Provable Security and Safety

The seL4 Microkernel and its Use in Critical Systems

Gernot Heiser | gernot.heiser@data61.csiro.au | @GernotHeiser
http://microkerneldude.wordpress.com

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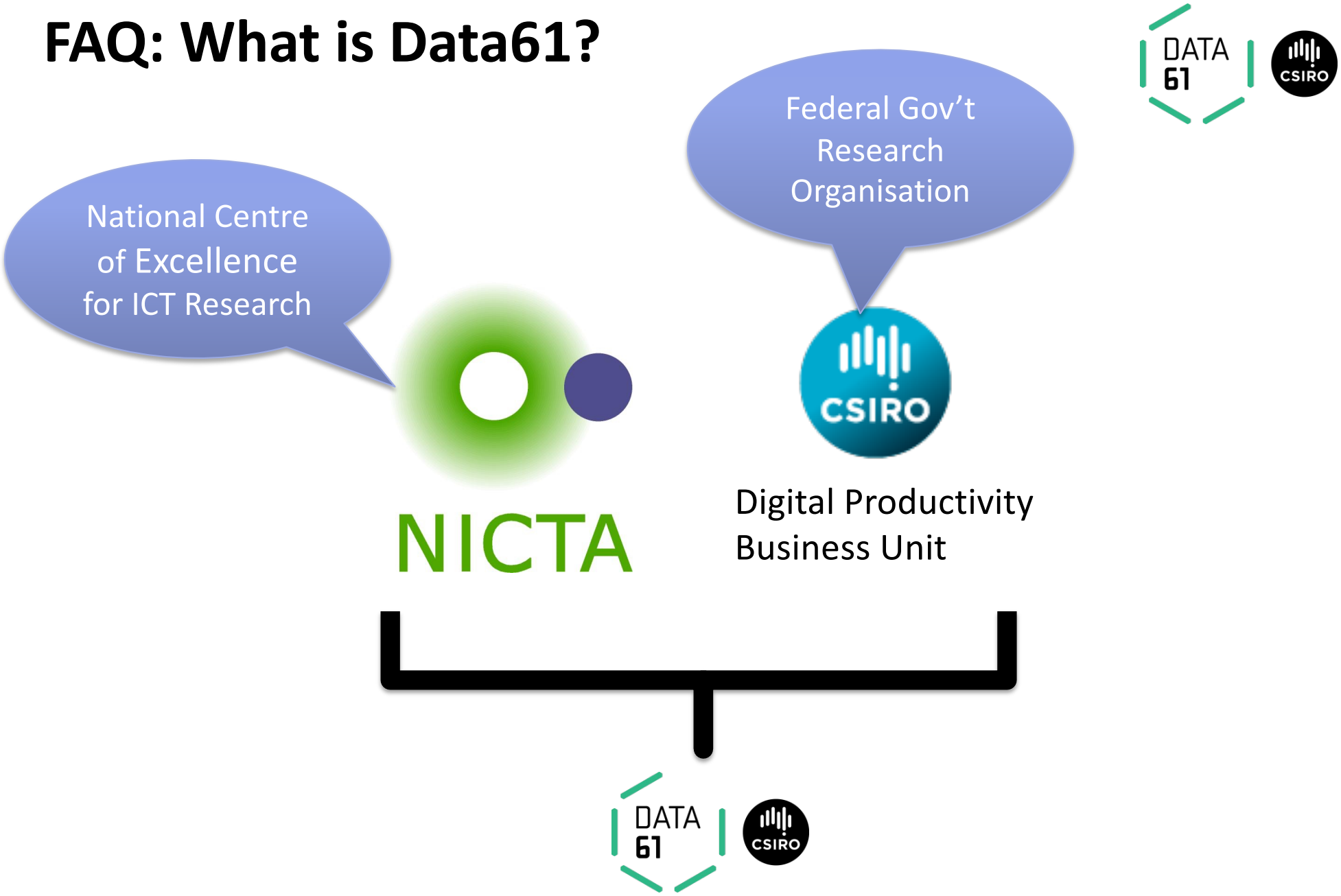
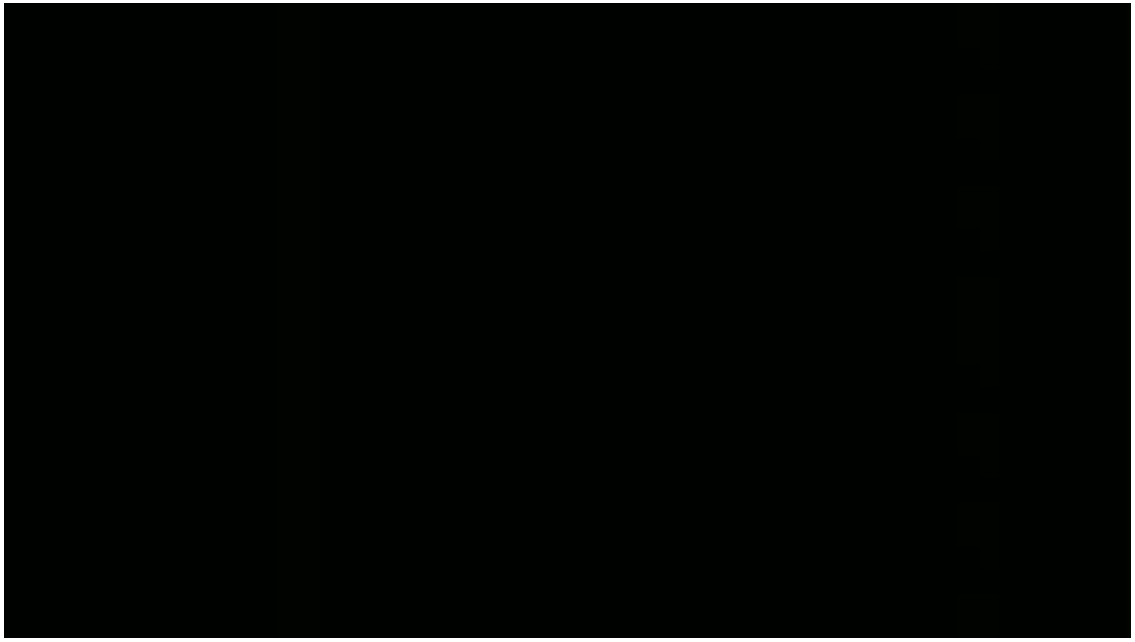
https://trustworthy.systems/

CSIRO

FAQ: What is Data61?

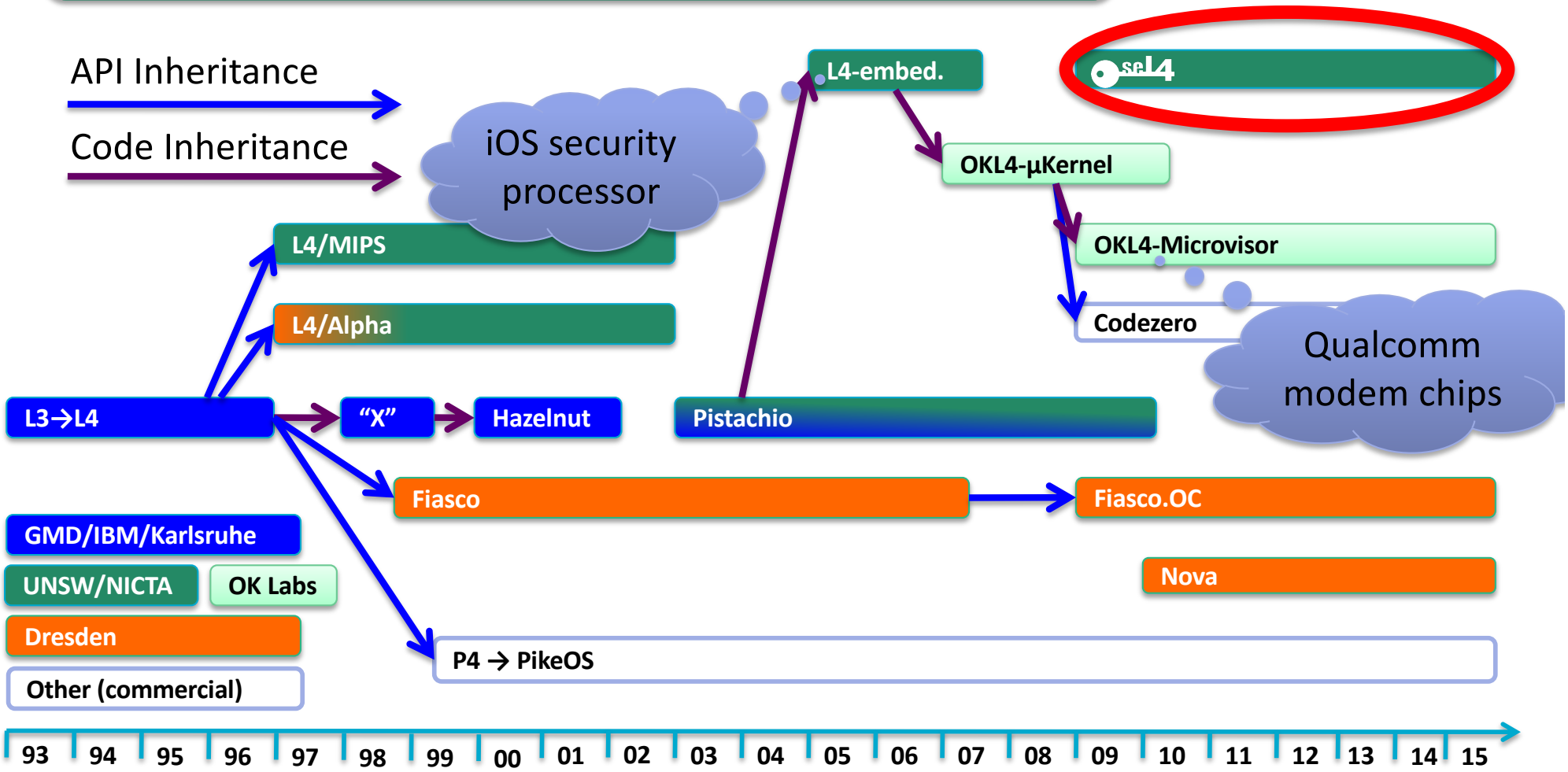


Mesa, AZ, 24 July 2015



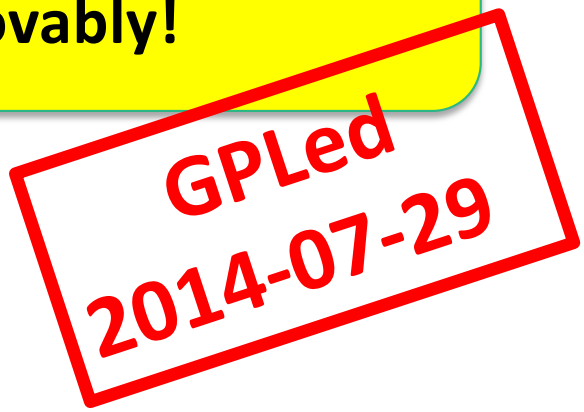
L4 Family Tree

seL4: The latest (and most advanced) member of the L4 microkernel family – 20 years of history and experience



What is seL4?

seL4: The world's most (only?) secure OS kernel – provably!



