Introduction to seL4

Gernot Heiser

NICTA and UNSW, Sydney, Australia

What is seL4?

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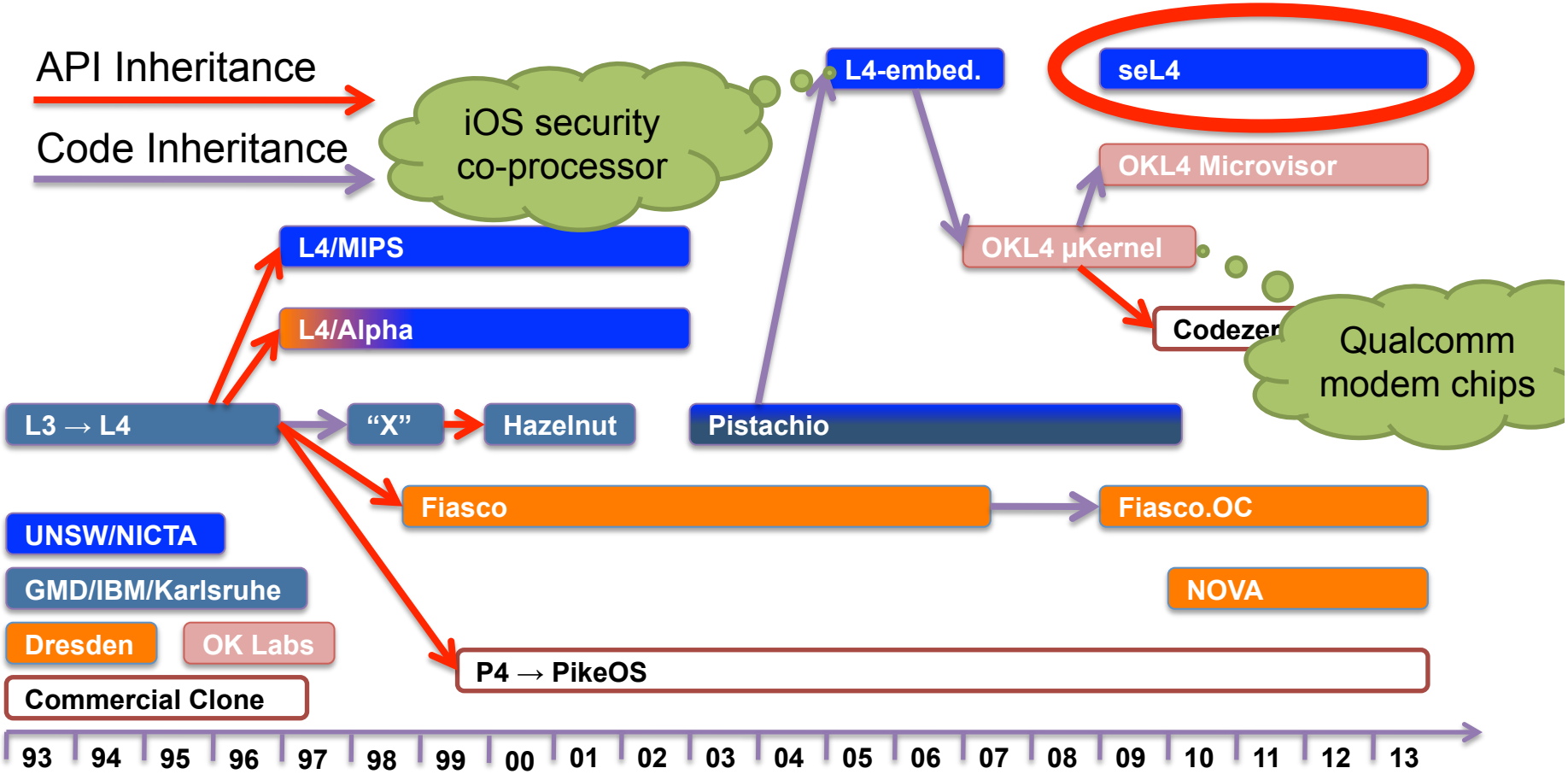
seL4: The latest (and most advanced) member of the L4 microkernel family – 20 years of history and experience



