The Road To Trustworthy Systems

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Windows

An exception 06 has occured at 0028:C11B3ADC in VxD DiskTSD(03) + 00001660. This was called from 0028:C11B40C8 in VxD voltrack(04) + 00000000. It may be possible to continue normally.

* Press any key to attempt to continue.
* Press CTRL+ALT+RESET to restart your computer. You will lose any unsaved information in all applications.

Press any key to continue

Trust Without Trustworthiness

What’s Next?

Our Vision: Trustworthy Systems

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- We will change industry's approach to the design and implementation
- of embedded software, resulting in systems which are *trustworthy*.

Trustworthy means *truly dependable* in that there are *hard guarantees* about the *security*, *safety* or *reliability* of the software.

Approach: Microkernel Technology

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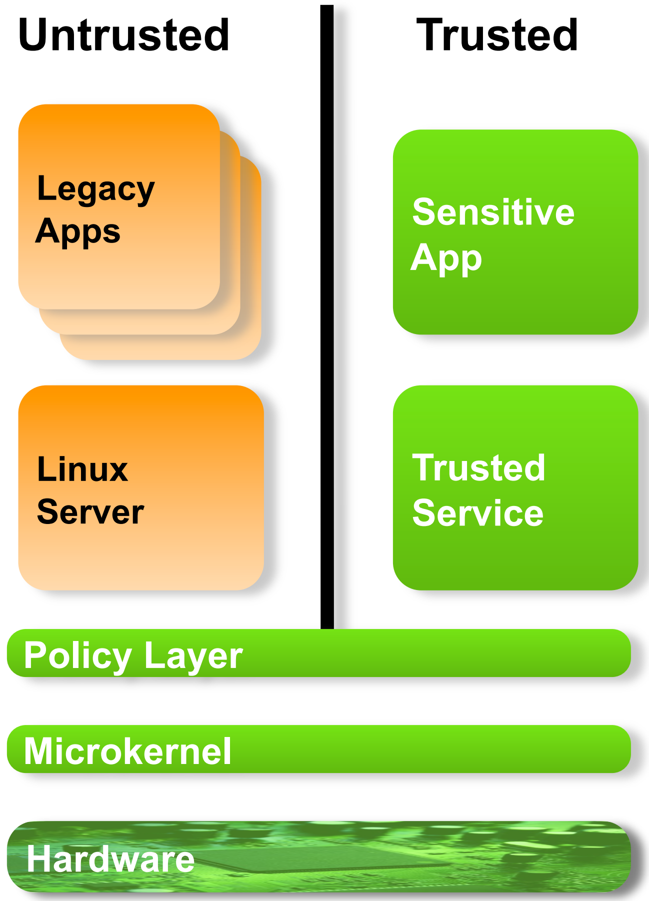
- Protect critical components by sandboxing complex components
- Provide tightly-controlled communication channels
- *Trustworthy microkernel* enforces security/safety policies
- Microkernel becomes core of trusted computing base
  - System trustworthiness only as good as microkernel



Trustworthy Systems Agenda

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1. **Ensure microkernel trustworthiness (seL4)**
   - Proof of functional correctness
   - Proof of safety/security properties
2. **Lift microkernel guarantees to whole system**
   - Use safety/security guarantees
   - Prove correctness of balance of trusted computing base
   - Prove safety/security of complete system

Ingredients:

- Functional correctness
- Isolation / non-interference / information flow
- Timeliness / worst-case latency guarantees
- Energy management