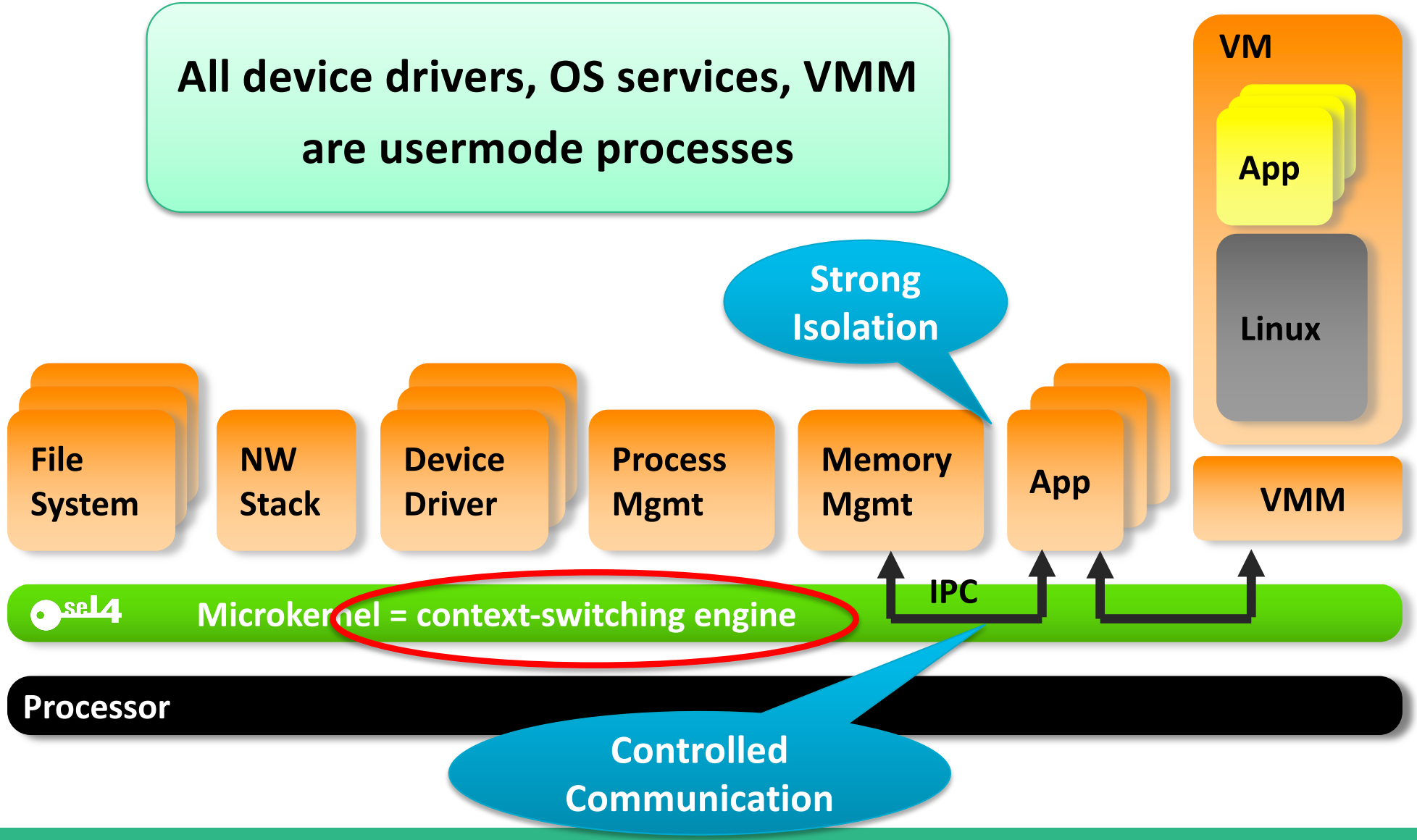
Philosophy Underlying seL4

1. Security is paramount and drives design

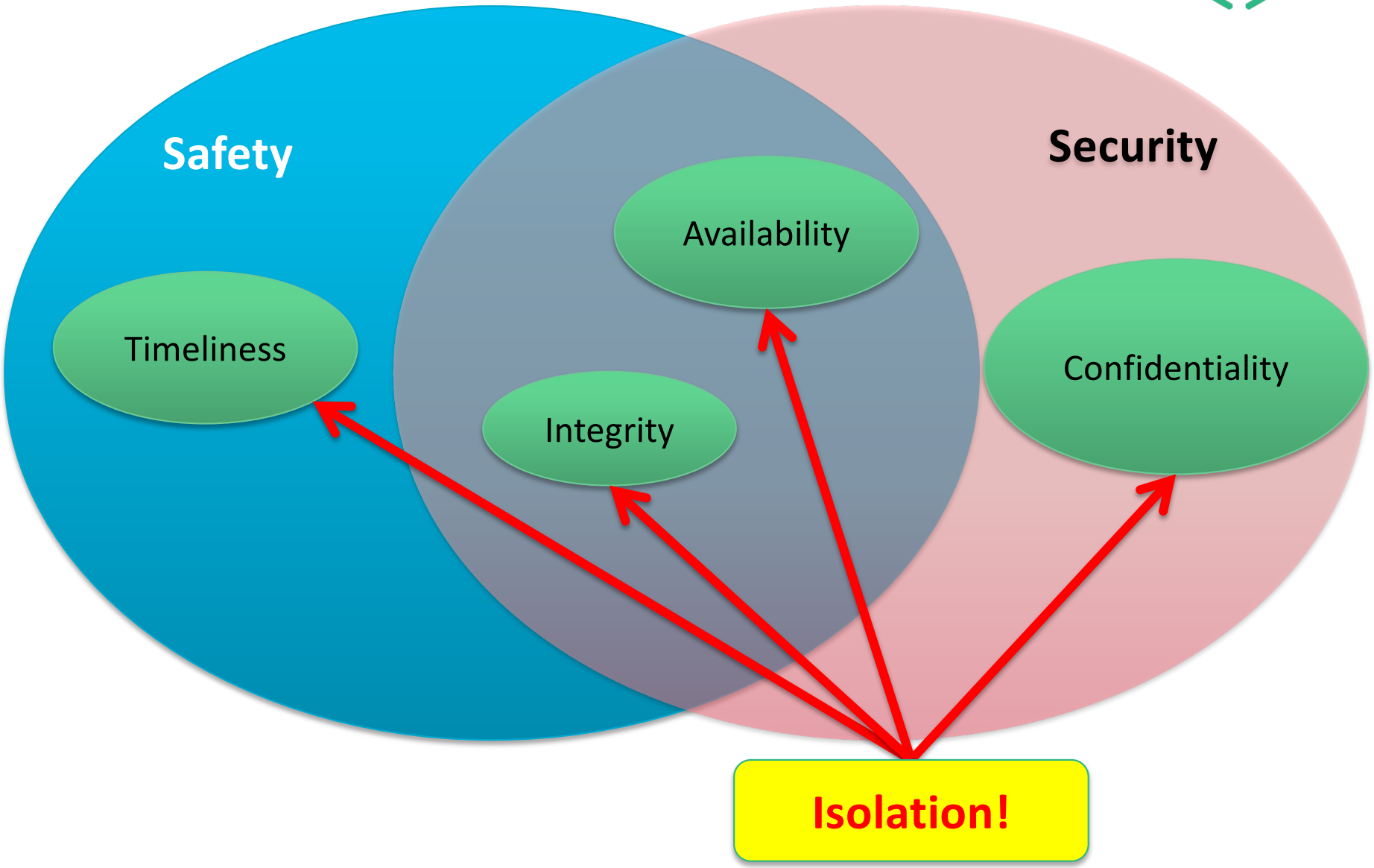
2. Security is no excuse for bad performance