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

seL4: Mathematical *Proof* of Security & Safety

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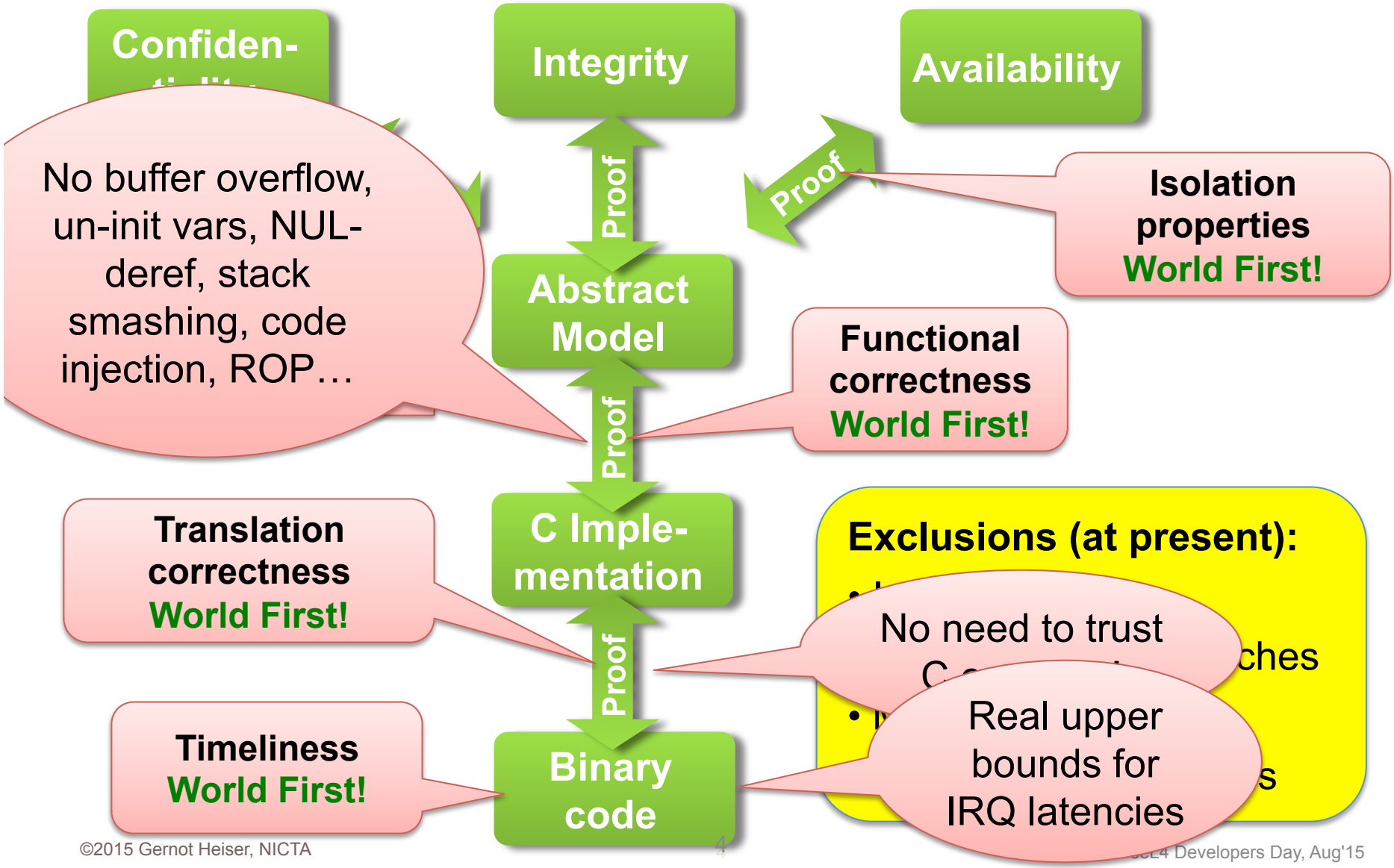