Proof of Functional Correctness

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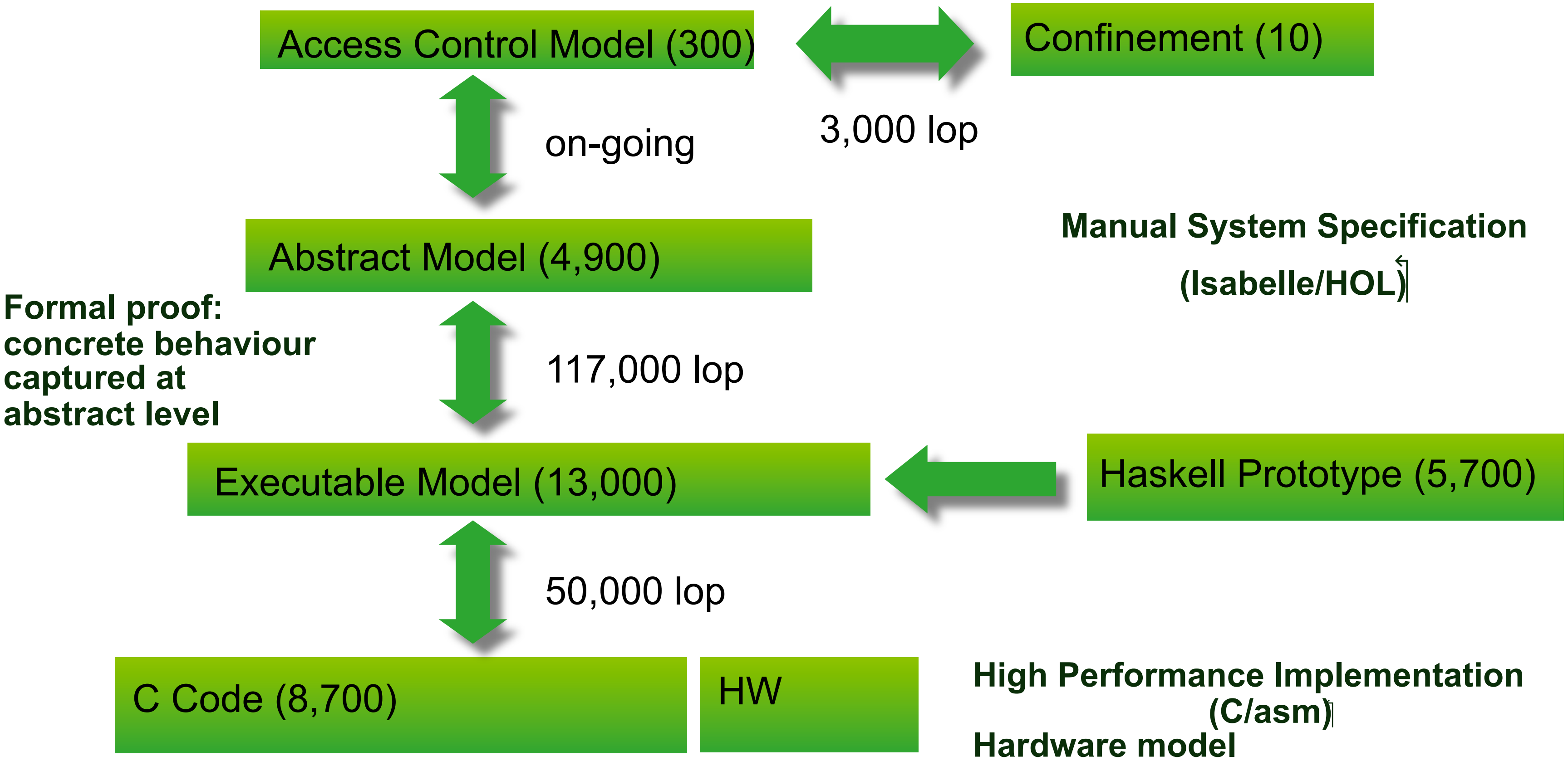

Correctness

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```
datatype
  rights = Read
         | Write
         | Grant
         | Create

record cap =
  entity :: entity_id
  ri

reco

type
```

```
lemma isolation:
  "⟦sane s;
    s' ∈ execute cmds s;
    isEntityOf s eS;
    sEntityOf s e;
    ntity c = e;
    :> subSysCaps s eS⟧
    ⟹ c :> subSysCaps s' eS"
```

```
constdefs
  schedule :: "unit s_monad"
  "schedule ≡ do
```

```
schedule :: Kernel ()
schedule = do
```

```
d
Thread
```

```
void
setPriority(tcb_t *tptr, prio_t prio) {
    prio_t oldprio;

    if(thread_state_get_tcbQueued(tptr->tcbState)) {
        oldprio = tptr->tcbPriority;
        ksReadyQueues[oldprio] = tcbSchedDequeue(tptr, ksReadyQueues[
        if(isRunnable(tptr)) {
            ksReadyQueues[prio] = tcbSchedEnqueue(tptr, ksReadyQueues
        }
        else {
            thread_state_ptr_set_tcbQueued(&tptr->tcbState, false);
        }
    }

