Can Truly Dependable Systems Be Affordable?

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NICTA Funding and Supporting Members and Partners

Present Systems are *NOT* Trustworthy!

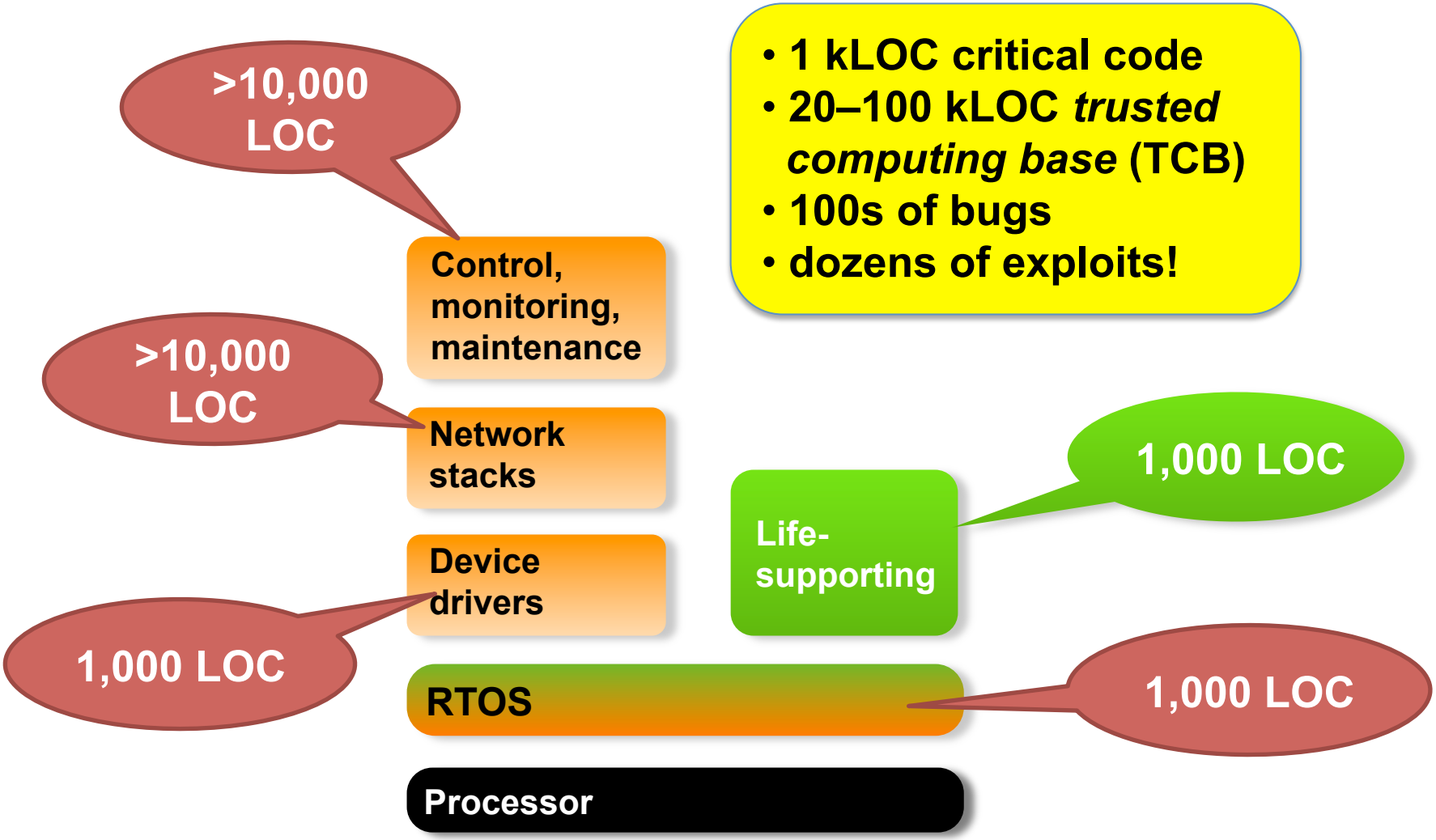
NICTA

Yet they are expensive:

- $1,000 per line of code for "high-assurance" software!

