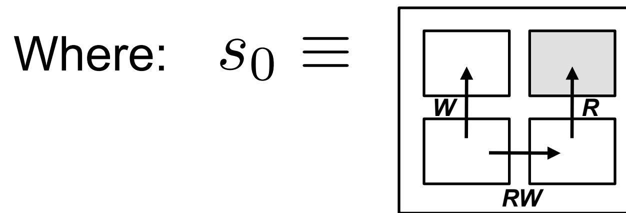

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$$\begin{aligned} s \xrightarrow{u} s' \equiv\ & let\ uc \in untrusted_components(s)\ in \\ & step(uc, s, any_inst, s') \end{aligned}$$

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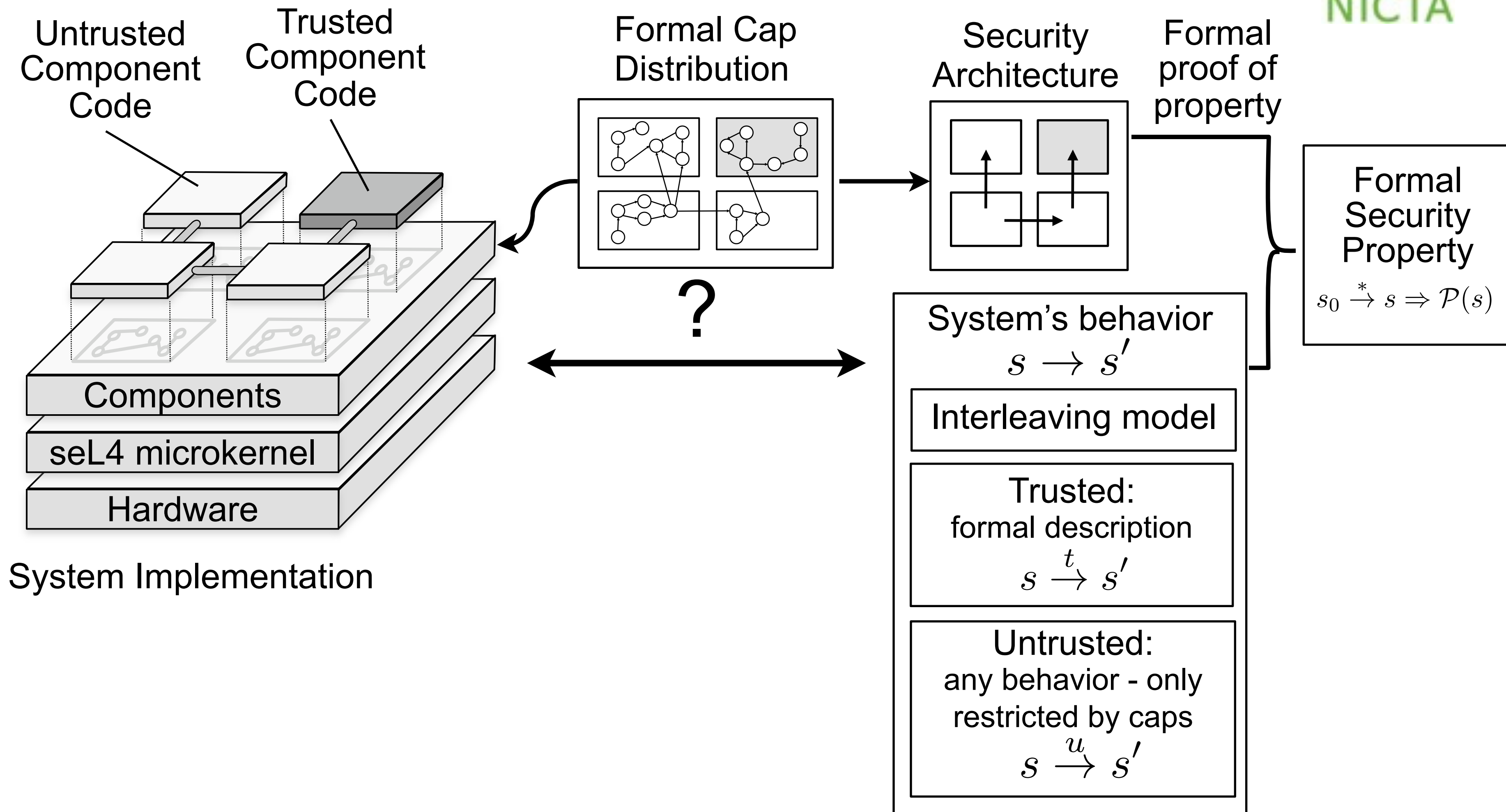
Security Proof