3. General-purpose platform for wide range of use cases

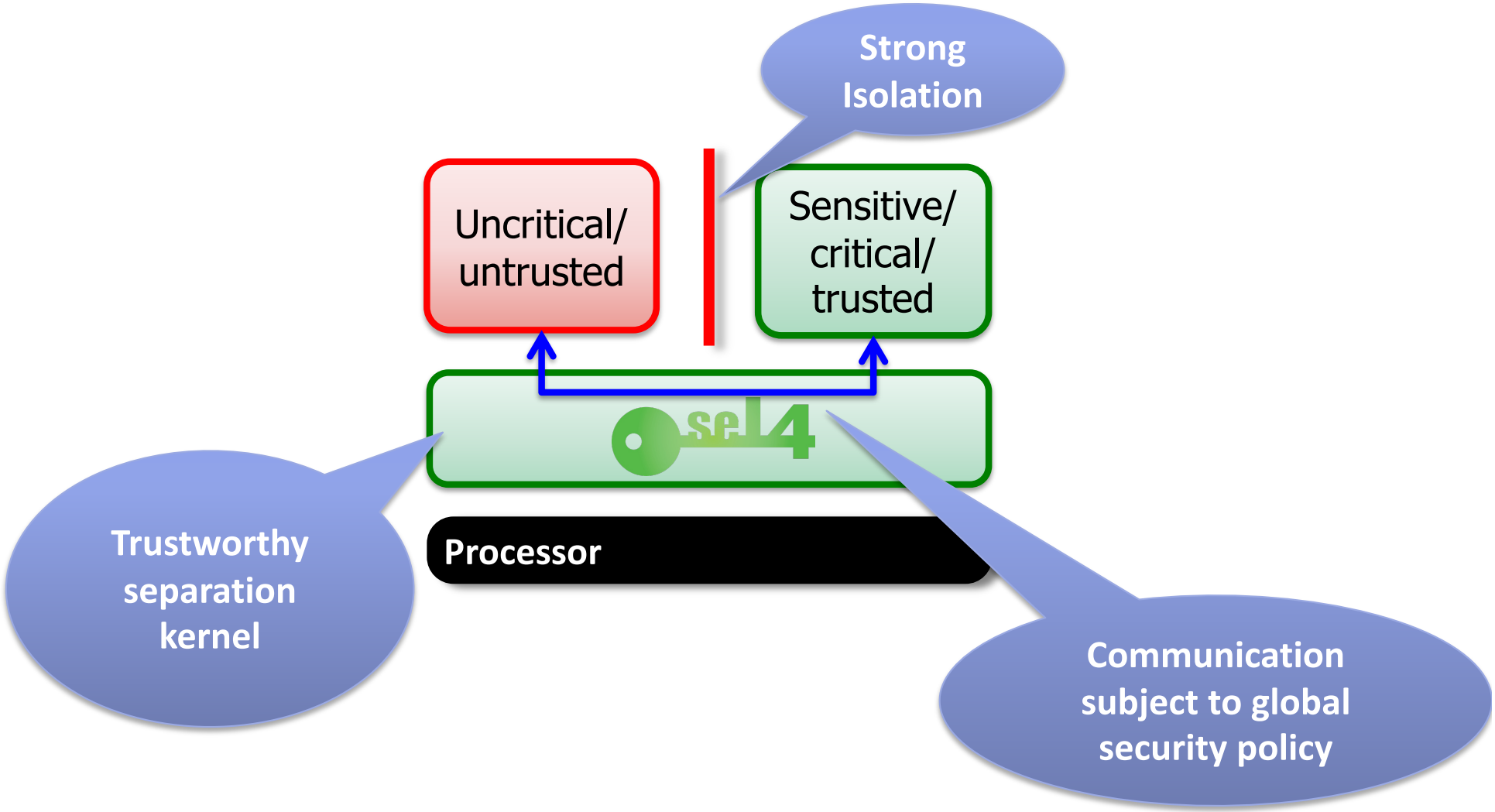
What seL4 Is Not: An Operating System



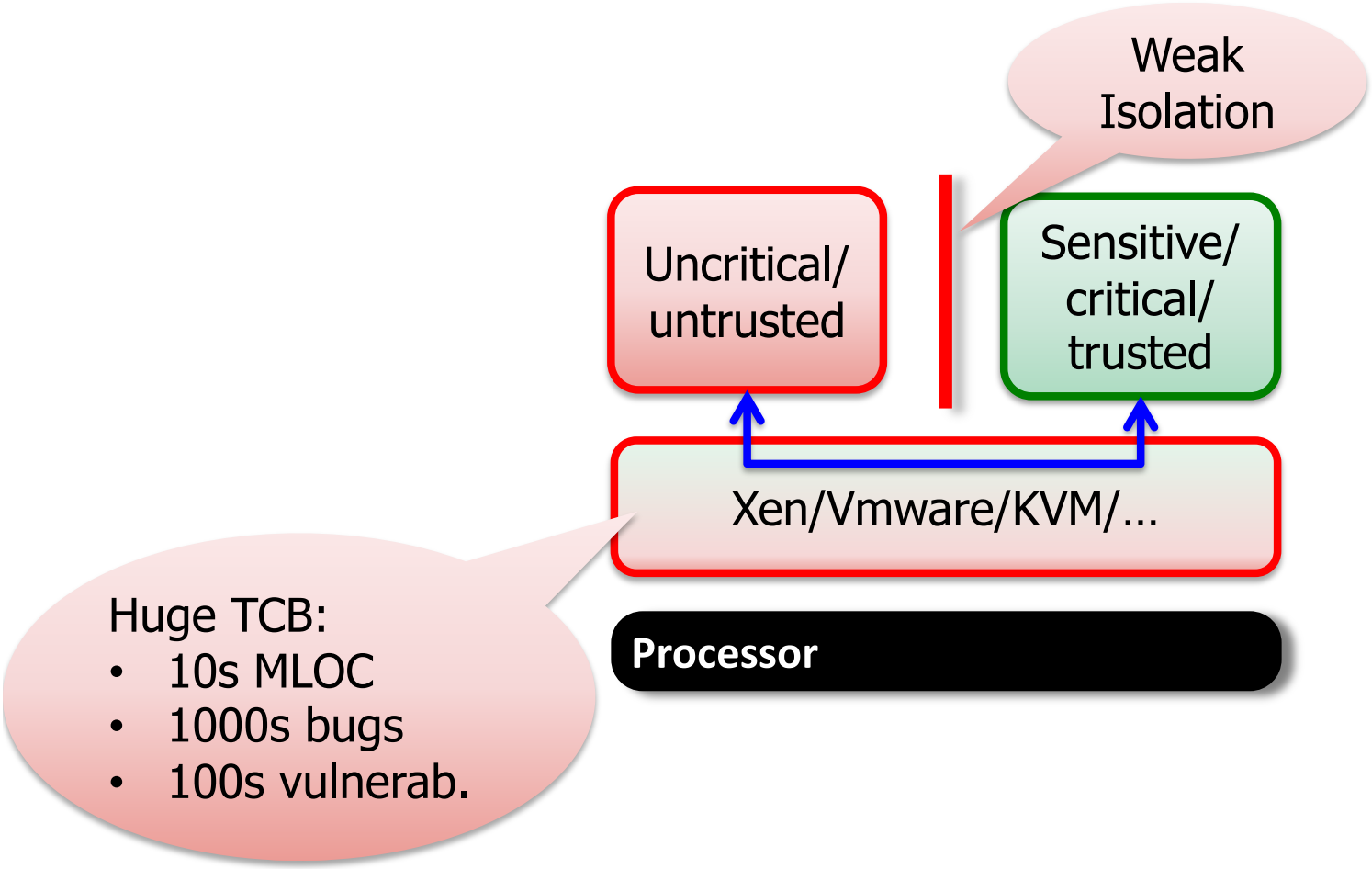
Requirements for Trustworthy Systems

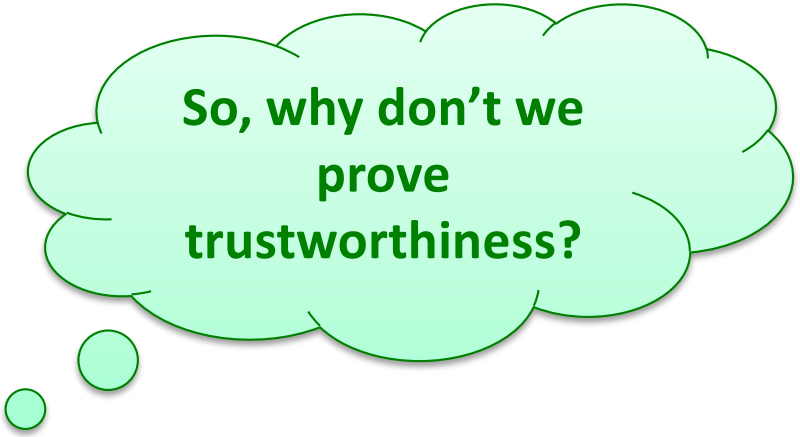


Fundamental Requirement: Isolation



“High Assurance” *Bad* Practice





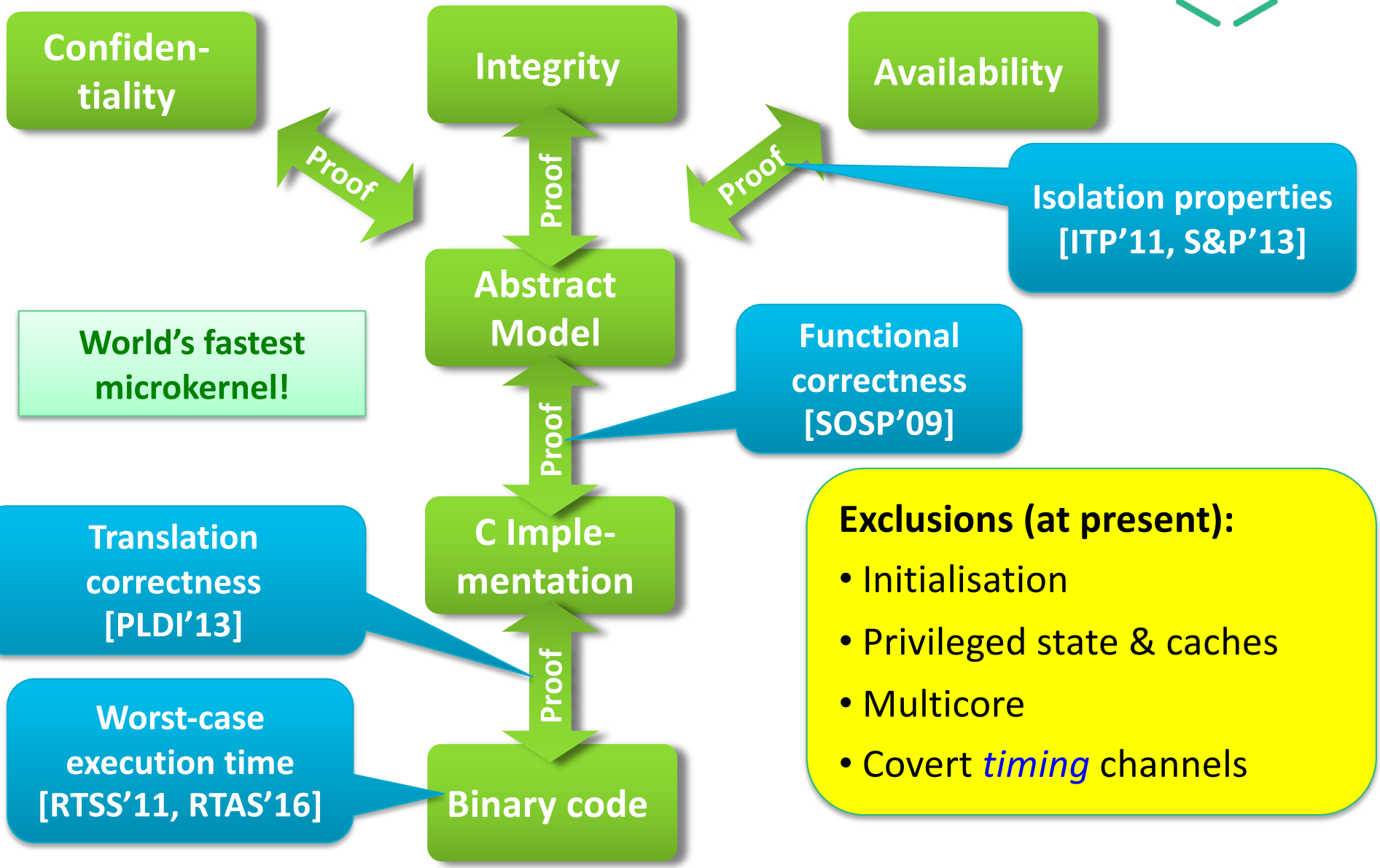
***Claim*:**

A system must be considered *untrustworthy* unless *proved* otherwise!