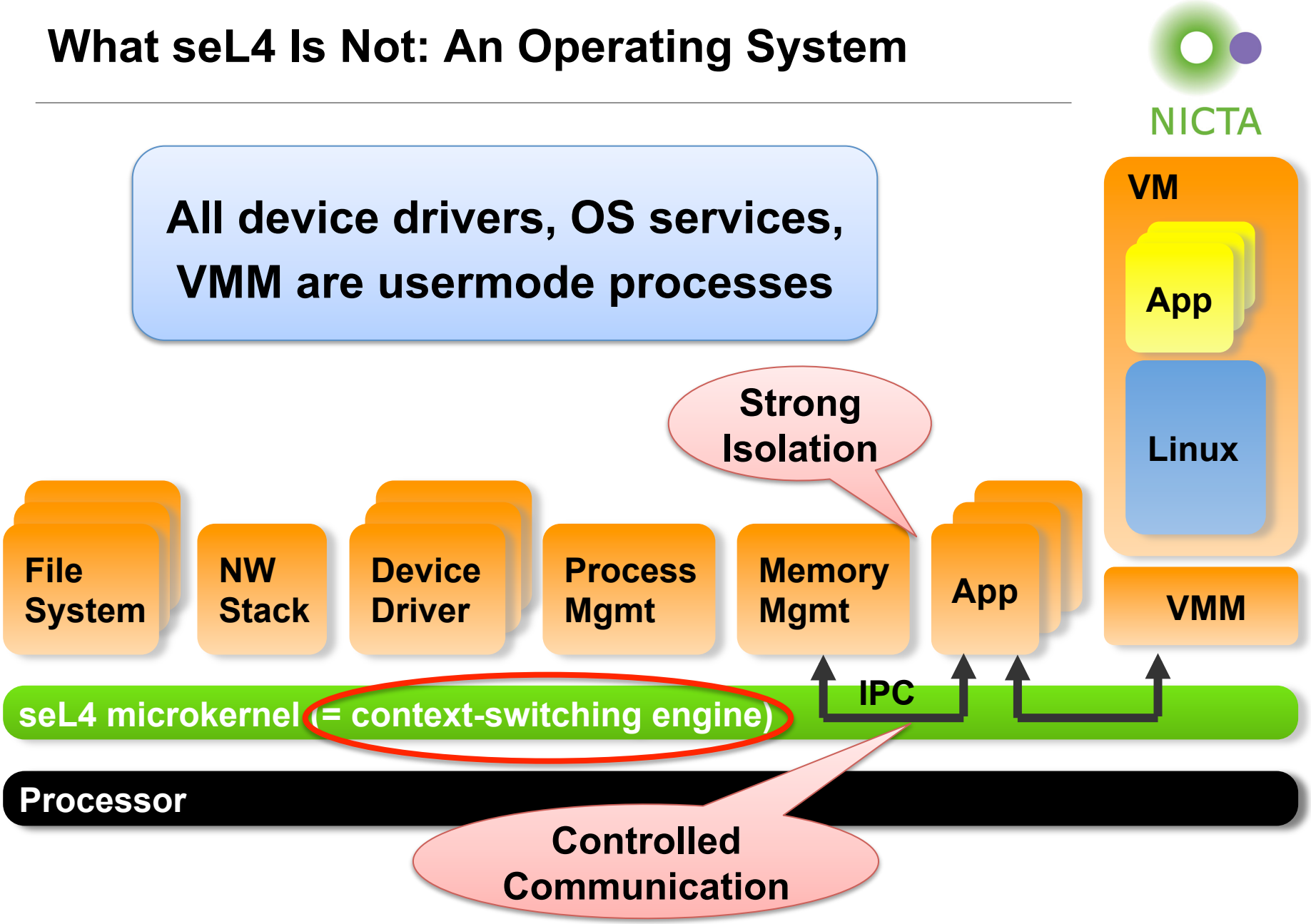
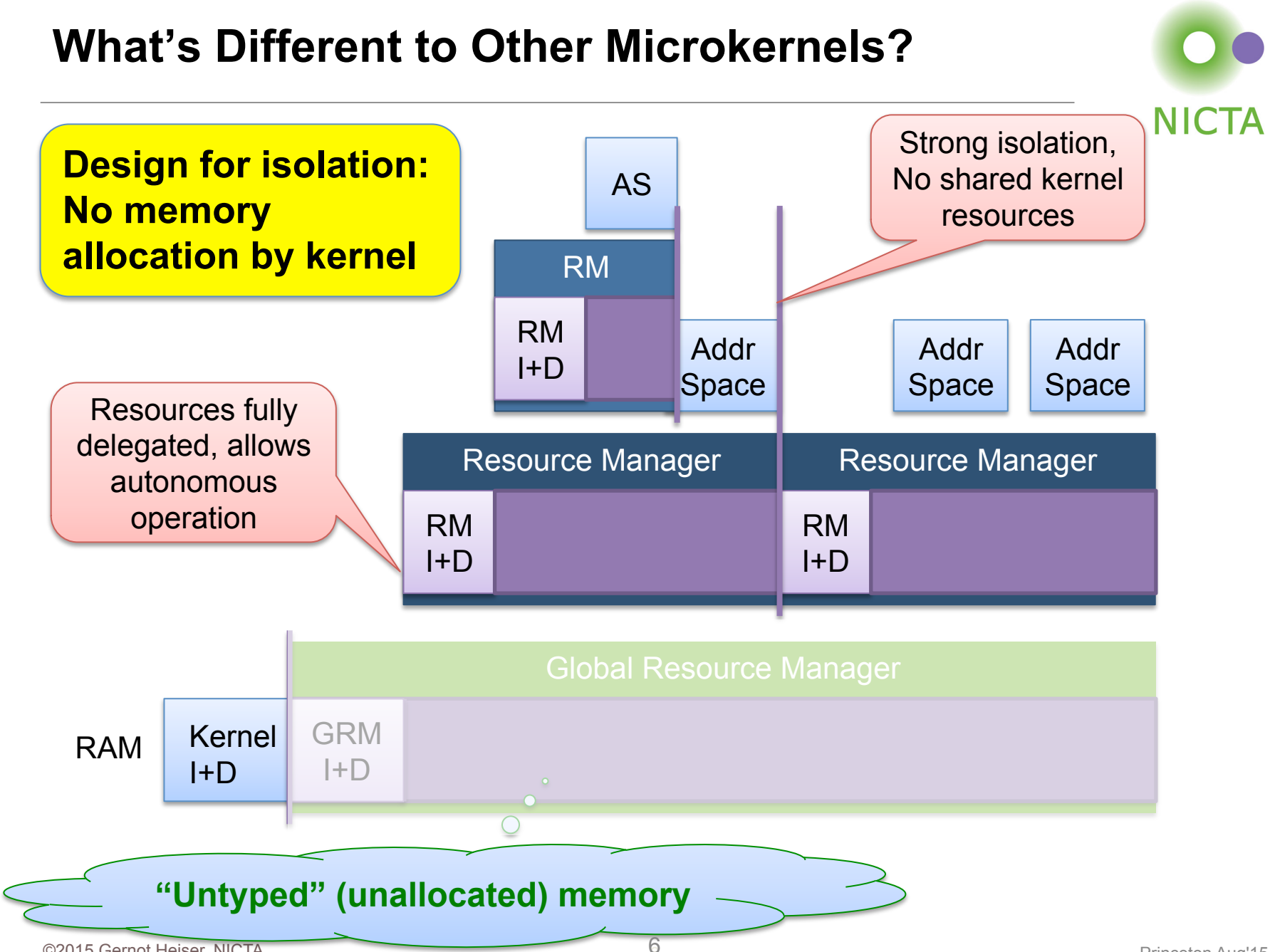