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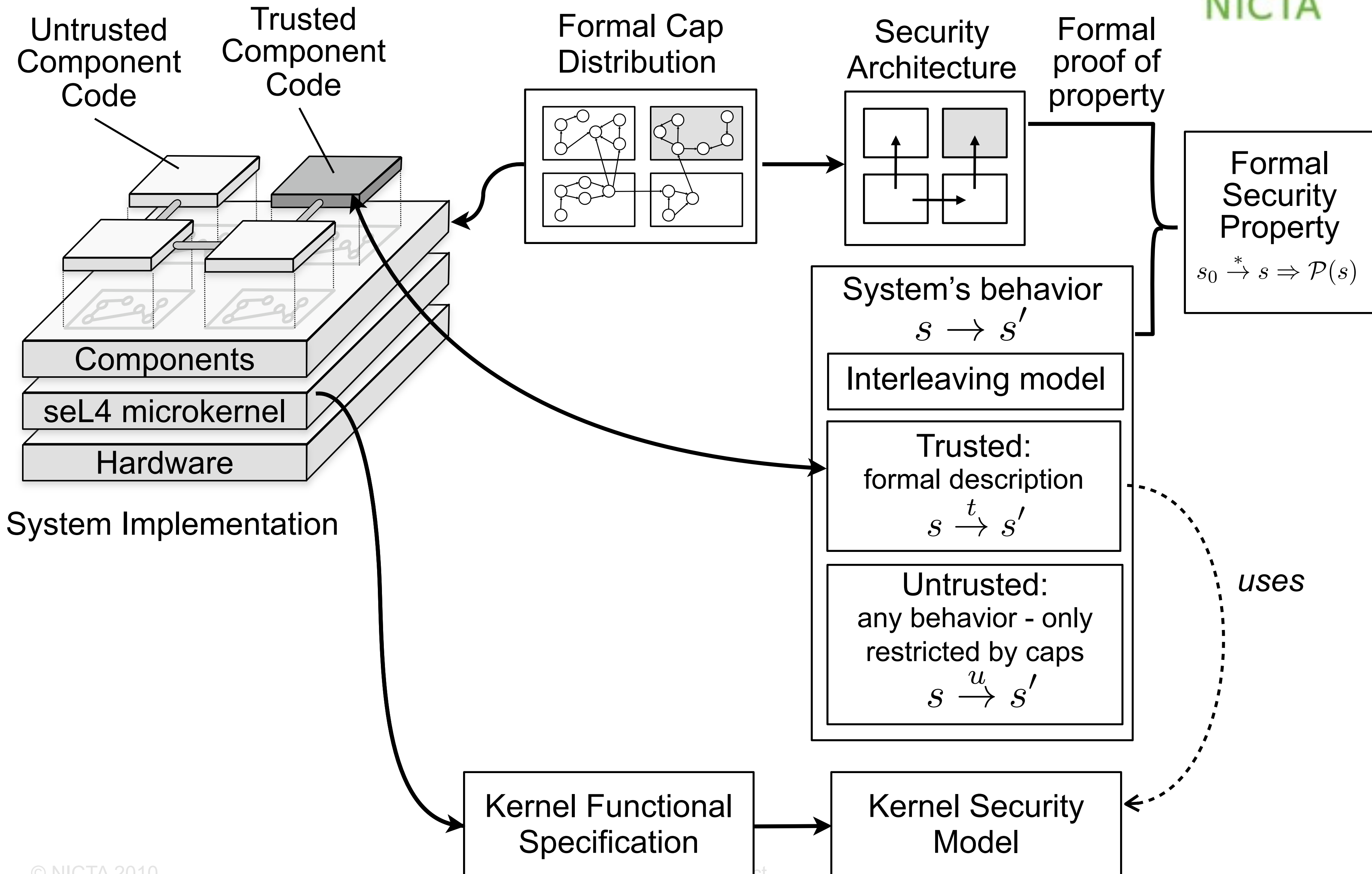
Verified TCB