Fundamental issue: large stacks, need isolation

E.g. medical implant

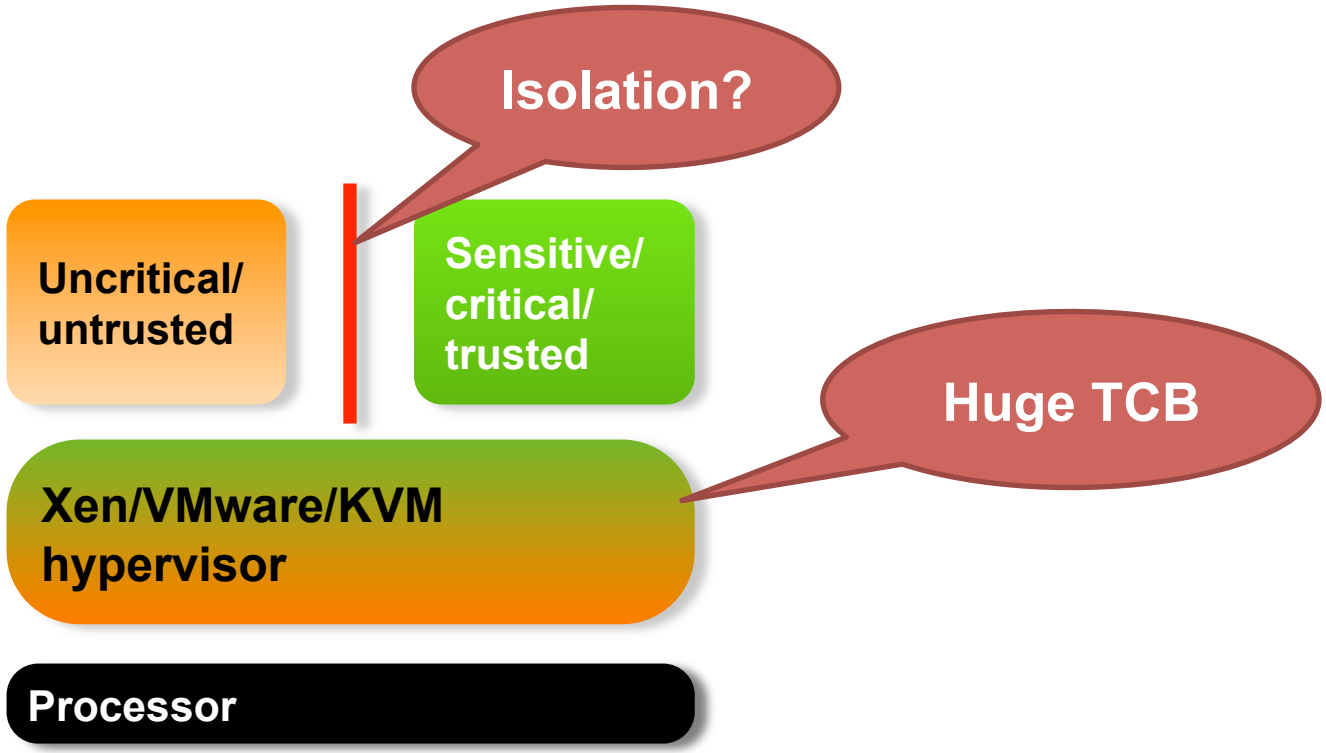


High Assurance *Bad* Practice

NICTA

- TCB of millions of LOC
- Expect 1000s of bugs
- Expect 100s of vulnerabilities

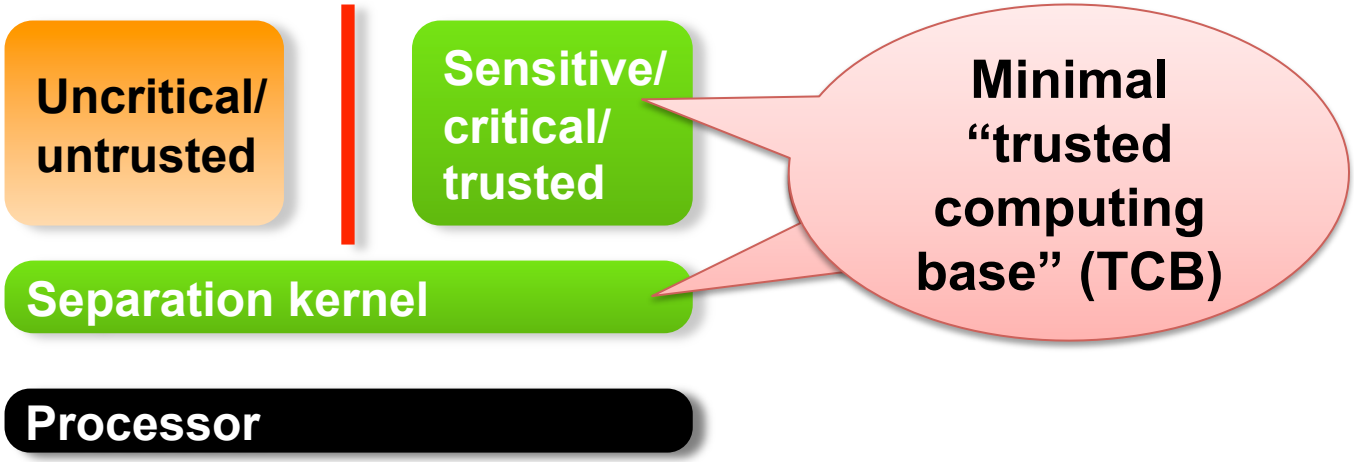
Hacker's delight!



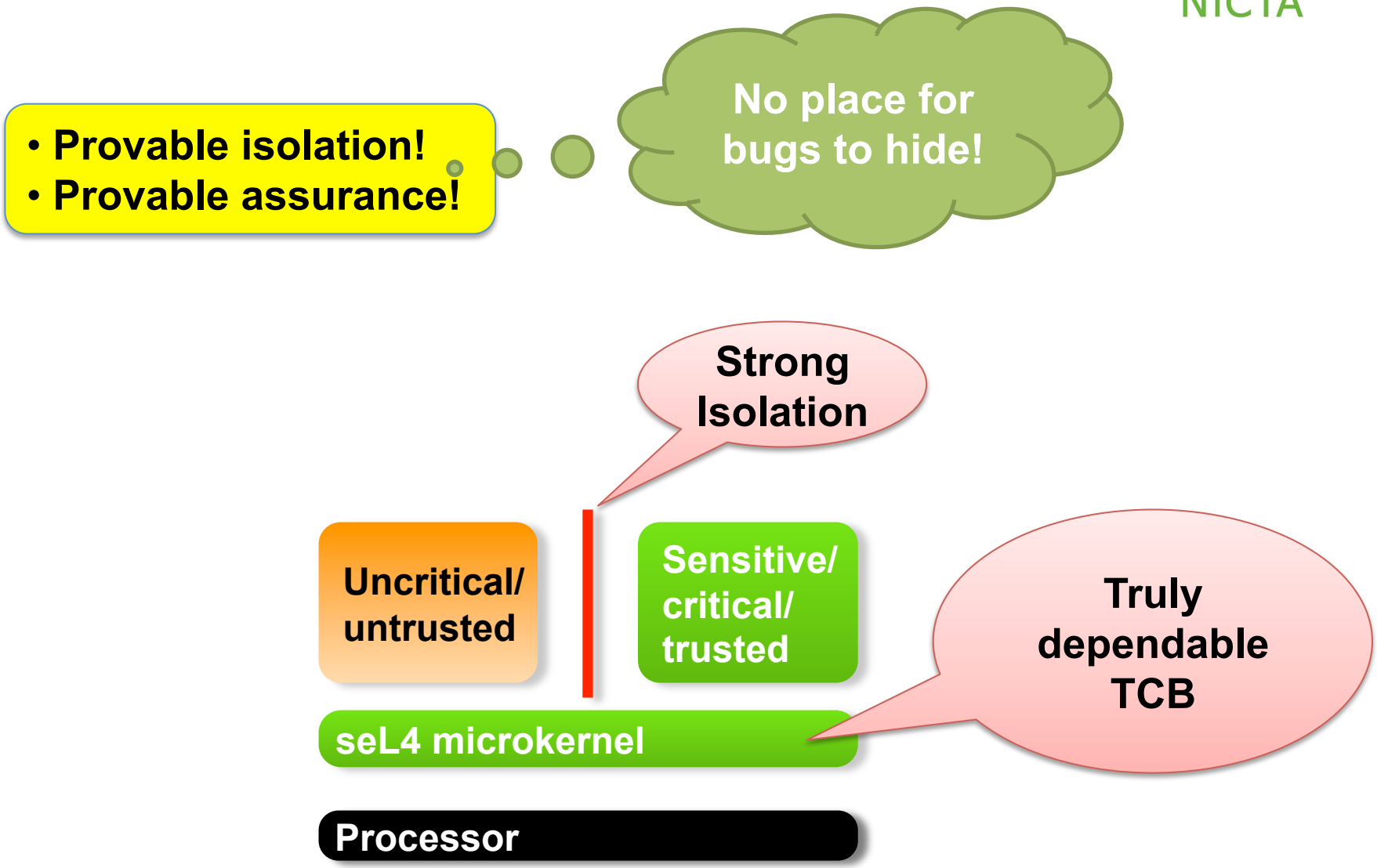
High Assurance Best Practice

- Isolate
- Minimise the TCB
- Assure TCB by
  - testing
  - code inspection
  - bug-finding tools