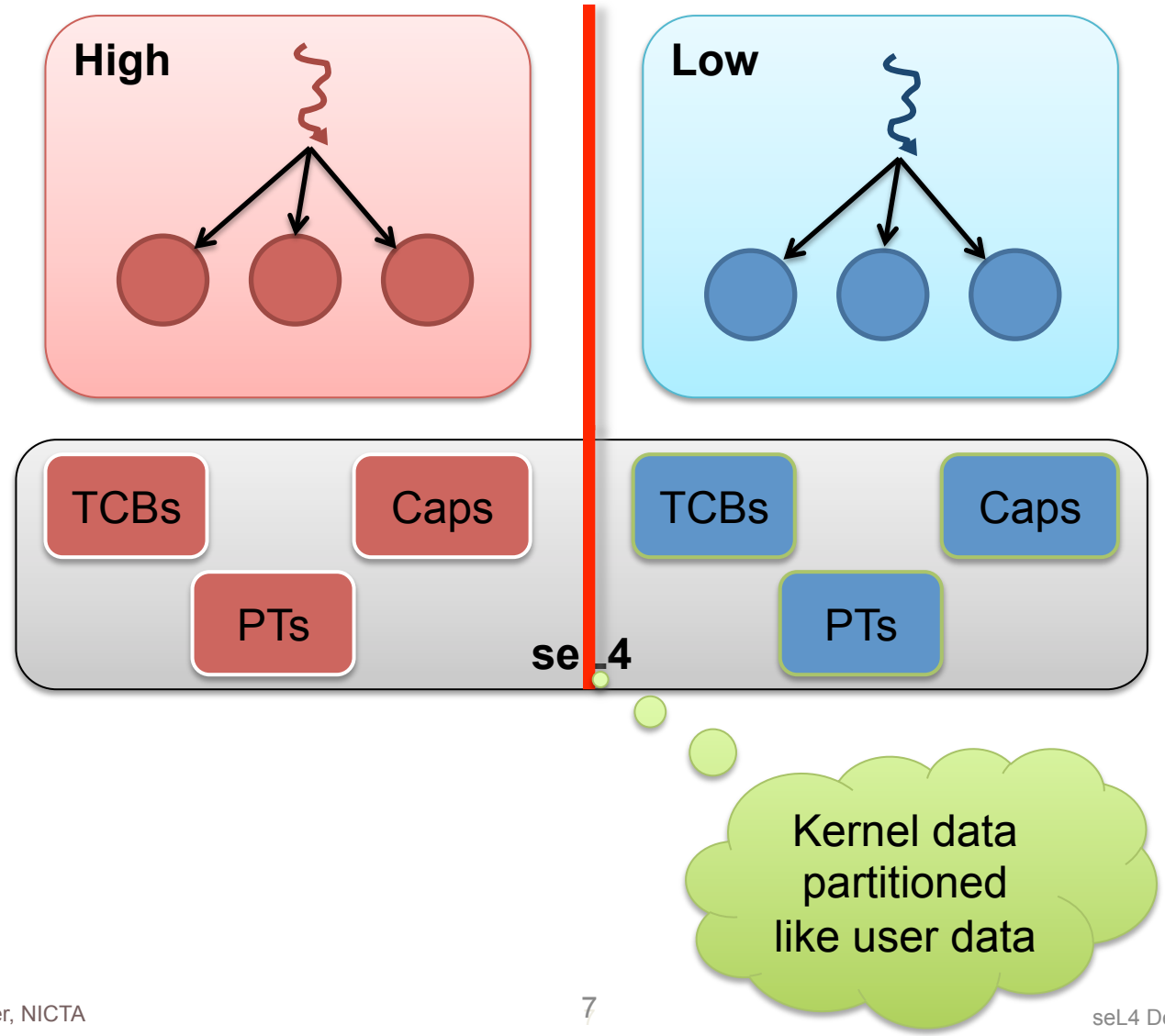
What seL4 Is Not: An Operating System



What's Different to Other Microkernels?