    tptr->tcbPriority = prio;
}

void
yieldTo(tcb_t *target) {
    target->tcbTimeSlice += ksCurThread->tcbTimeSlice;
```

ecification

L)

e (5,700)

mance Implementation
(C/asm)
odel

Formal Verification Summary

Kinds of properties proved

- Behaviour of C code is fully captured by abstract model
- Behaviour of C code is fully captured by executable model
  - Can prove many interesting properties on higher-level models
- Kernel never fails, behaviour is always well-defined
  - assertions never fail
  - will never de-reference null pointer
  - cannot be subverted by misformed input
- All syscalls terminate, reclaiming memory is safe, ...
- Well typed references, aligned objects, kernel always mapped…
- Access control is decidable

Effort:

- Average 6 people over 5.5 years

Verification vs Certification

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Common Criteria: Military-Strength Security

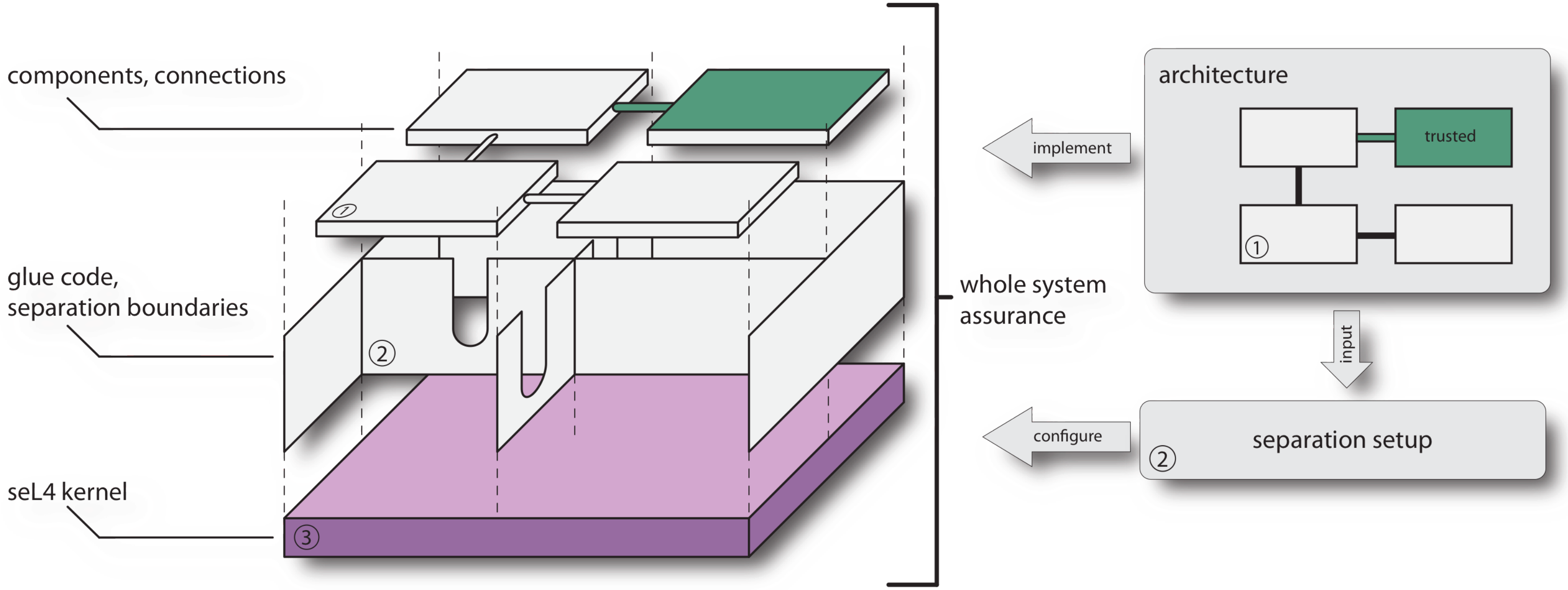
Evaluation Level	Requirements	Functional Specification	Top Down Design	Imple-mentation	Cost
EAL1		Informal			
EAL2		Informal	Informal		
EAL3		Informal	Informal		
EAL4		Informal	Informal	Informal	
EAL5		Semi-formal	Semi-formal	Informal	
EAL6	Formal	Semi-formal	Semi-formal	Informal	1K/LoC
EAL7	Formal	Formal	Formal	Informal	
seL4	Formal	Formal	Formal	Formal	0.6K/LoC

Phase Two: Full-System Guarantees