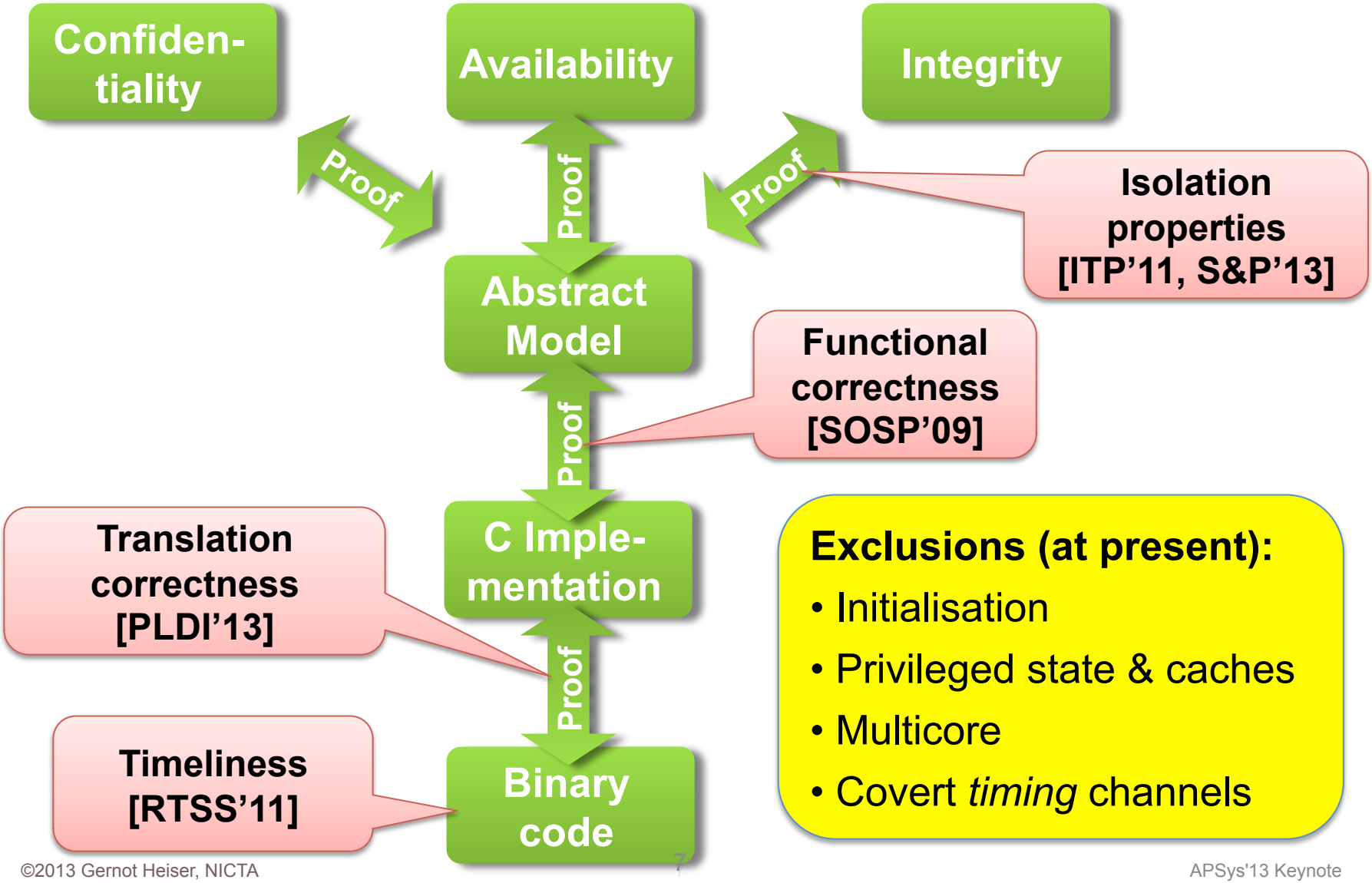
Always incomplete!



State of the Art: NICTA's seL4 Microkernel



NICTA's seL4: Mathematical *Proof* of Isolation



NICTA's seL4 Microkernel: Unique Assurance

First and only operating-system with functional-correctness proof: operation is always according to specification

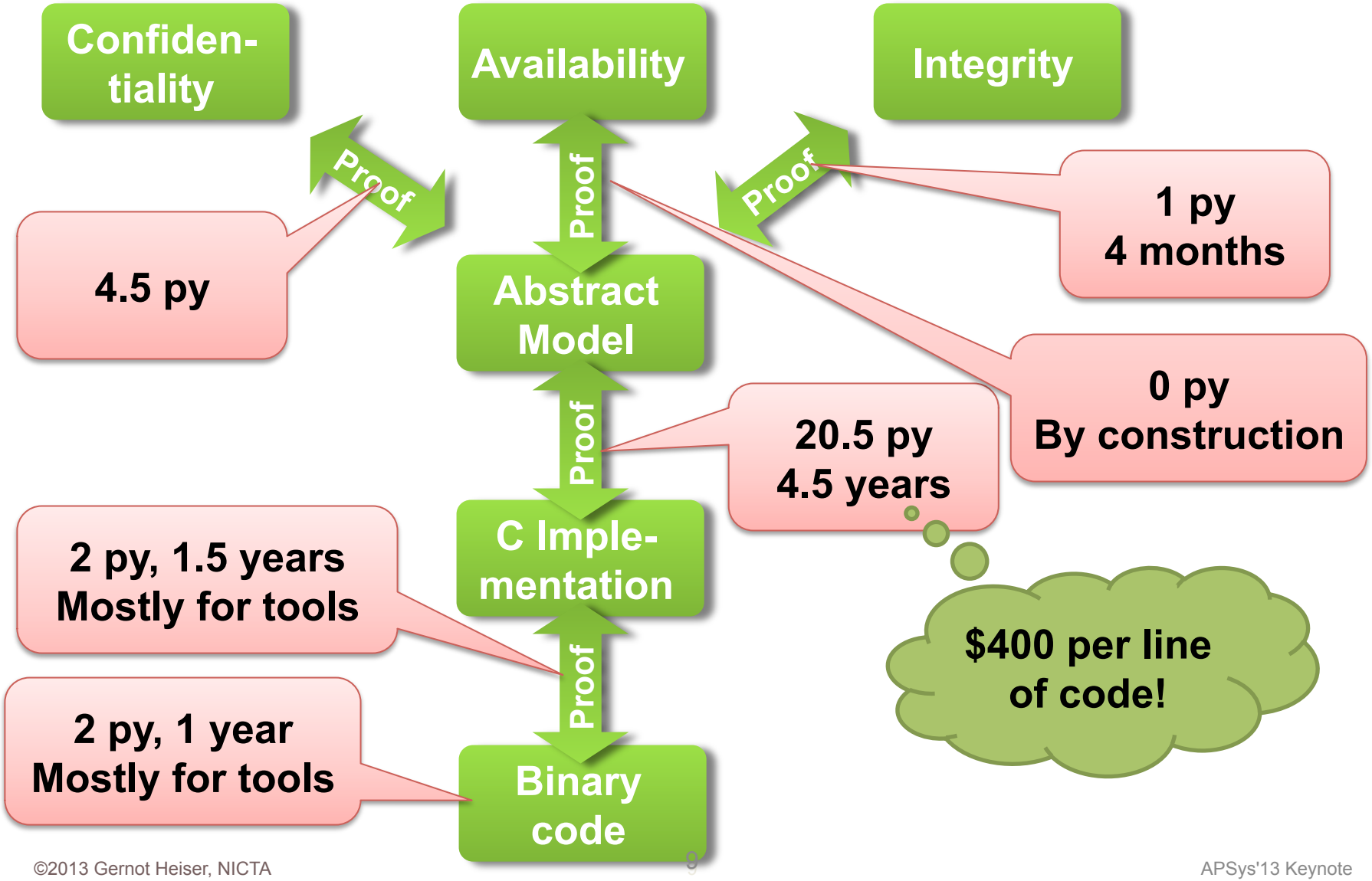
Predecessor deployed on 2 billion devices

First and only operating-system with *proof* of integrity and confidentiality enforcement – at the level of binary code!