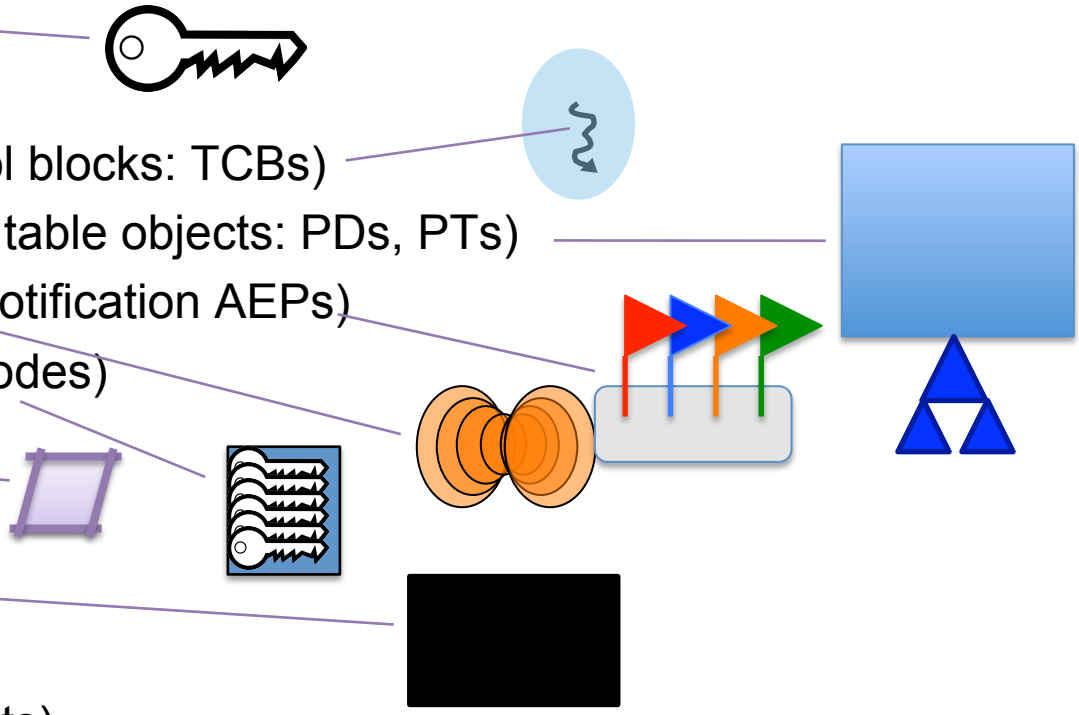


seL4 Isolation Goes Deep

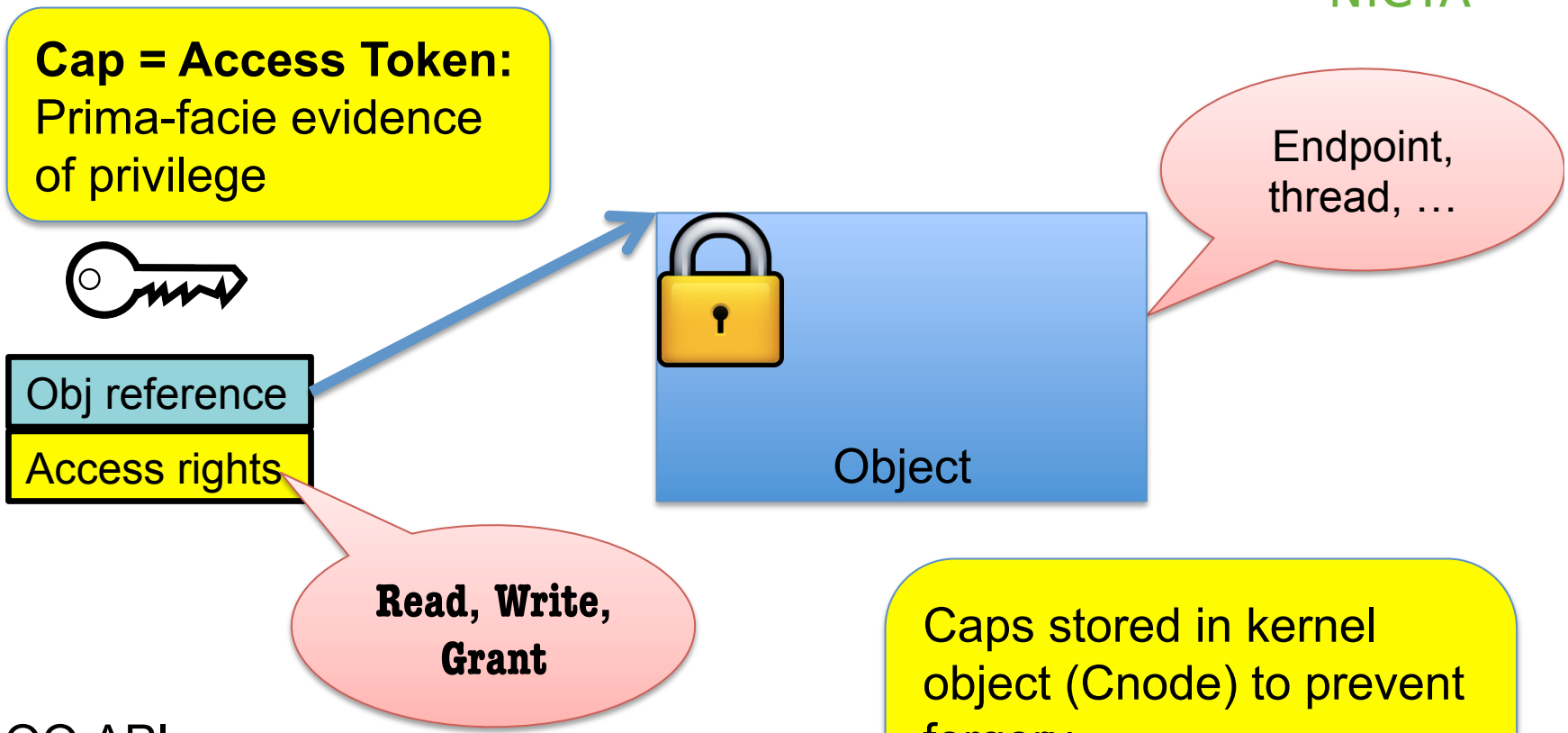


seL4 Concepts

- Capabilities (Caps)
  - mediate access
- Kernel objects:
  - Threads (thread-control blocks: TCBs)
  - Address spaces (page table objects: PDs, PTs)
  - Endpoints (IPC EPs, Notification AEPs)