Corollary [with apologies to Dijkstra]:

Testing, code inspection, etc. can only show *lack of trustworthiness*!

seL4: Provable Isolation



Fundamental Design Decisions for seL4

1. Memory management is user-level responsibility
   - Kernel never allocates memory (post-boot)
   - Kernel objects controlled by user-mode servers

Isolation

2. Memory management is fully delegatable
   - Supports hierarchical system design
   - Enabled by *capability-based access control*

Perfor-mance

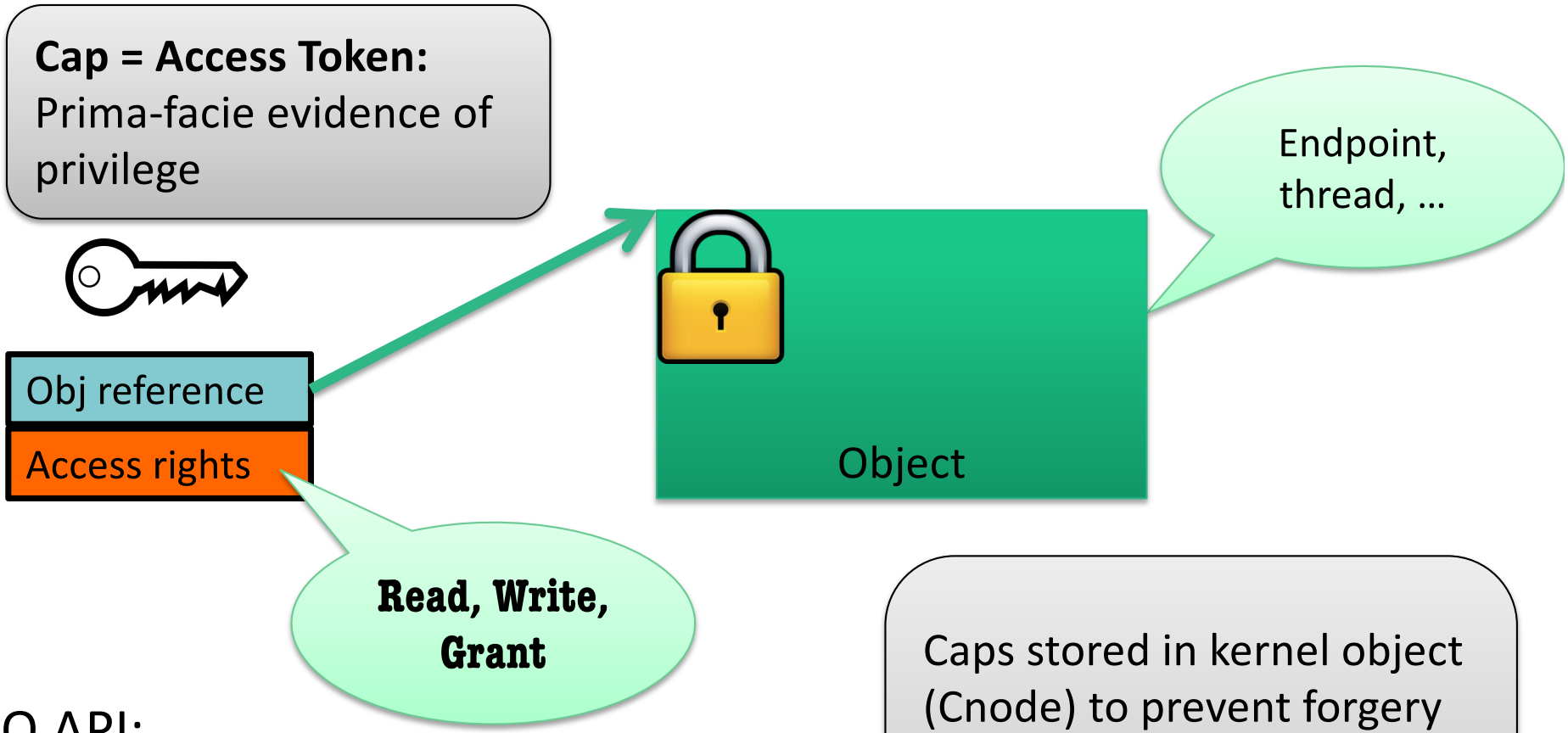
3. "Incremental consistency" design pattern
   - Fast transitions between consistent states
   - Restartable operations with progress guarantee

Real-time

4. No concurrency in the kernel
   - Interrupts never enabled in kernel
   - Interruption points to bound latencies
   - Clustered multikernel design for multicores

Verification, Performance

Key Mechanism: seL4 Capabilities



- OO API:

  `err = method( cap, args );`

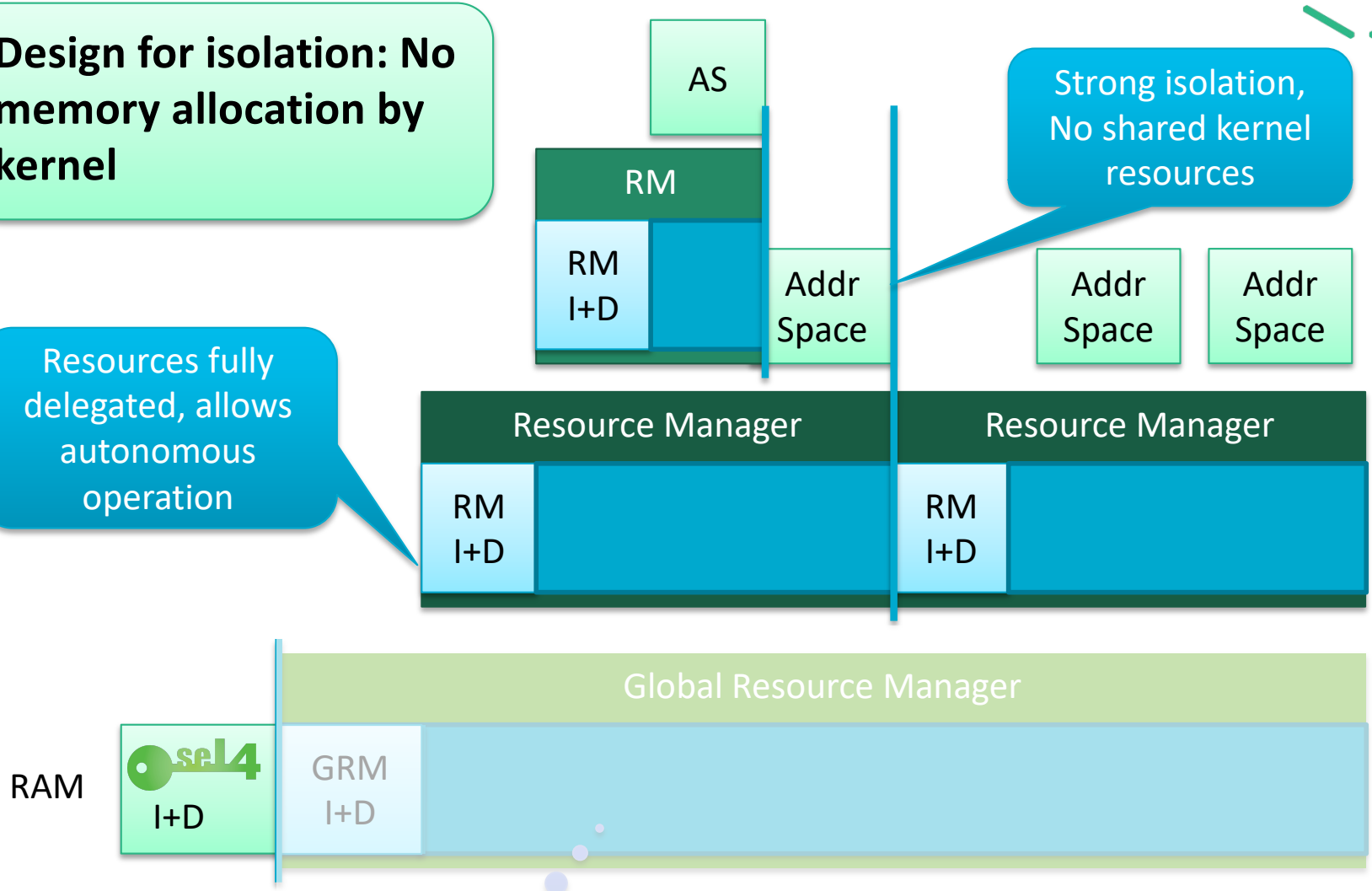
- Used in some earlier microkernels:
  - KeyKOS [‘85], Mach [‘87], EROS [‘99]

Caps stored in kernel object (Cnode) to prevent forgery

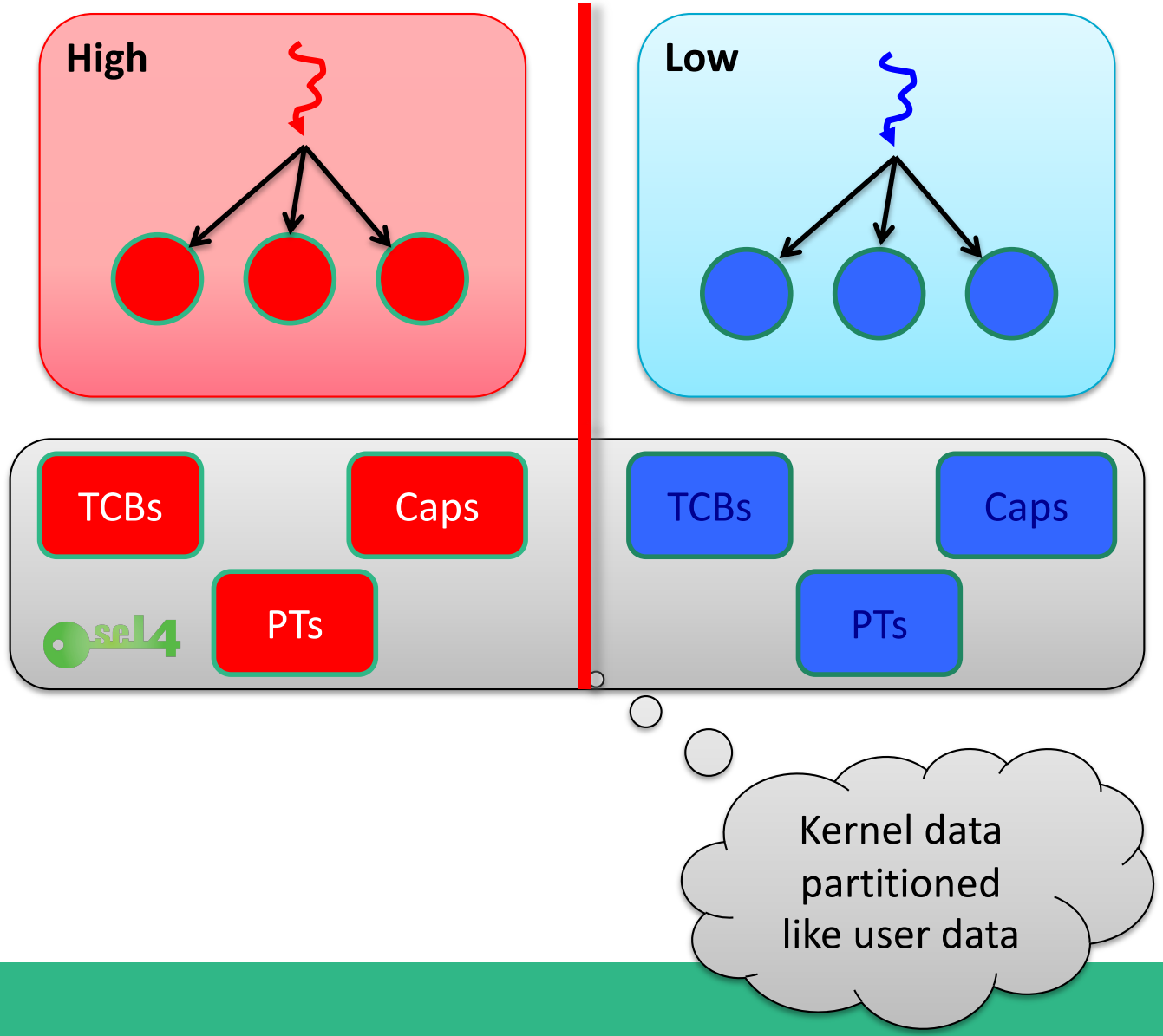
➢ user references cap through handle: CPTR

What's Different to Other Microkernels?