World's fastest microkernel on ARM architecture

First and only protected-mode operating-system with complete and sound timing analysis

seL4: Cost of Assurance



Cost of Assurance

Industry Best Practice:

- "High assurance": $1,000/LOC, no guarantees, *unoptimised*
- Low assurance: $100–200/LOC, 1–5 faults/kLOC, *optimised*

State of the Art – seL4:

  - $400/LOC, 0 faults/kLOC
- Estimate repeat would cost half
  - that's about the development cost of the predecessor Pistachio!
- Aggressive optimisation [APSys'12]
  - much faster than traditional high-assurance kernels
  - as fast as best-performing low-assurance kernels

What Have We Learnt?

Formal verification *probably* didn't produce a more *secure* kernel

- In reality, traditional separation kernels are *probably* secure

But:

- We now have certainty
- We did it *probably* at less cost

Real achievement:

- Cost-competitive at a scale where traditional approaches still work
- Foundation for scaling beyond: **2 × cheaper, 10 × bigger!**

How?

- Combine theorem proving with
  - synthesis
  - domain–specific languages (DSLs)

Next Step: Full System Assurance

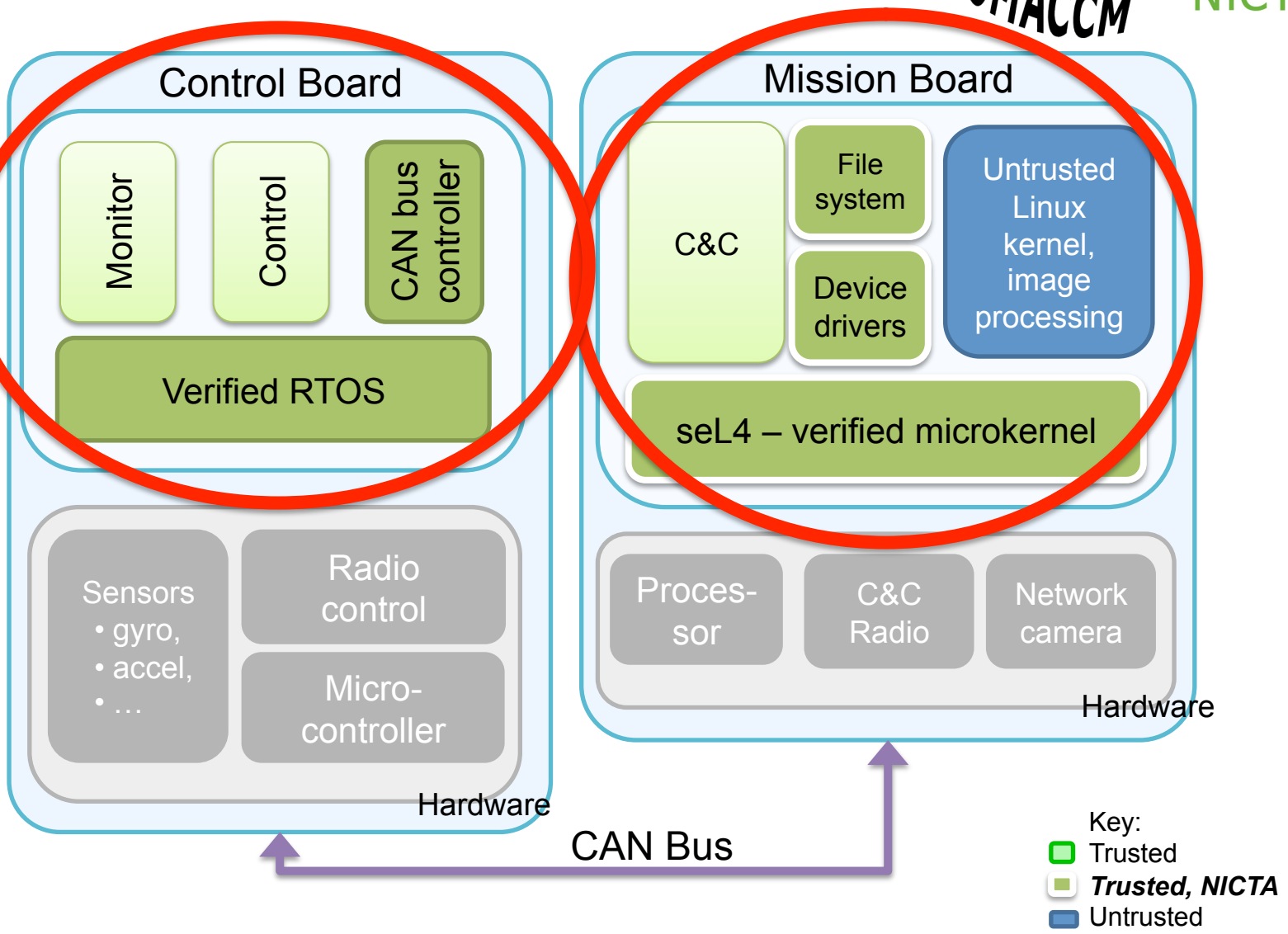
DARPA HACMS Program:

- Provable vehicle safety
- "Red Team" must not be able to divert vehicle

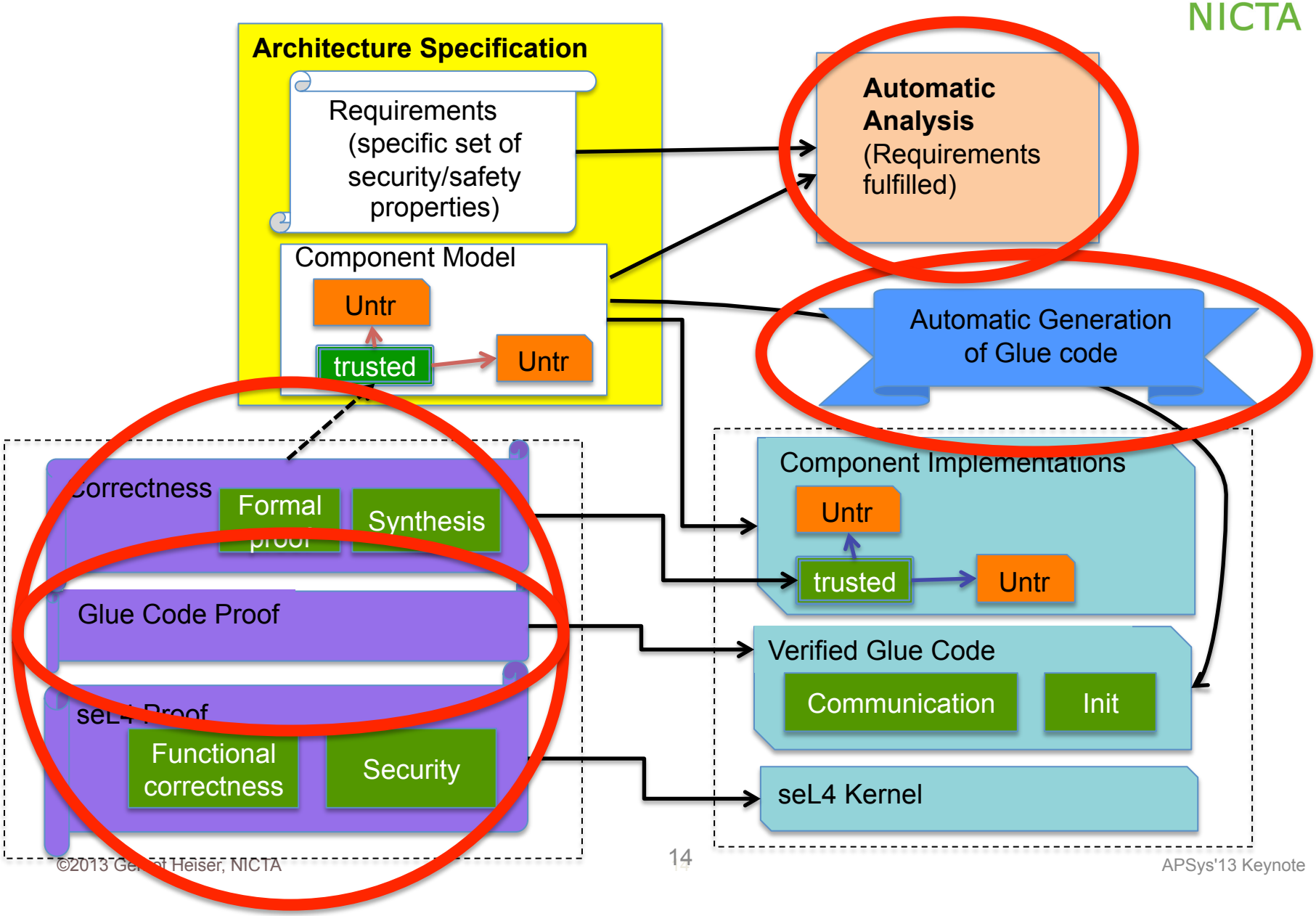
SMACCMcopter
Research Vehicle

Boeing Unmanned
Little Bird (AH-6)
Deployment Vehicle

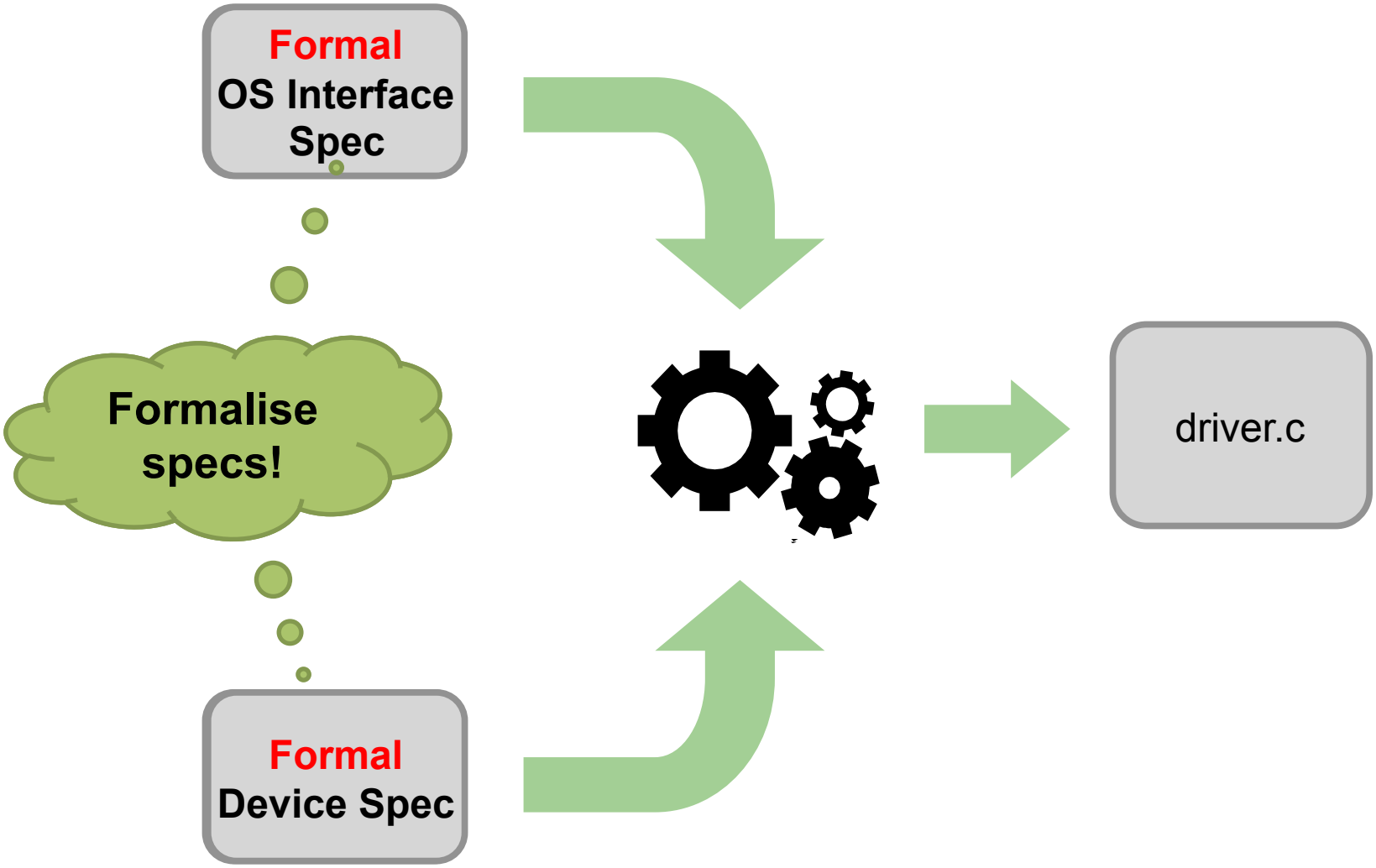
System Structure



Architecting System-Level Security/Safety



Synthesis: Device Drivers [SOSP'09]



Actually works! (On Linux & seL4)