- Achieved: Verification of microkernel (8,700 LOC)

- Next step: Guarantees for real-world systems (1,000,000 LOC)

Overview of Approach



- Build system with minimal TCB
- Formalize and prove security properties about architecture
- Prove correctness of trusted components
- Prove correctness of setup
- Prove temporal properties (isolation, WCET, …)
- Maintain performance

Proof of Concept: Secure Access Controller

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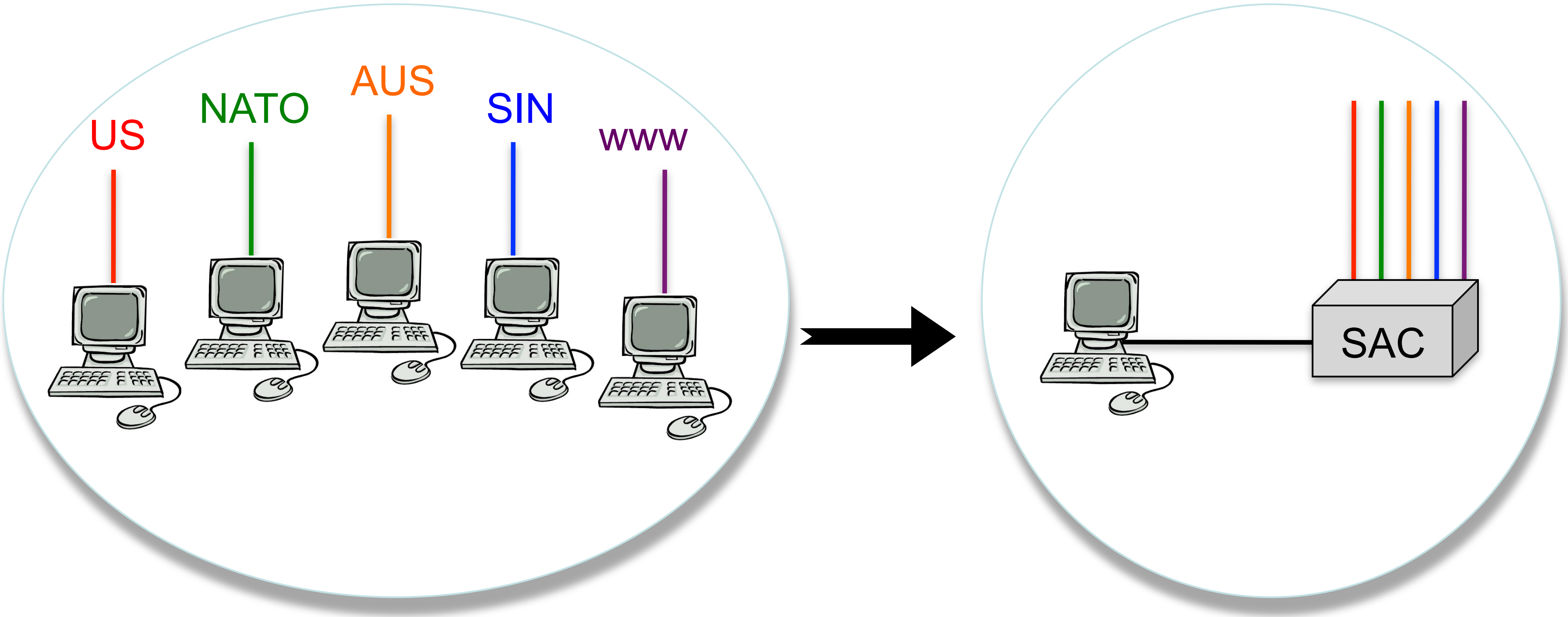

SAC Aim

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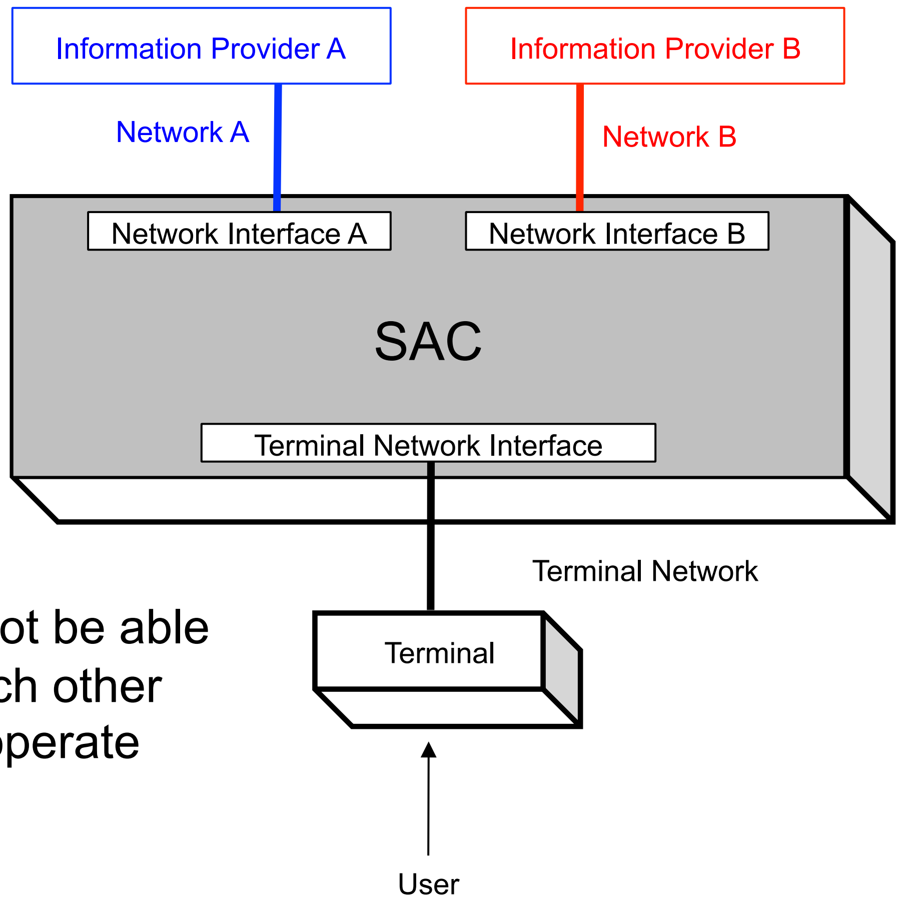

Provider A & B should not be able to leak info between each other even if they actively cooperate