Design for isolation: No memory allocation by kernel



seL4 Isolation Goes Deep



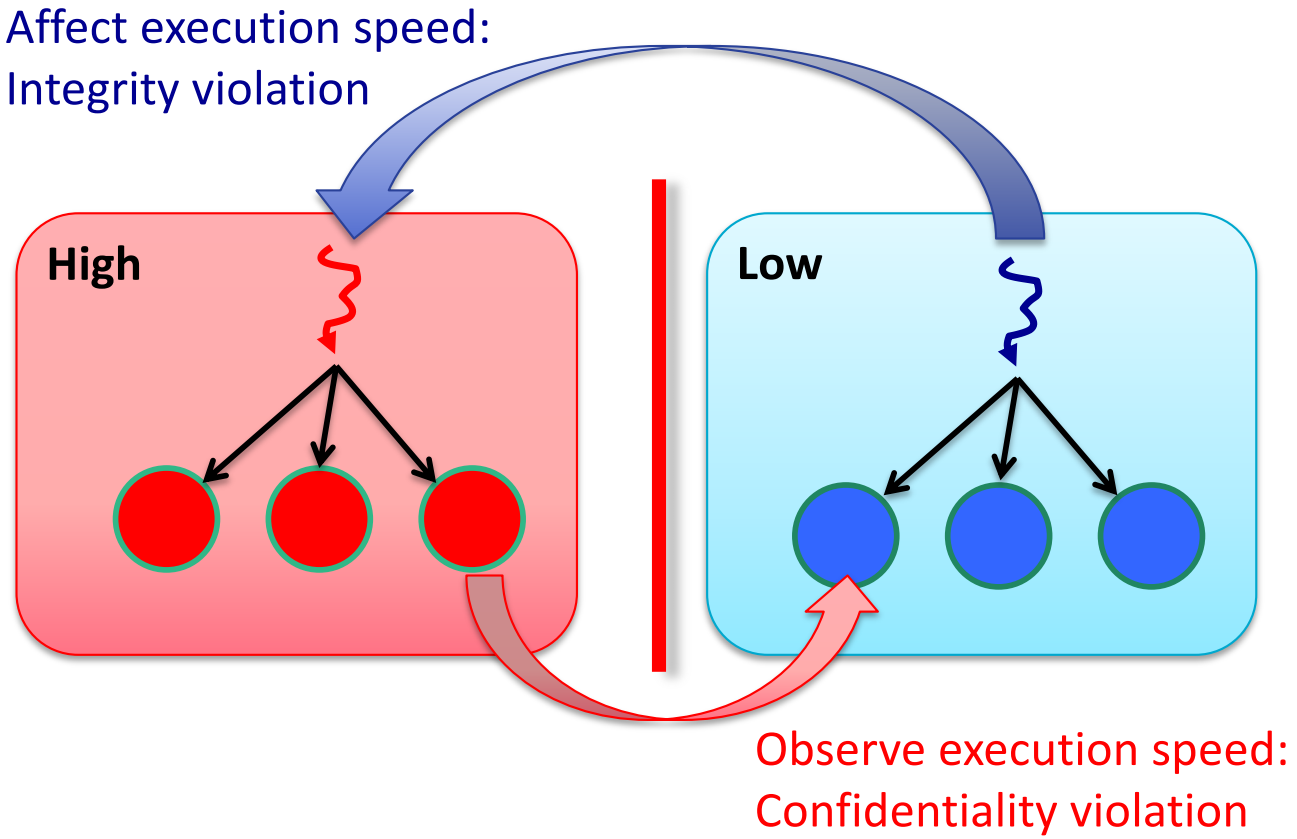
WiP: Temporal Isolation Guarantees

Safety: Timeliness

- Execution interference

Security: Confidentiality

- Leakage via timing channels



Using seL4: DARPA HACMS Program

HACMS: High-Assurance Cyber-Military Systems

- Goal: create technology for the construction of high-assurance cyber-physical systems
  - functionally correct
  - satisfying appropriate safety and security properties

- Specific project aims:
  - Protect autonomous systems from cyber attacks
  - Demonstrate deployment in real-world systems
  - **Open-source all non-vehicle-specific code**

HACMS: 3 Teams

Air Team – “SMACCM”

Land Team

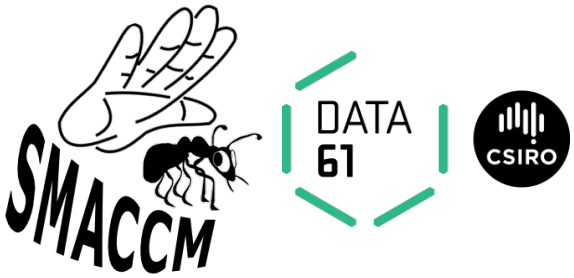
Image courtesy of chanpipat at FreeDigitalPhotos.net

Red Team

HACMS: 3 Phases

- Phase 1: August ‘12 to January ‘14
  - Simplified high-assurance system
- Phase 2: February ‘14 to July ‘15
  - Adding real-world complexity
  - Full-system demo
- Phase 3: August’15 to January’17
  - Transition to real-world military vehicle
    - Boeing Unmanned Little Bird helicopter
    - Autonomous US Army trucks
    - Possibly research drone as “minimal viable product”

Secure, Mathematically-Assured Composition of Control Models



SMACCM Objectives:

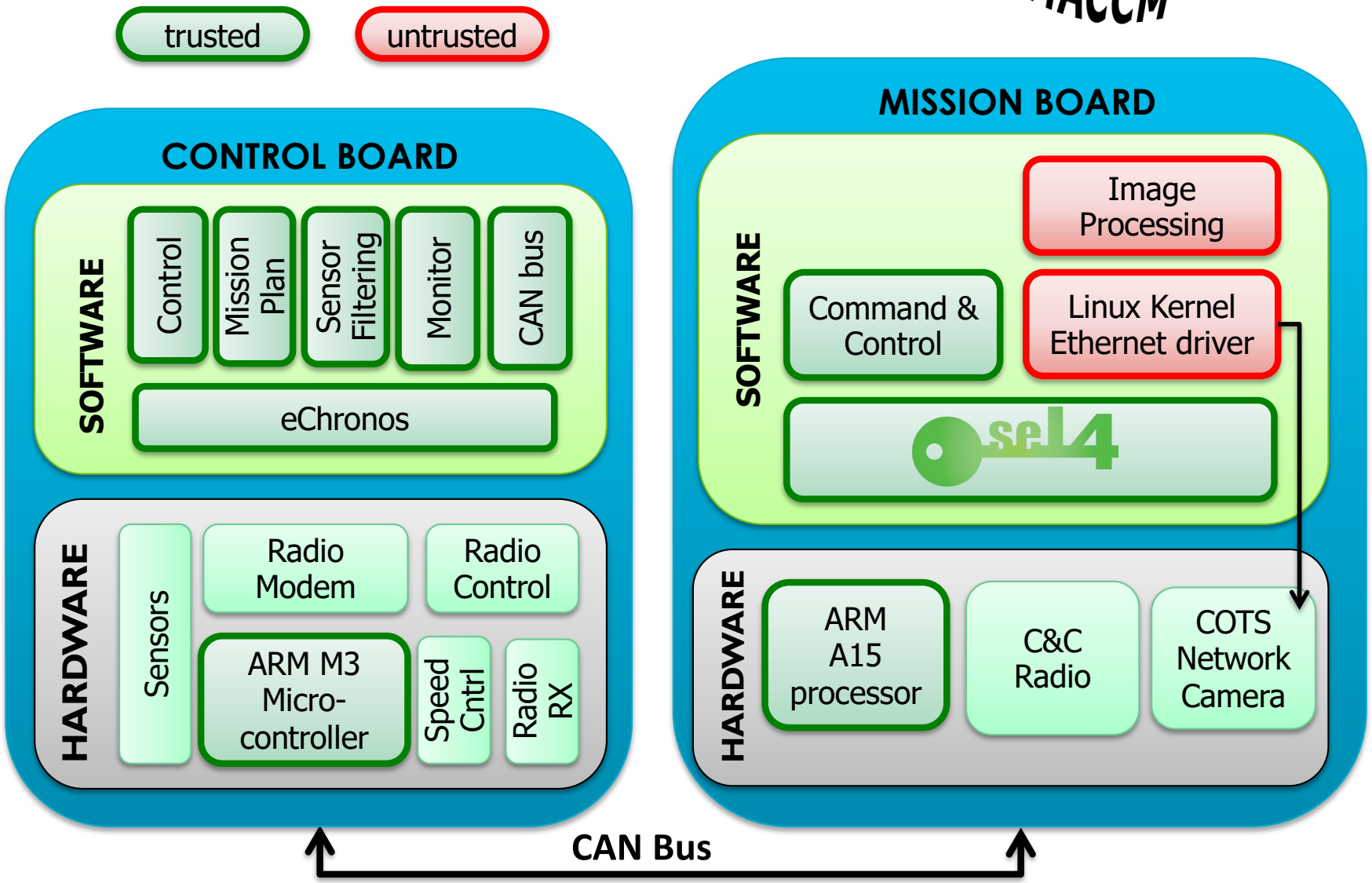
- Provable vehicle safety
- "Red Team" must not be able to divert vehicle
- No sacrificing performance