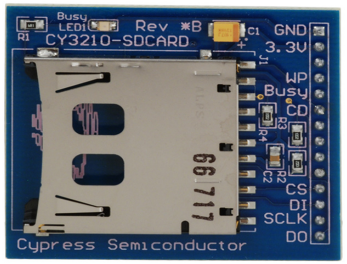
IDE disk controller

W5100 Eth shield

Intel PRO/1000 Ethernet

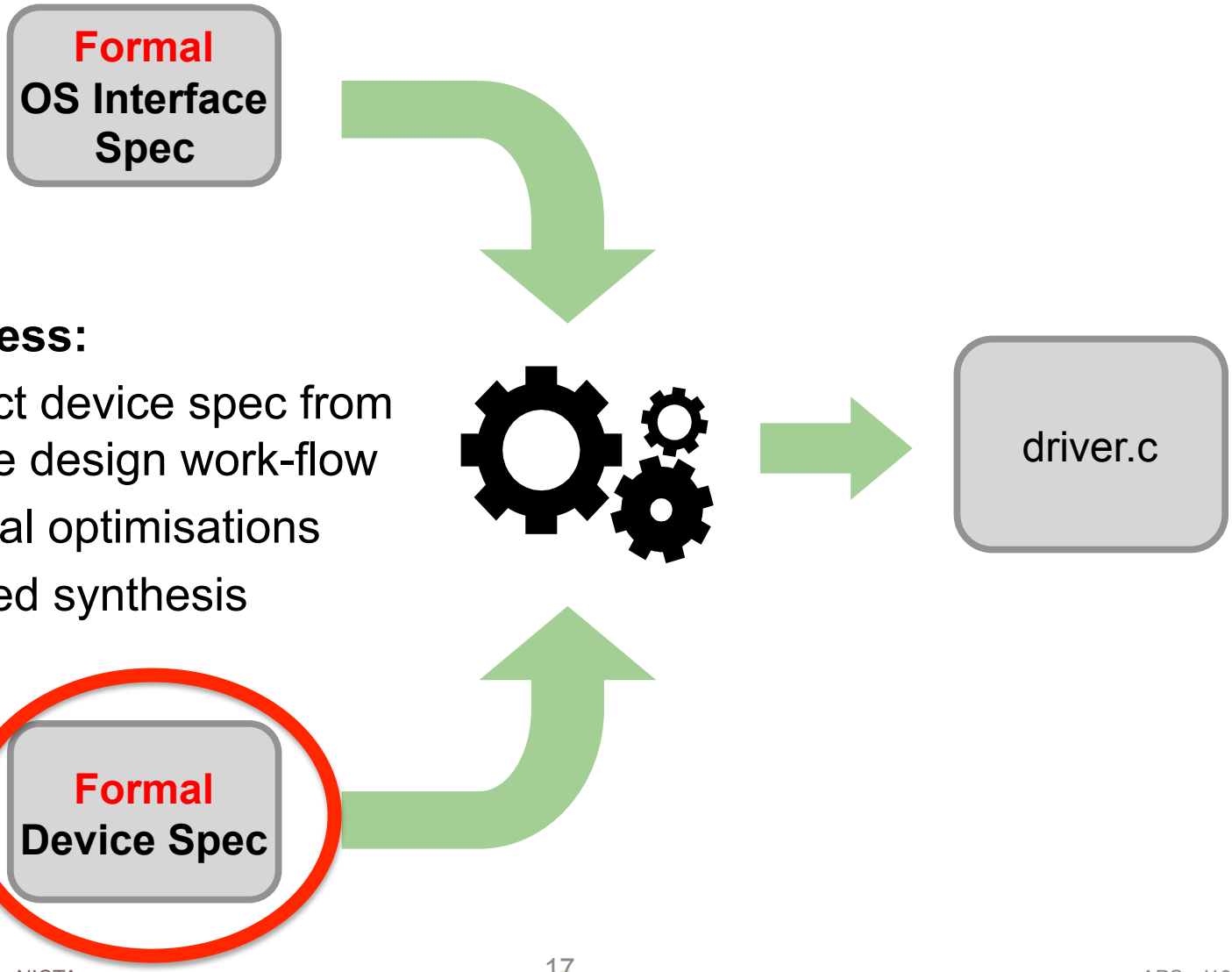
UART controller

Asix AX88772 USB-to-Eth adapter

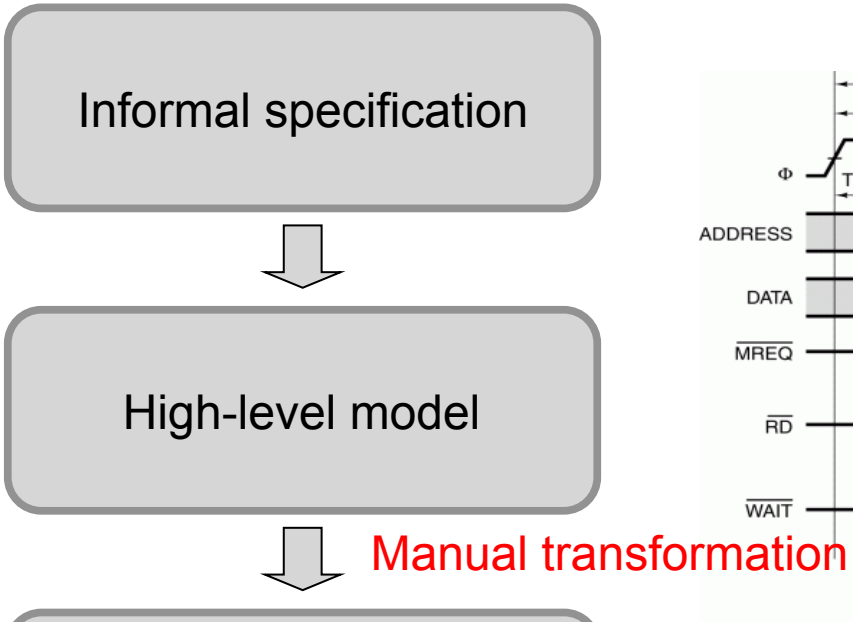


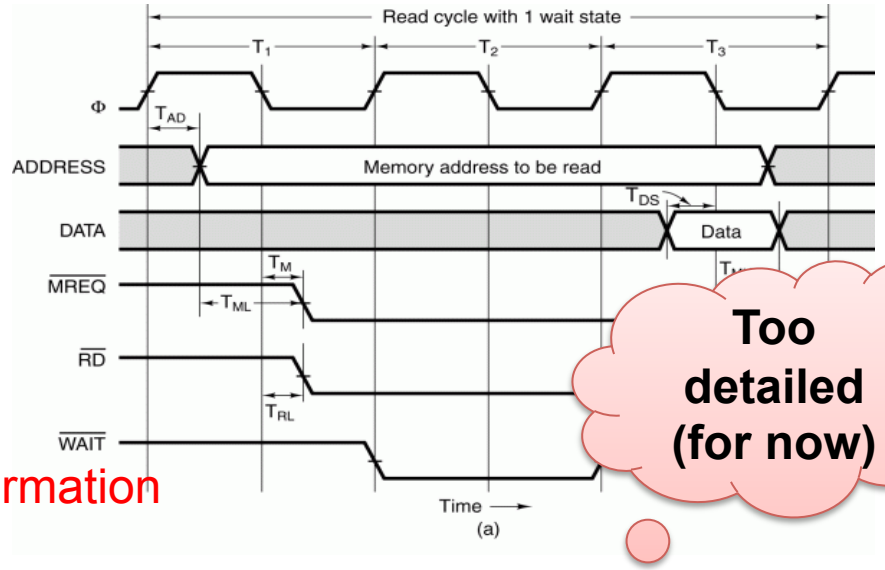
SD host controller

Synthesis: Device Drivers



Hardware Design Workflow