Our Solution Overview

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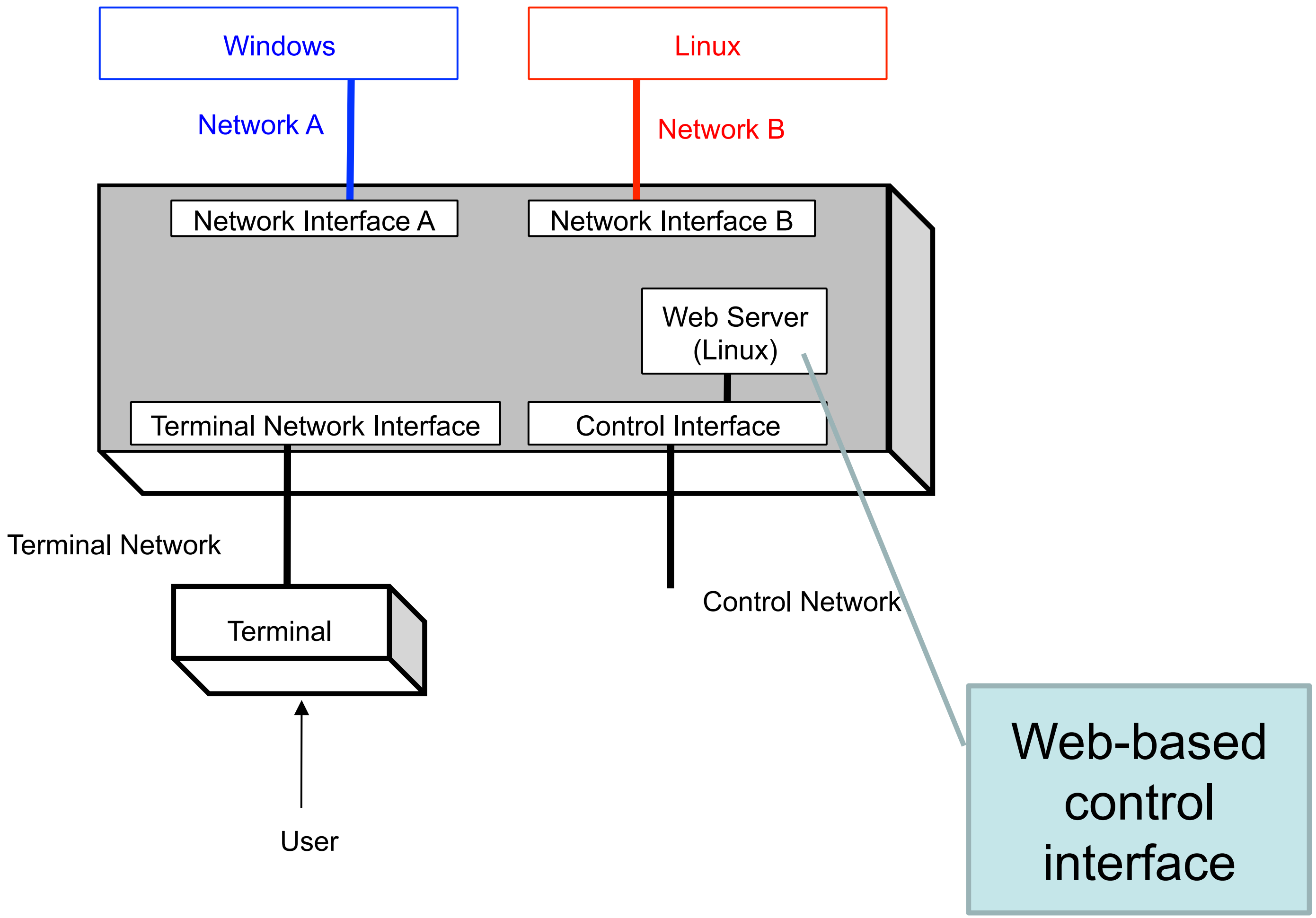
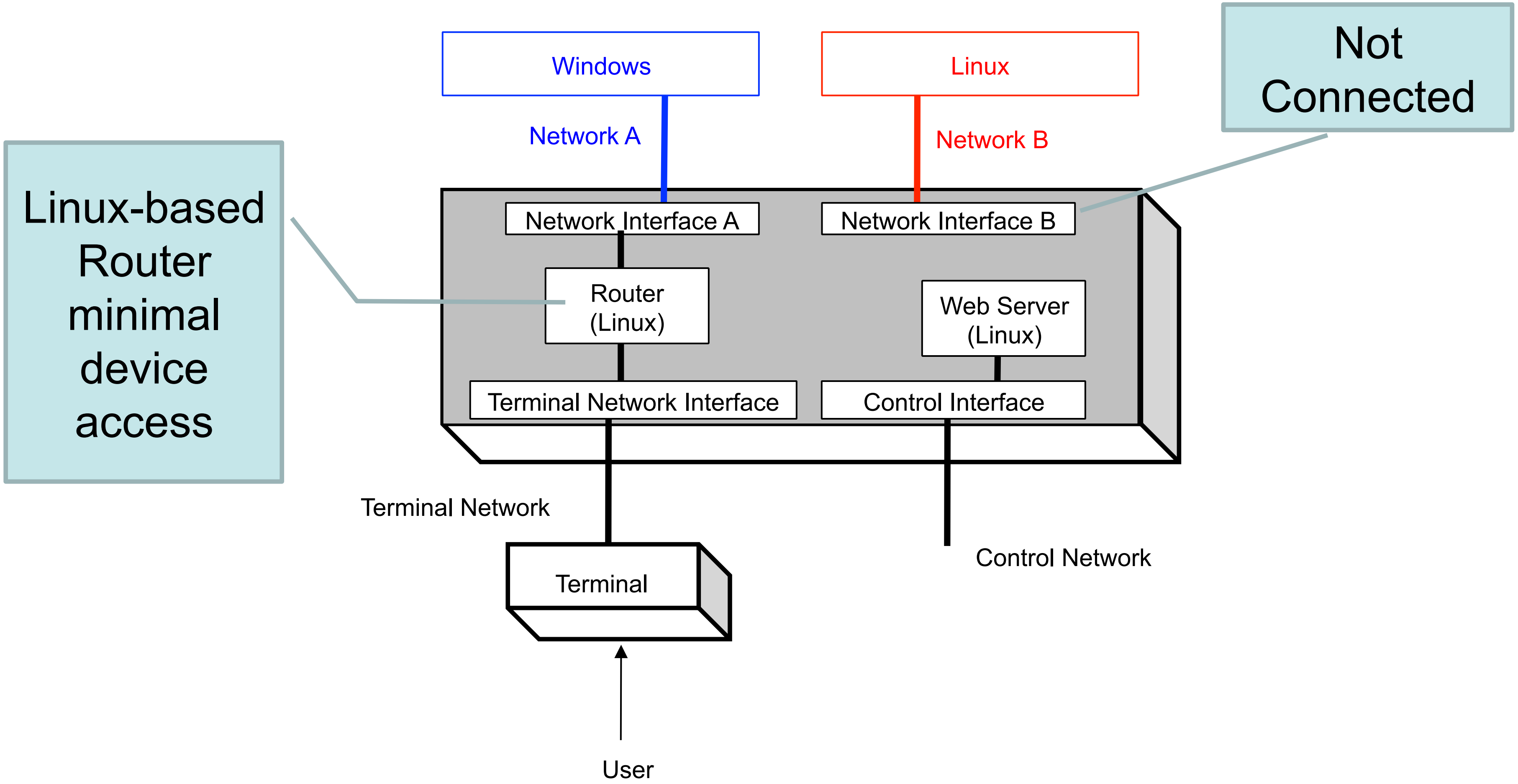
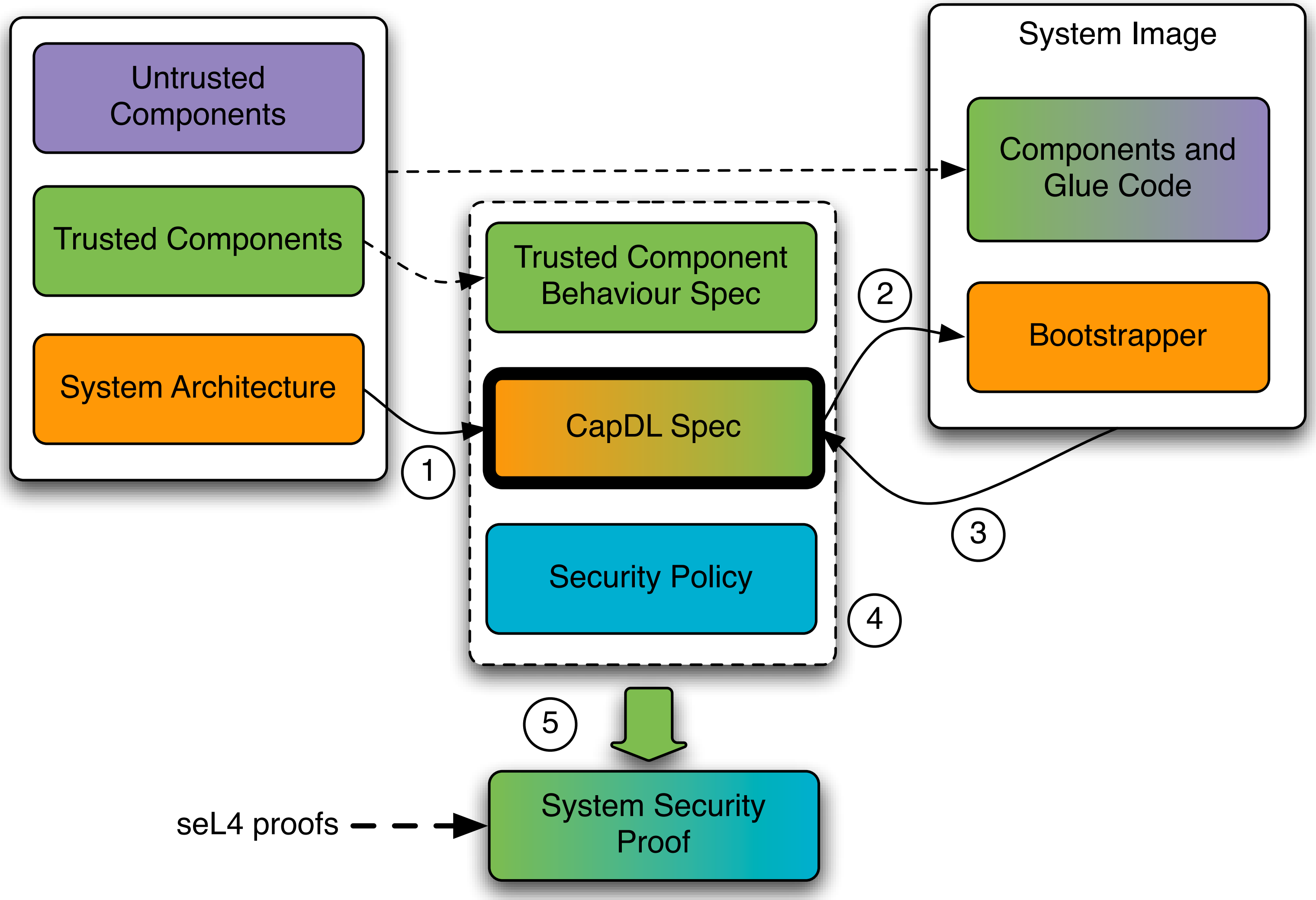


Solution Overview



Specifying Security Architecture



Component Side-Channel Mitigation

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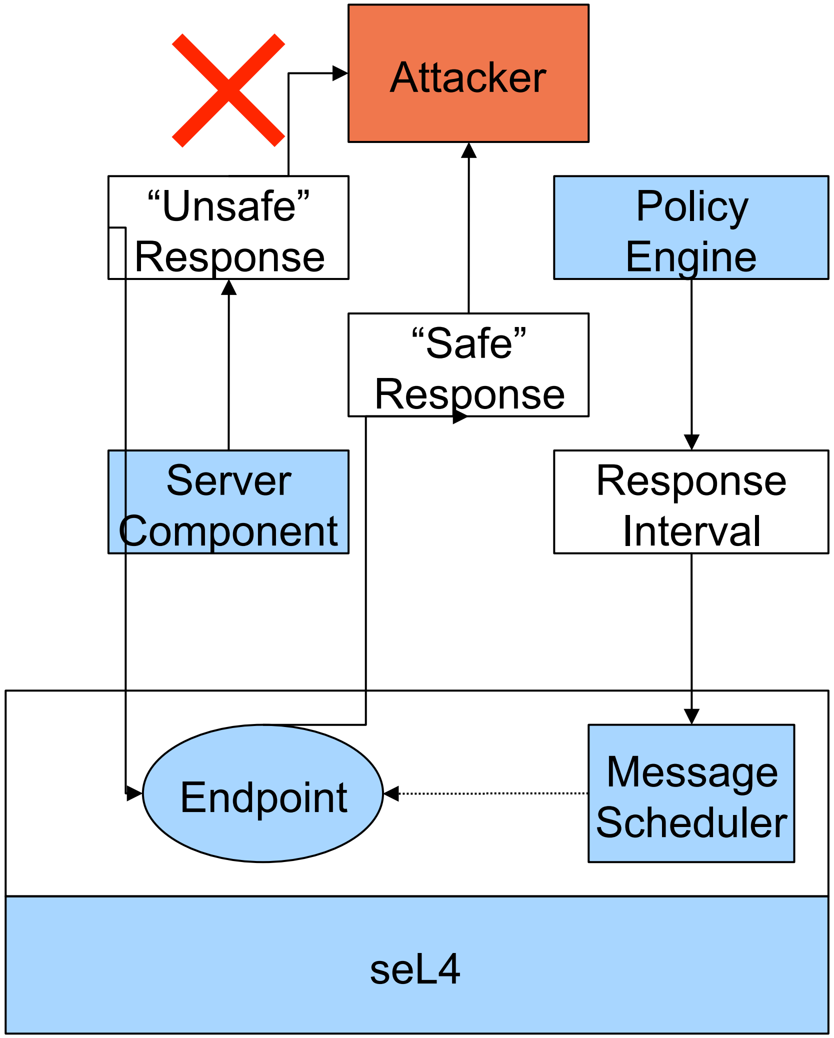
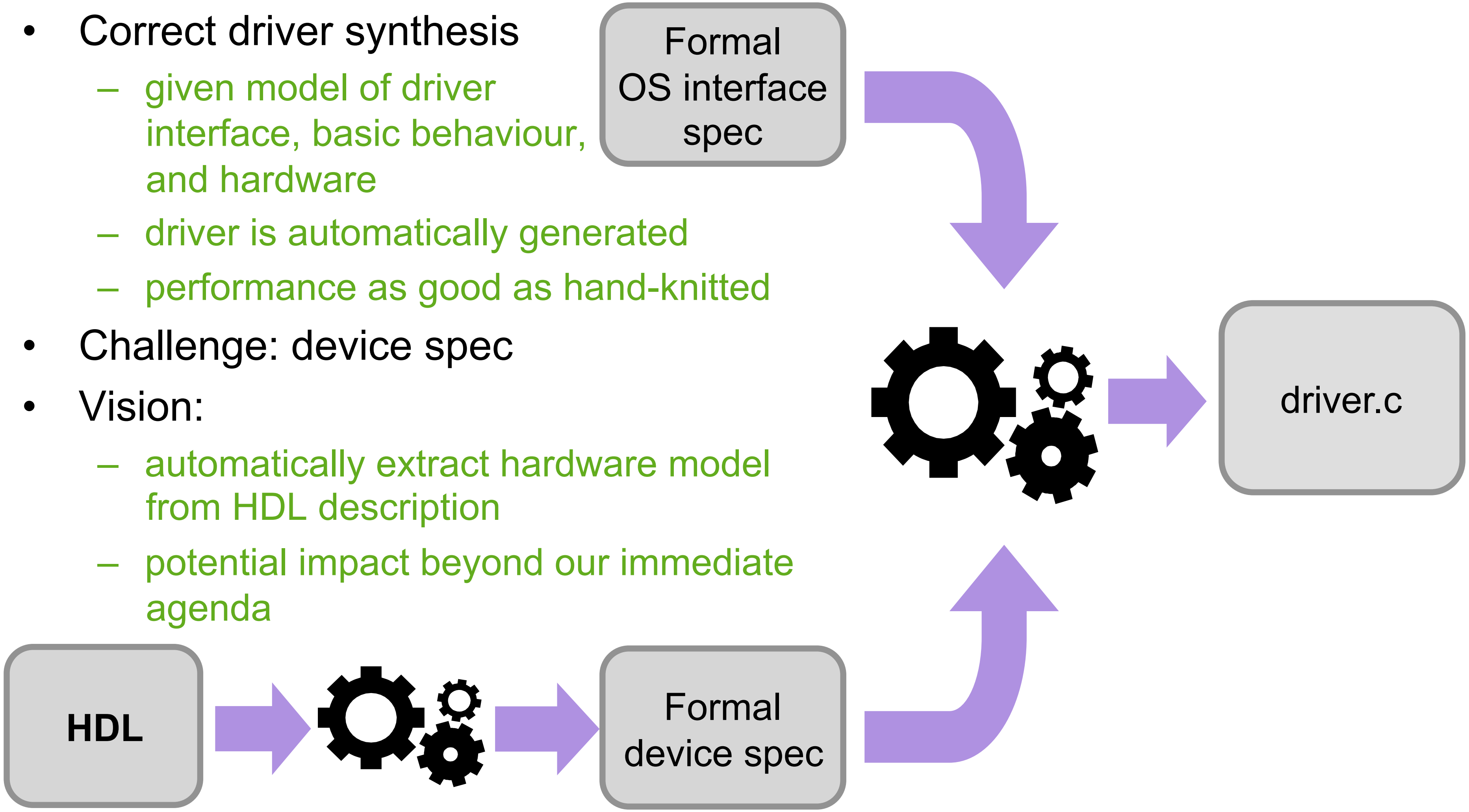


- Component response time variability exposes secrets.
- Add a response time control policy.
- Real-time scheduling gives a mechanism.
- seL4 endpoints give a framework.

Trusted Synthesized Drivers

- Correct driver synthesis