Unmanned Little Bird Deployment Vehicle

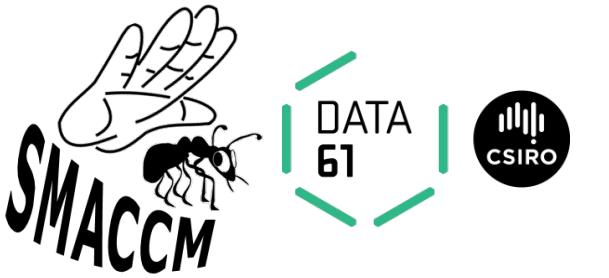
SMACCMcopter Research Vehicle

NICTA Rockwell Collins BOEING | galois | University of Minnesota

SMACCMcopter Architecture



SMACCM Building Blocks



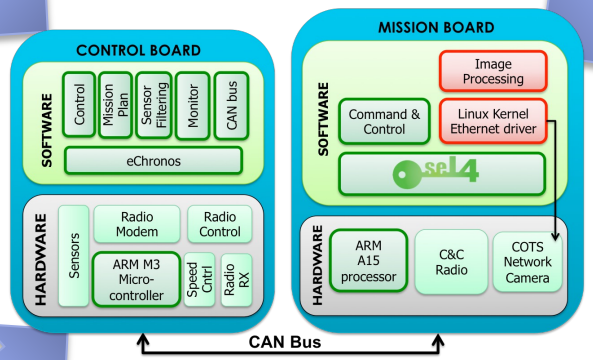
Secure Components
Ivory/Tower

galois

Rockwell Collins

Secure Architecture
AADL Analysis

University of Minnesota



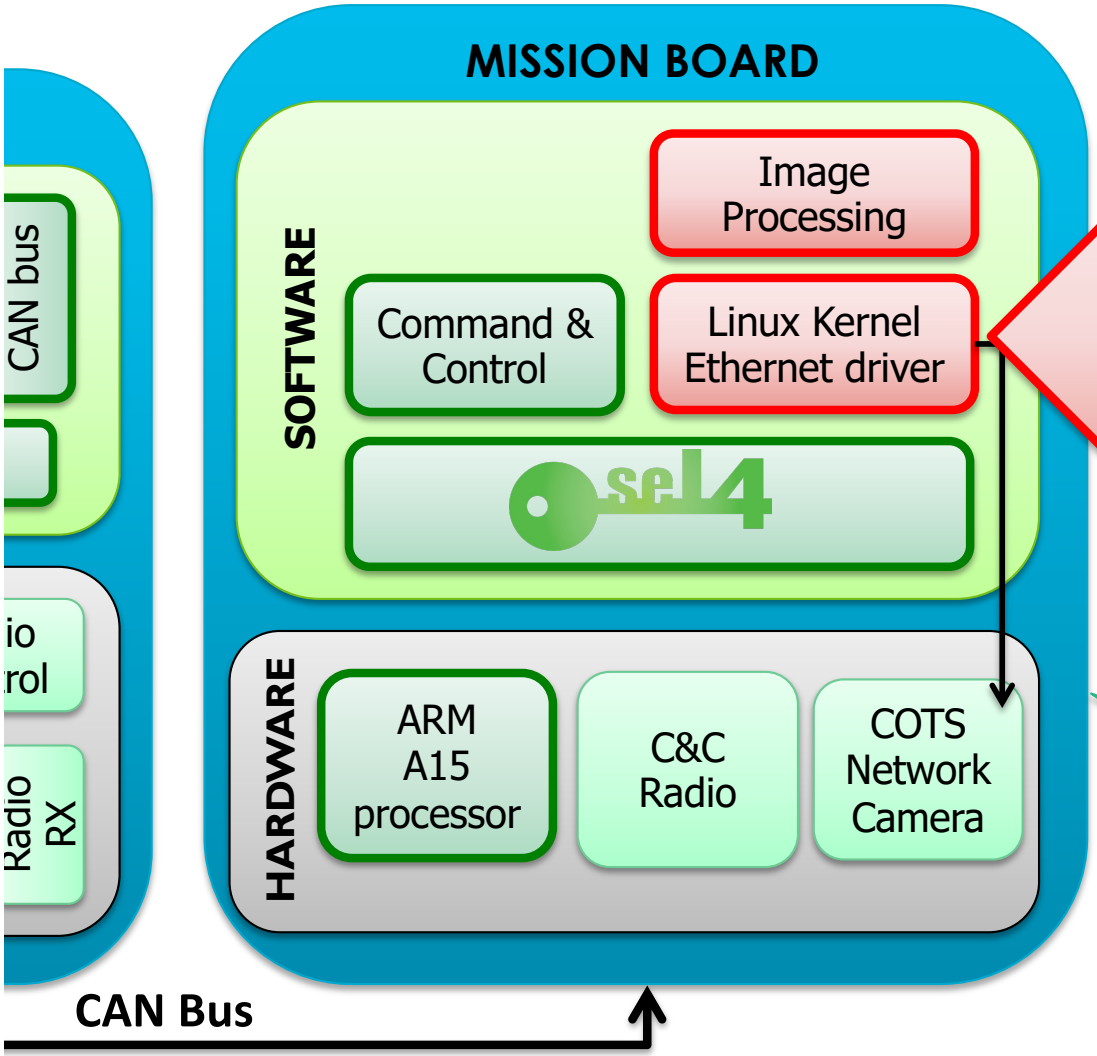
Secure Kernel
seL4

NICTA

Automatic Synthesis

BOEING

Phase 2 Security Evaluation

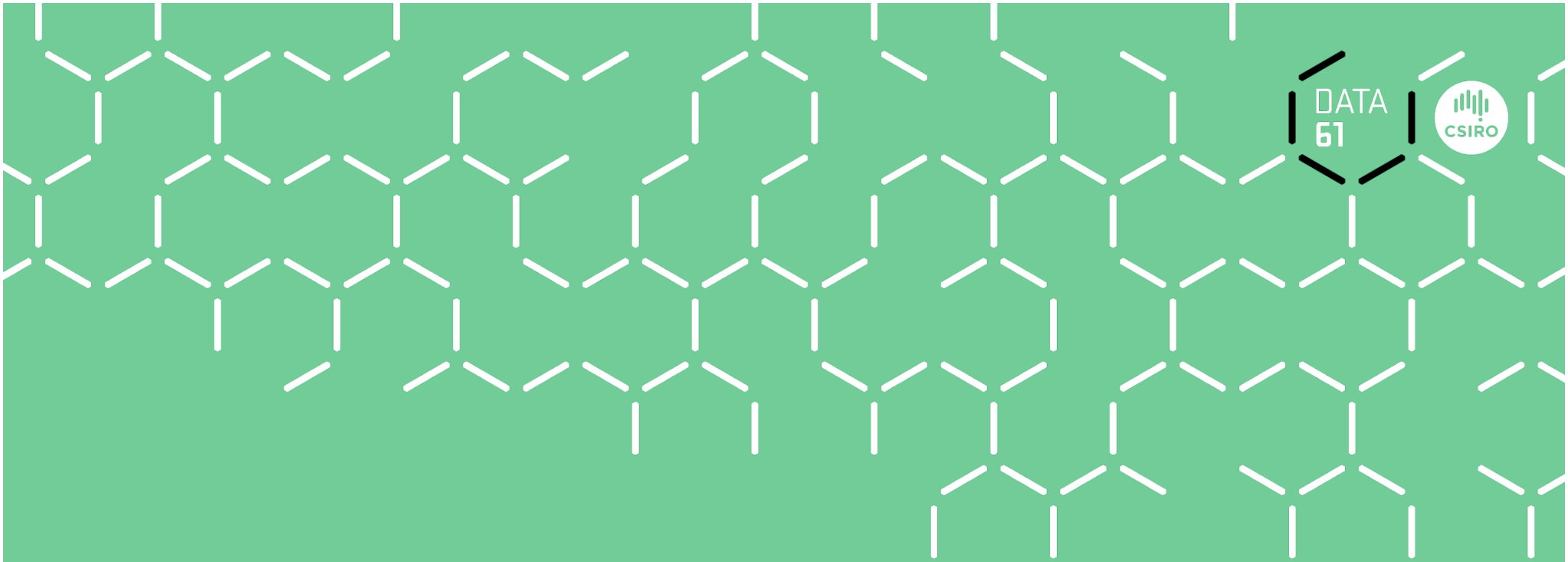


Root access

Image courtesy of chanpipat at FreeDigitalPhotos.net

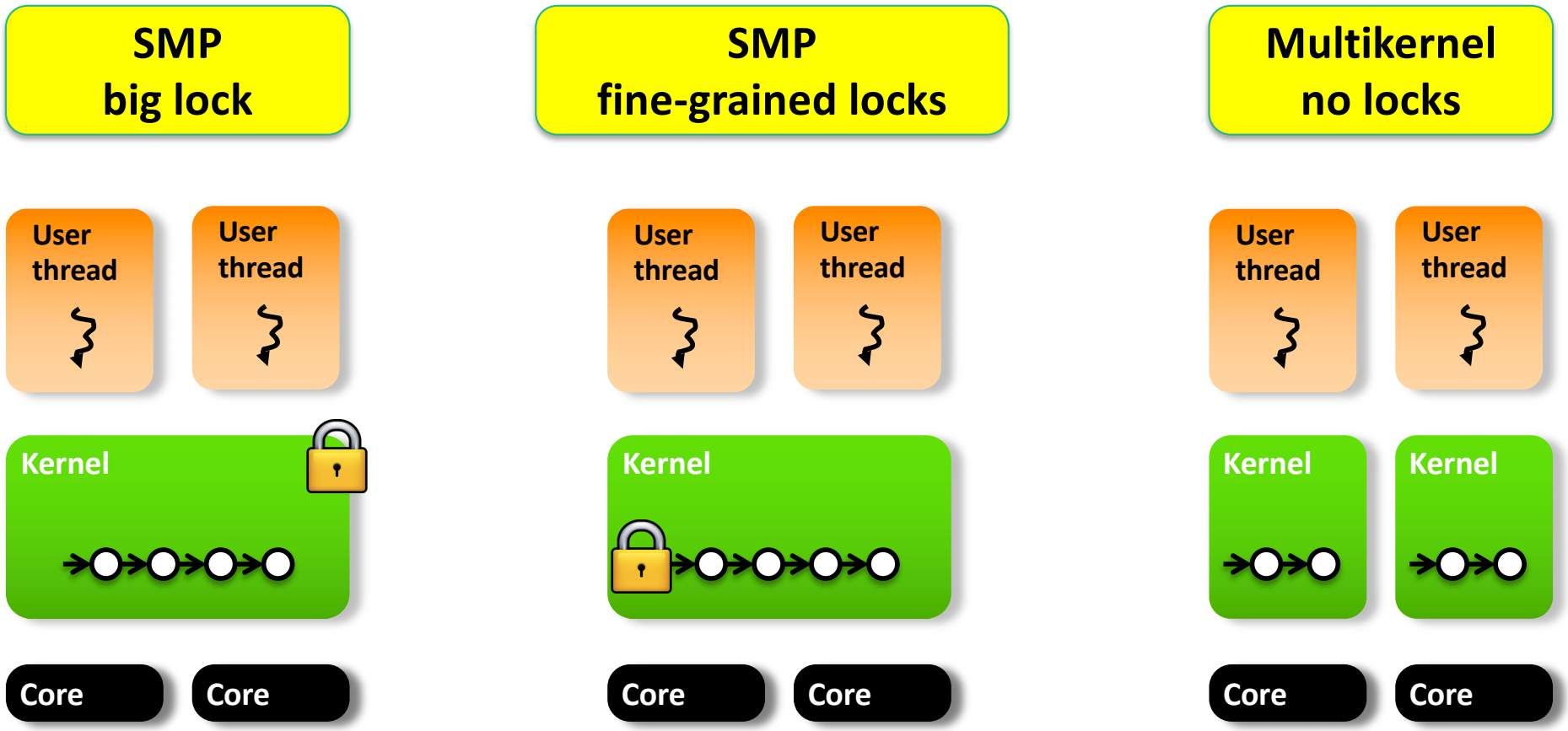
Red Team unable to compromise rest of system (white-box attack)