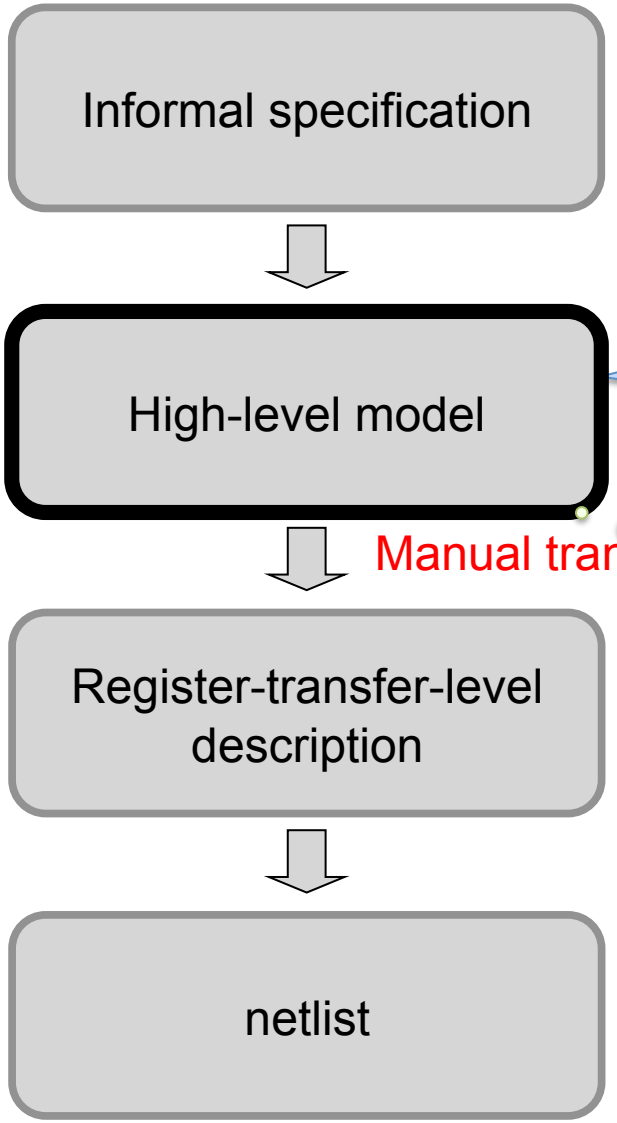




Too detailed (for now)

- Low-level description: registers, gates, wires.
- Cycle-accurate
- Precisely models internal device architecture and interfaces
- “Gold reference”

Hardware Design Workflow

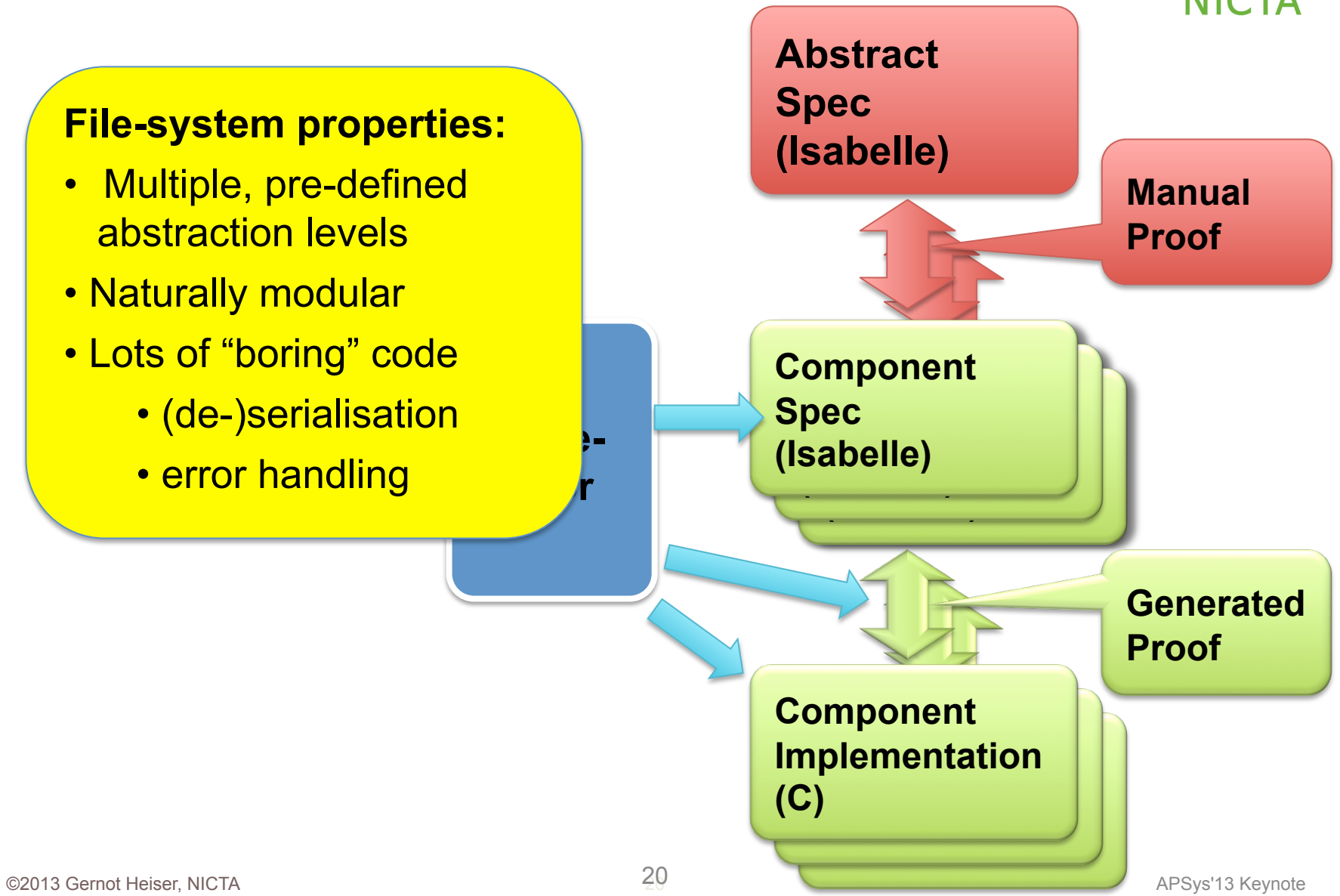


- Captures external behaviour
- Abstracts away structure and timing
- Abstracts away the low-level interface