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From imagination to impact

Agenda

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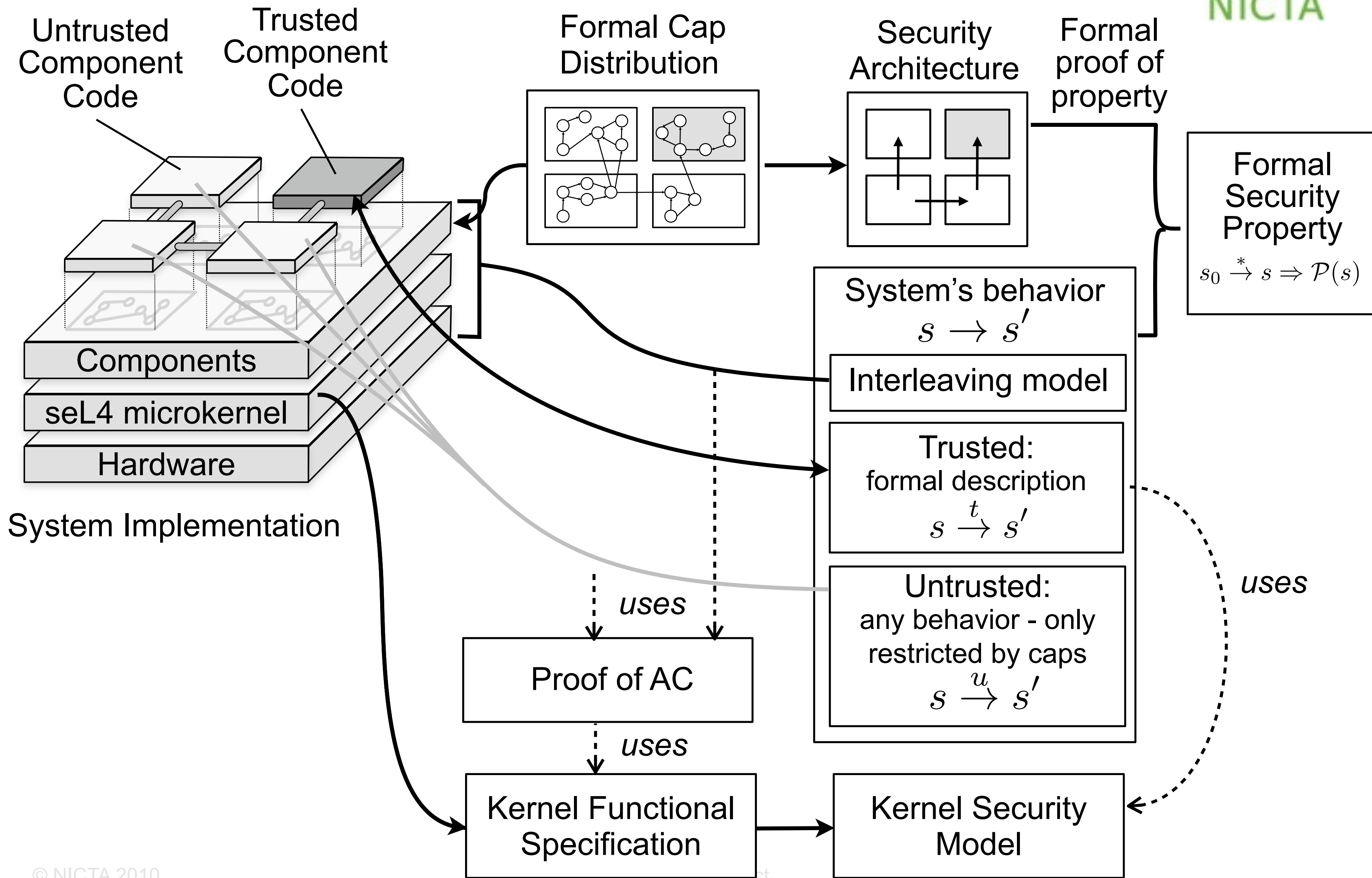
Proof of access control



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What is AC good for?