"World's most highly assured drone" [DARPA]

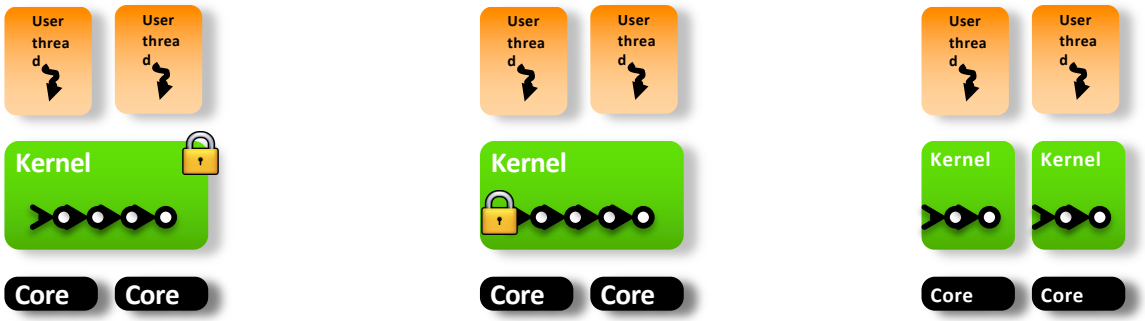


Dealing with Multicore

Approaches for Multicore Kernels



Multicore Kernel Trade-Offs

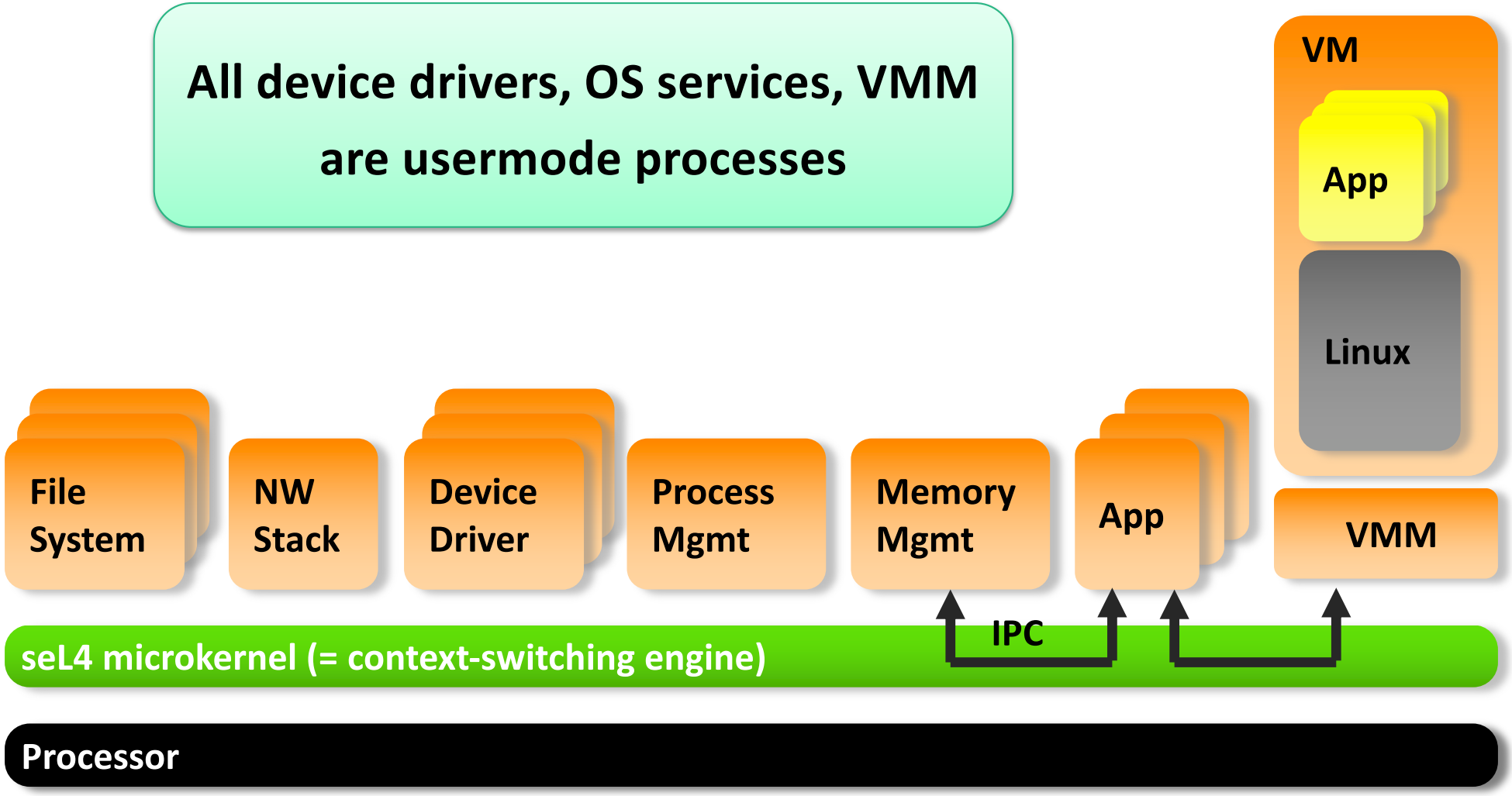


Really?

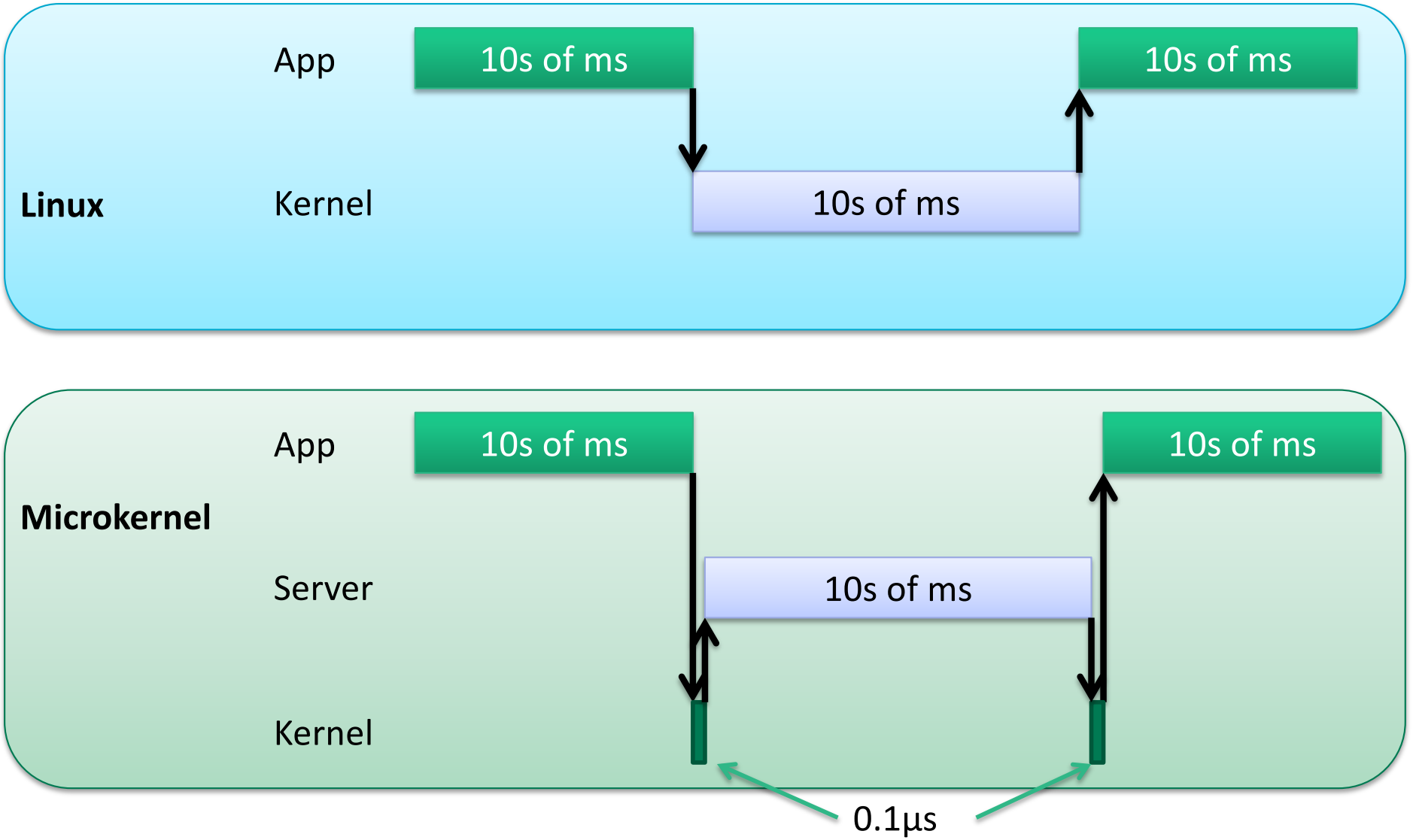
Property	Big Lock	Fine-grained Locking	Multikernel
Data structures	shared	shared	distributed
Scalability	poor	good	excellent
Concurrency in kernel	zero	high	zero
Kernel complexity	low	high	low
Resource management	centralised	centralised	distributed

Remember: Microkernel ≠ Operating System!