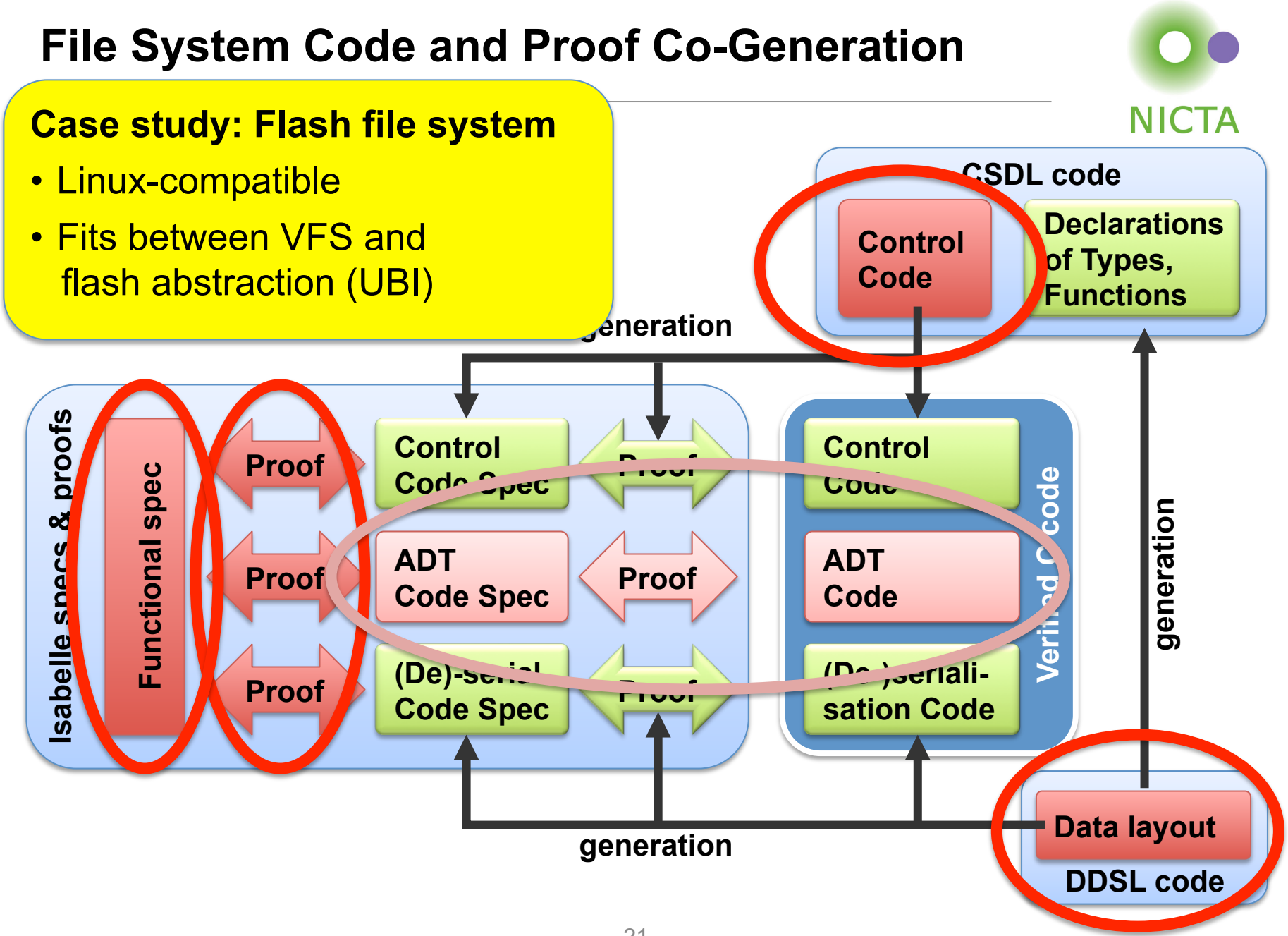
Use for now

```
bus_write(u32 addr, u32 val)
{
  ...
}
```

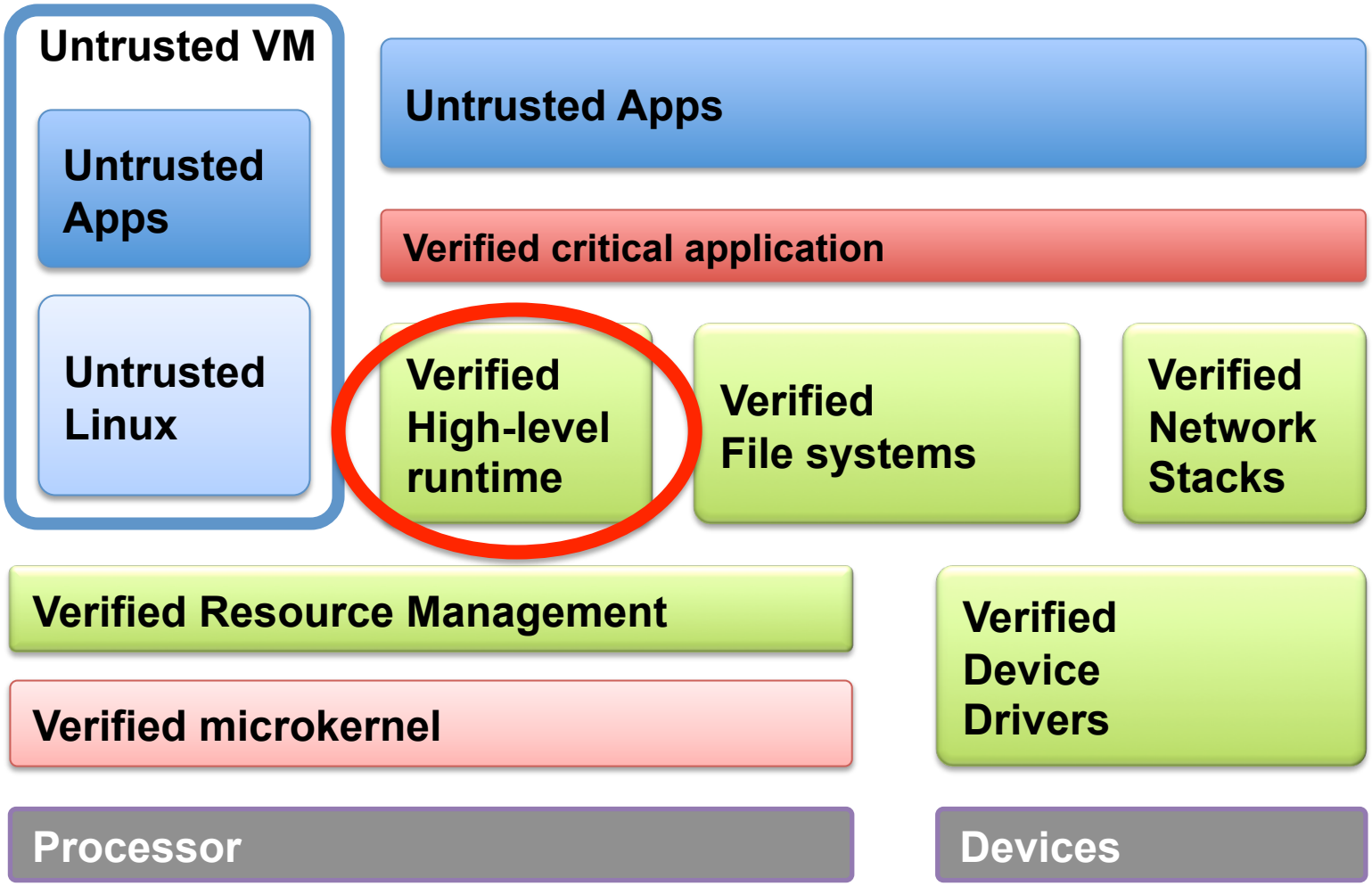
DSLs: File System



File System Code and Proof Co-Generation



Vision: Trustworthy System



Lessons Learnt So Far

Formal methods are expensive?

- Cost-effective for high assurance on small to moderate scale
- $200-400/LOC for 10kLOC

We think we can scale bigger and cheaper:

- Componentisation
  - verify components in isolation – enabled by seL4 guarantees
  - cost – performance tradeoff
- Synthesis
- Abstraction: DSLs, HLLs increase productivity

Big challenge: Proof composition

The next few years will be exciting!