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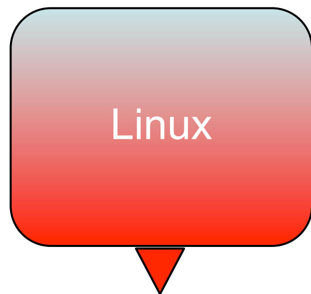
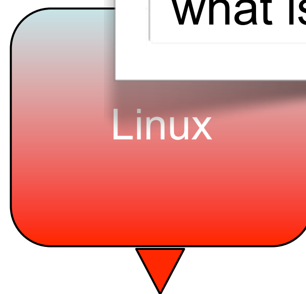
What is AC good for?





Examples

- R does not write to NicB if it does not have a write capability to it
- R does not change RM's program counter

Question: for all operation *op* s.t.

$$s \xrightarrow{op} s'$$

what is allowed to change in s' ?

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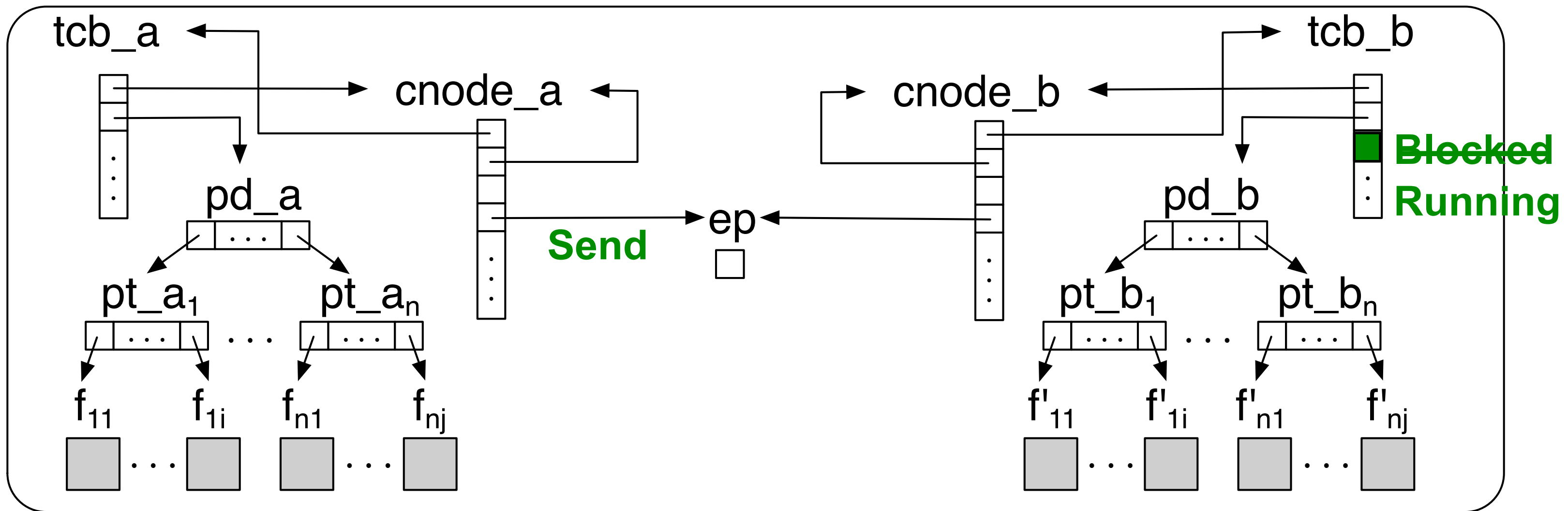
Example

If ***op*** is ***set_thread_state tcb_b v***
If **tcb_a** is running in state **s** where **s** is:



Then in which condition may **tcb_b** change

and what is allowed to change?