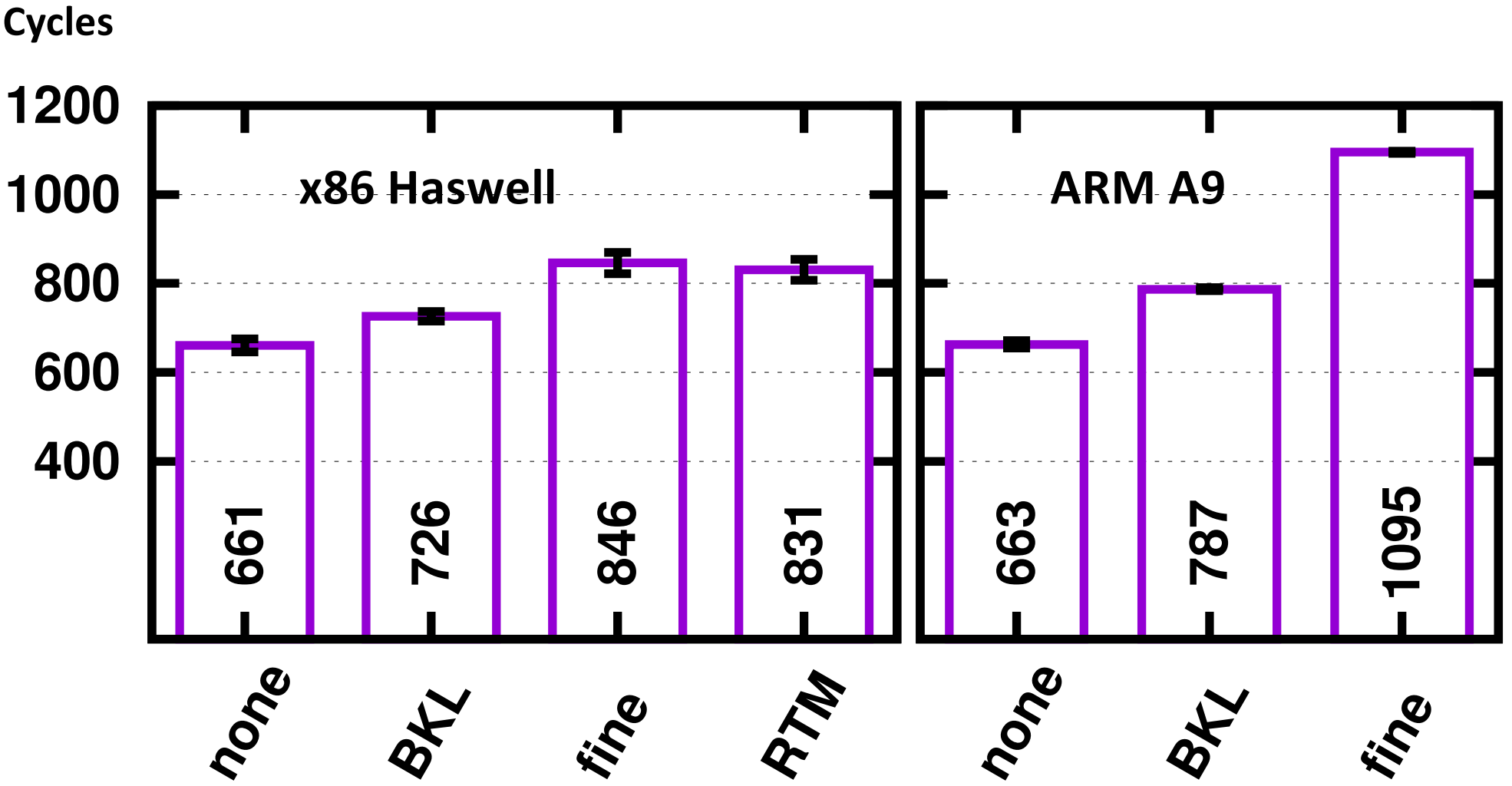
All device drivers, OS services, VMM are usermode processes



Microkernel vs Linux Execution



Cost of Locking: Round-Trip Intra-Core IPC

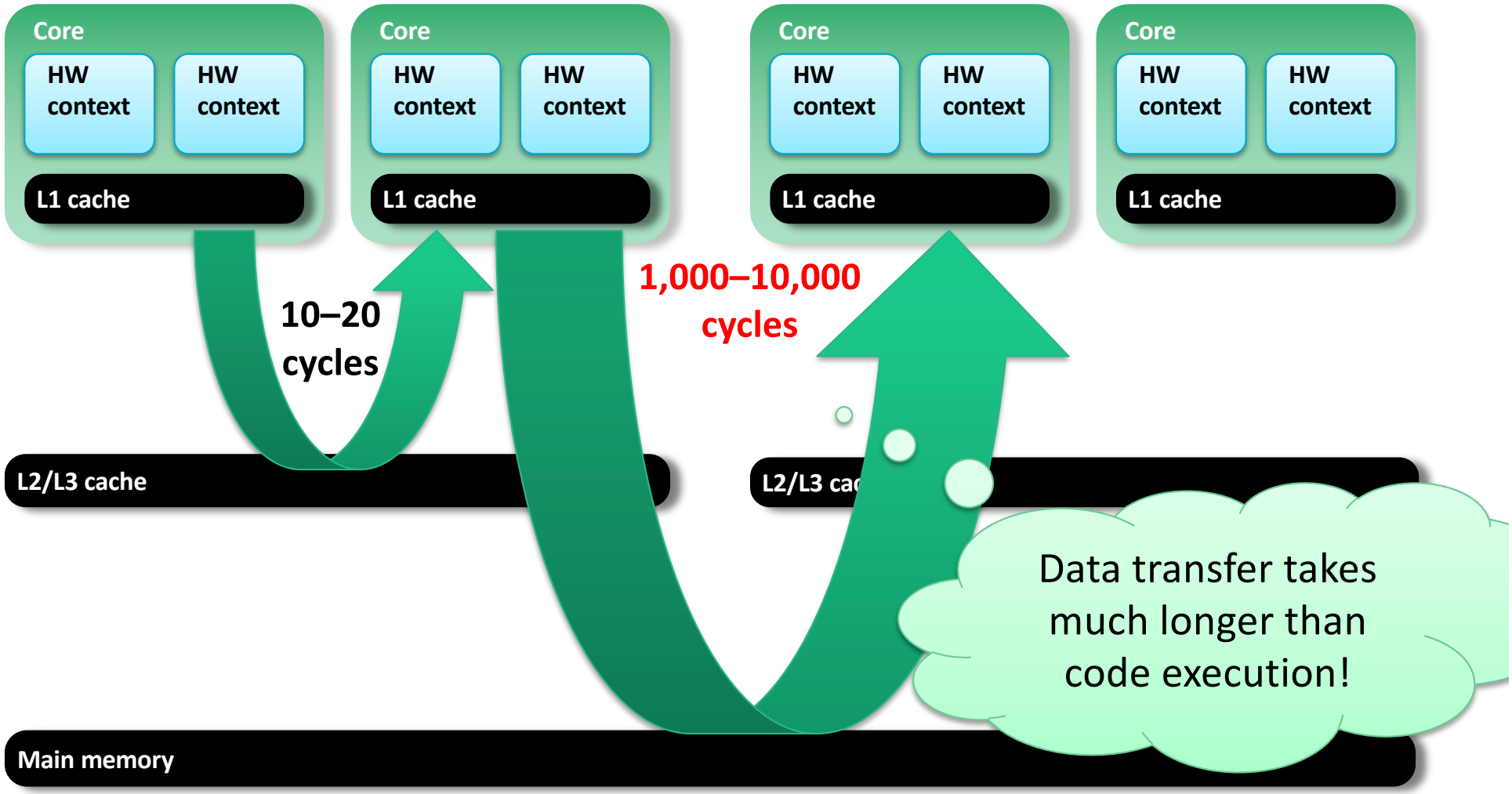


Microkernel Multicore Design

Assertion 1: Minimise locks, not locked code

- Amount of locked code is small anyway, 100–200 instructions
- Corresponds to fine- to medium-grained locks in Linux
- Cost of locks is within an OoM of kernel execution time
- Kernel times are short ⇒ contention is low

Cache Line Migration Latencies



Microkernel Multicore Design

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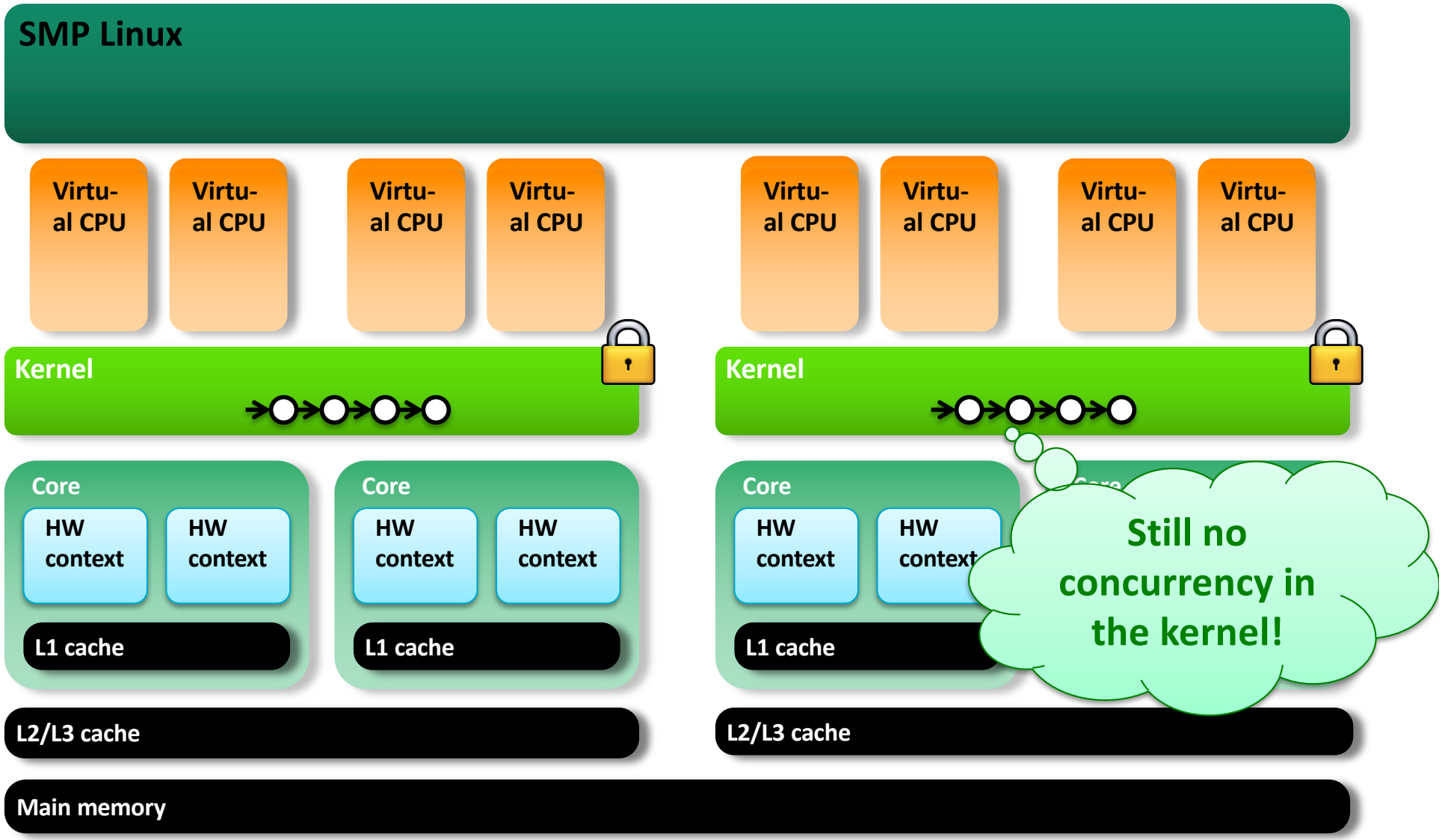
Assertion 2: Don’t share mikrokernel data without shared cache

- Migrating only a few cache lines takes longer than rest of syscall

seL4 Multicore Design: Clustered Multikernel



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Assertion 3: Big lock will perform for closely-coupled cores

- Shared caches presently have moderate core counts
- Big lock in a *well-designed* microkernel will scale there

Thank you

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