  - given model of driver interface, basic behaviour, and hardware
  - driver is automatically generated
  - performance as good as hand-knitted
- Challenge: device spec
- Vision:
  - automatically extract hardware model from HDL description
  - potential impact beyond our immediate agenda



Kernel Worst-Case Execution Time

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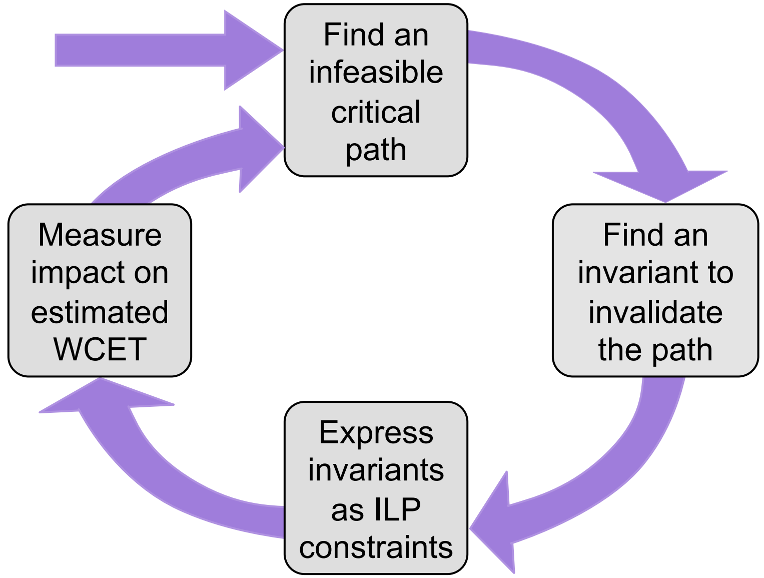
- seL4 is small as an OS kernel (9 kLOC)
  - … but large as an object for WCET analysis
  - … and full of performance optimisations
- However, we know a lot about it (in a very formal way!)
  - Plenty of invariants proved during verification
  - E.g. loop iteration counts, non-interference
- Can make use of this for WCET analysis
  - Collaboration with WCET experts at NUS (Abhik Roychoudhury)



Trustworthy Systems Are Possible!

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- World's first functional correctness proof of an OS kernel (seL4)
  - 100 citations in 12 months [SOSP 2009]
- Demonstrated secure virtualization using seL4 microkernel
  - Multi-level secure device for national-security use
  - Small and verifiable trusted computing base
  - Untrusted Linux system
- Demonstrated synthesis of high-performance device-drivers
  - Path to eliminating dominant source of OS crashes

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