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Example

If ***op*** is ***set_thread_state tcb_b v***
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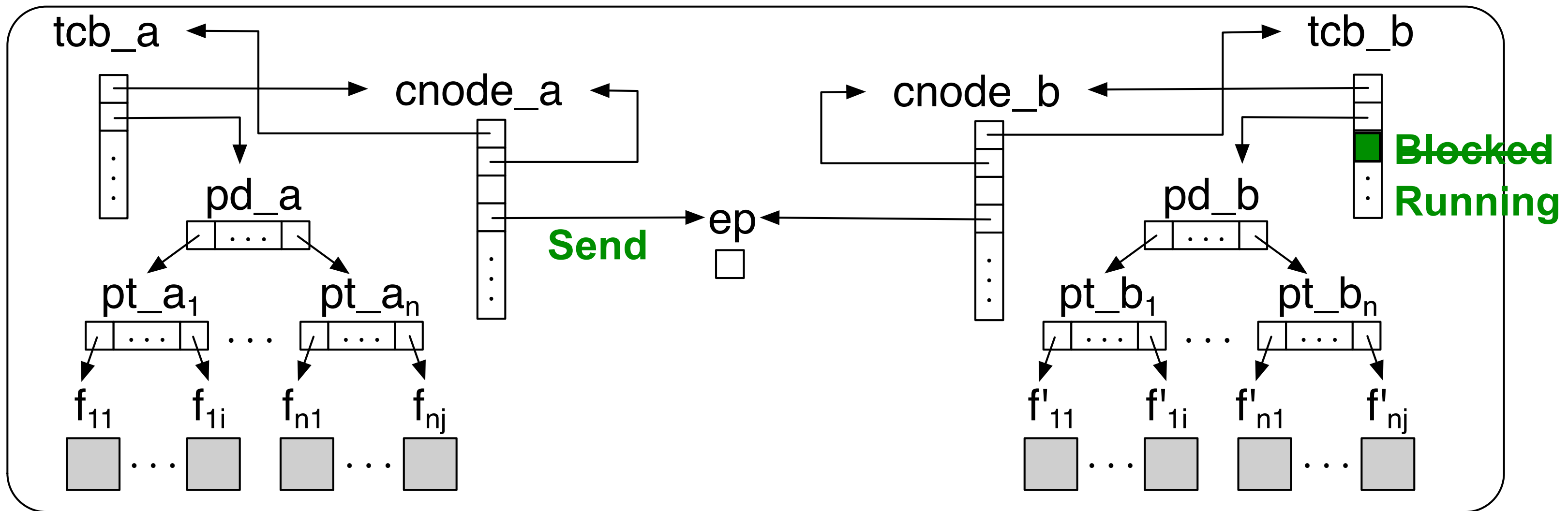


<u>Obvious (but wrong) solution</u>:

only the thread-state field of **tcb_b** is allowed tc c ange
and only under the following conditi

- **tcb_a** has a cap t
- or **tcb** ... **tcb_b** is waiting on in state **s**
- or **tcb** ... he untyped region containing **tcb_b**, in state **s**
- or ...

Policy closely depends on state

Solution: Labelling

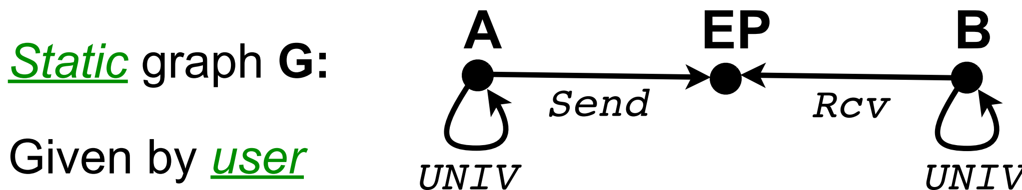
A EP B

tcb_a cnode_a pd_a pt_a_1 pt_a_n f_{11} f_{1i} f_{n1} f_{nj}

ep

cnode_b tcb_b pd_b pt_b_1 pt_b_n f'_{11} f'_{1i} f'_{n1} f'_{nj}

Static graph **G:**



Given by *user*

State must be *subset* a of **G**

G is *subjective*: current label contains the (untrusted) running thread

We prove:

1. **Graph preservation (authority confinement)**
2. **Access control at the label level**

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Solution: Labelling

If **A** is the running label in **G**

then for any operation ***op*** that changes **s** to **s'**,

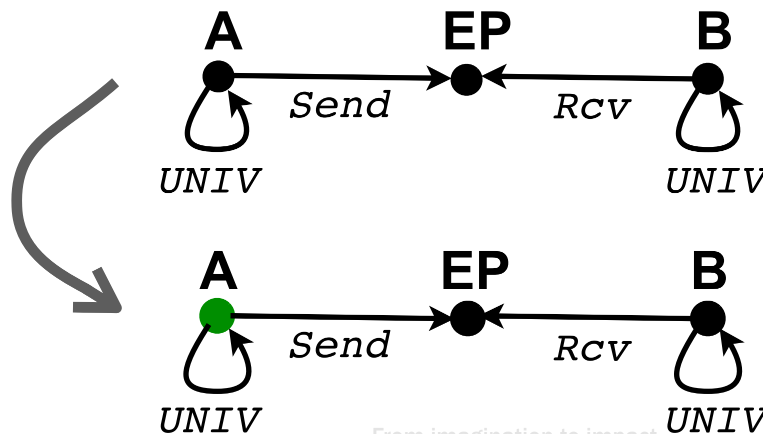
for any object **obj** of label **B**,

obj can only be changed if **A=B** or in 4 small precise cases, as:

"***obj*** *is a TCB blocked on an endpoint of label* ***EP****,*

*and (**A**,Send,**EP**)* ⊆ ***G***

and only the thread-state of ***obj*** *can be changed, to Running*"



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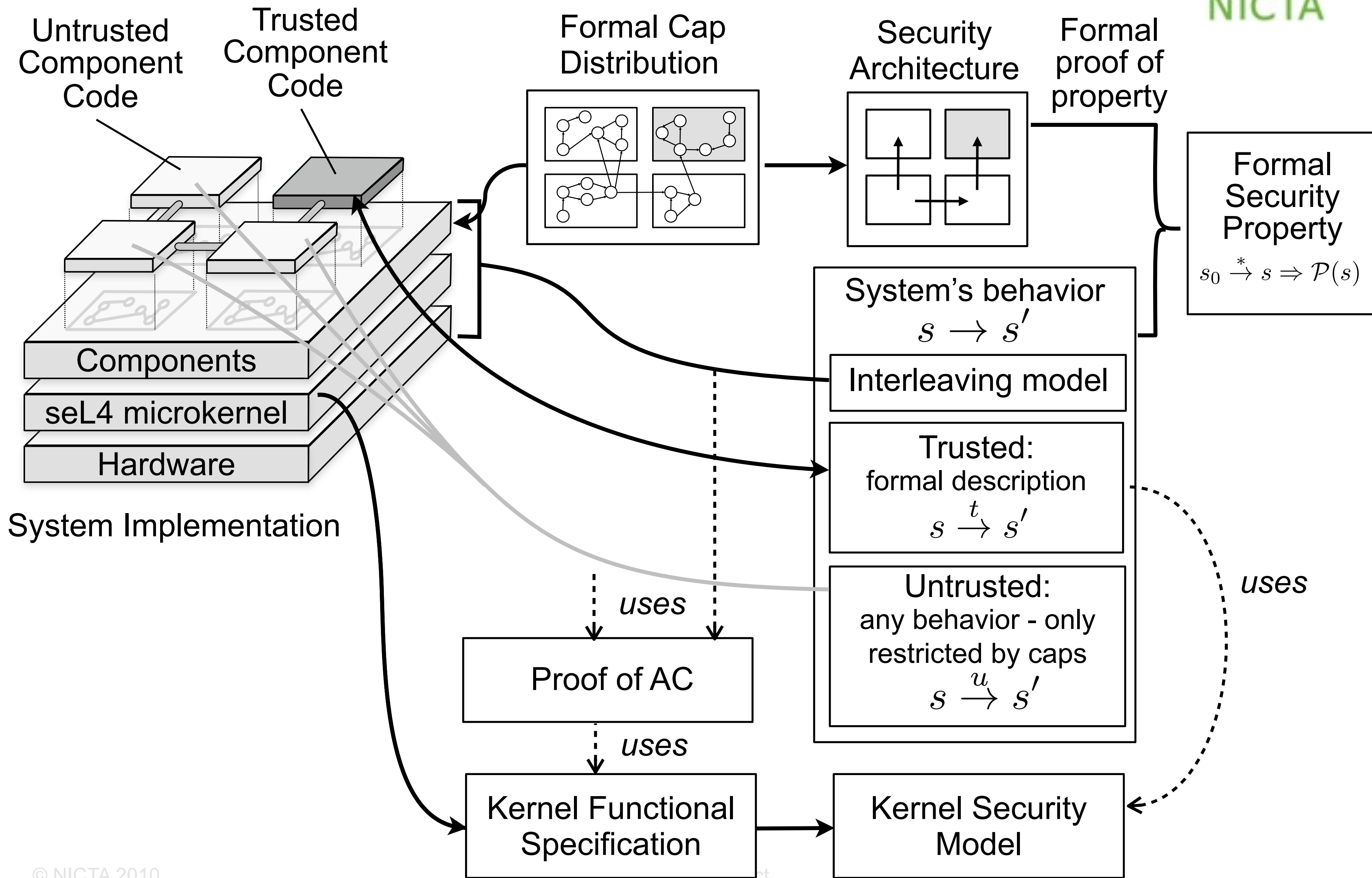
Conclusion



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Conclusion

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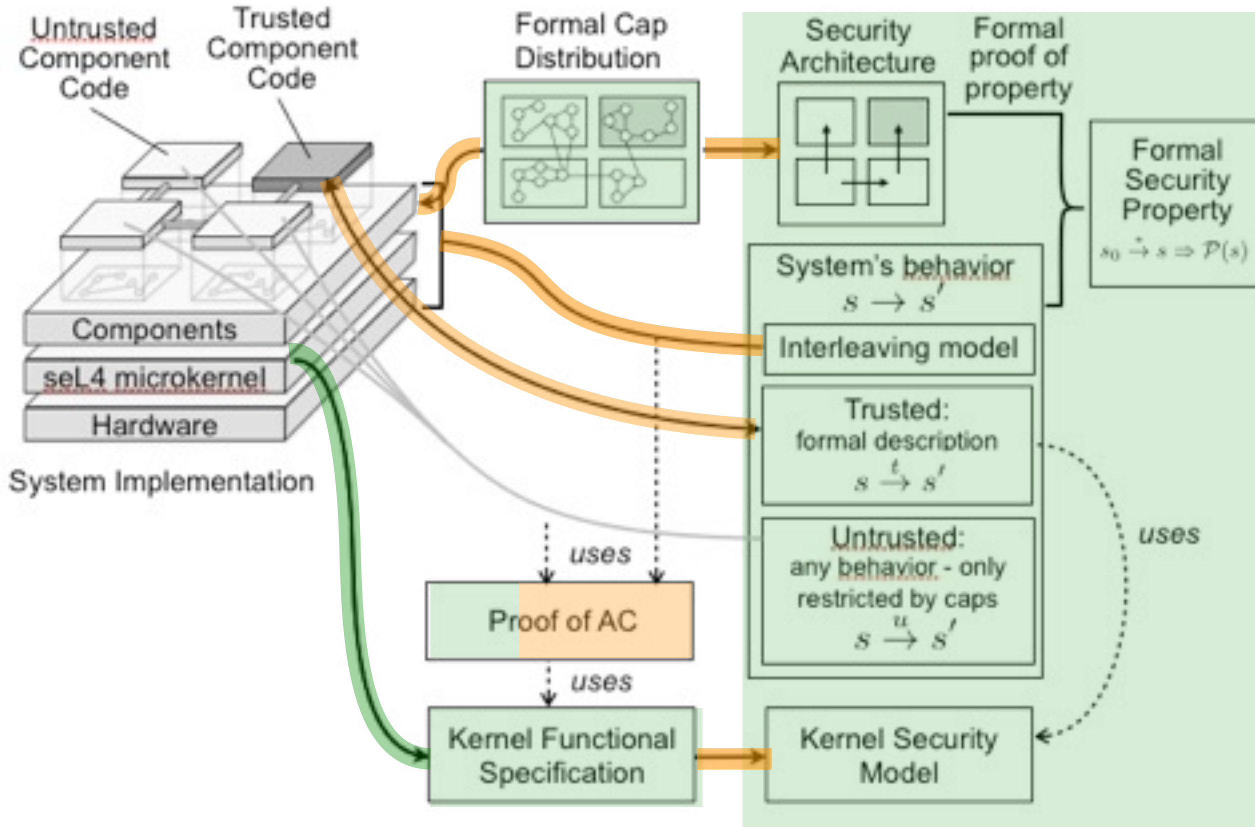

Results so far:

- Case study sec. proof
- seL4 enforces integrity
- capDL
- seL4 correctness proof
- certification: ST
- seL4 binary and formal spec released

Challenges:

Automation
verified code generator from high level code

Integration
system trace reasoning, concurrency

Confidentiality
preserved by refinement

Proof engineering
- refactoring
- efficient proof rerun

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Questions?