  - Capability spaces (CNodes)
  - Frames
  - Interrupt objects
  - Untyped memory
- System calls
  - Send, Wait (and variants)
  - Yield



Key Mechanism: seL4 Capabilities



- OO API:

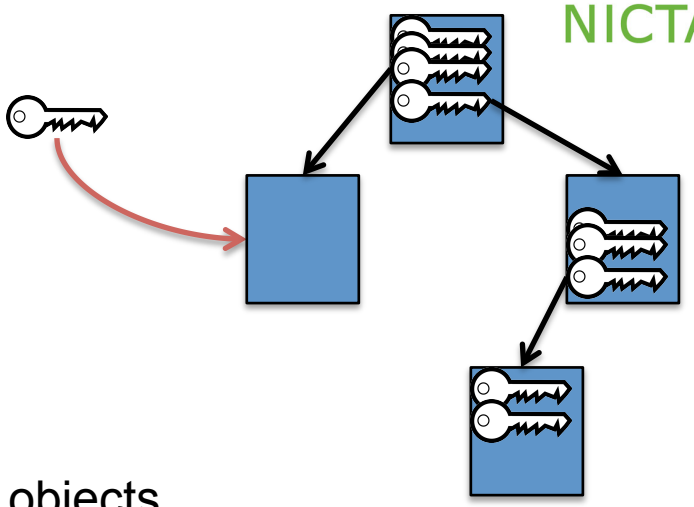
  ```
  err = method( cap, args );
  ```

- 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

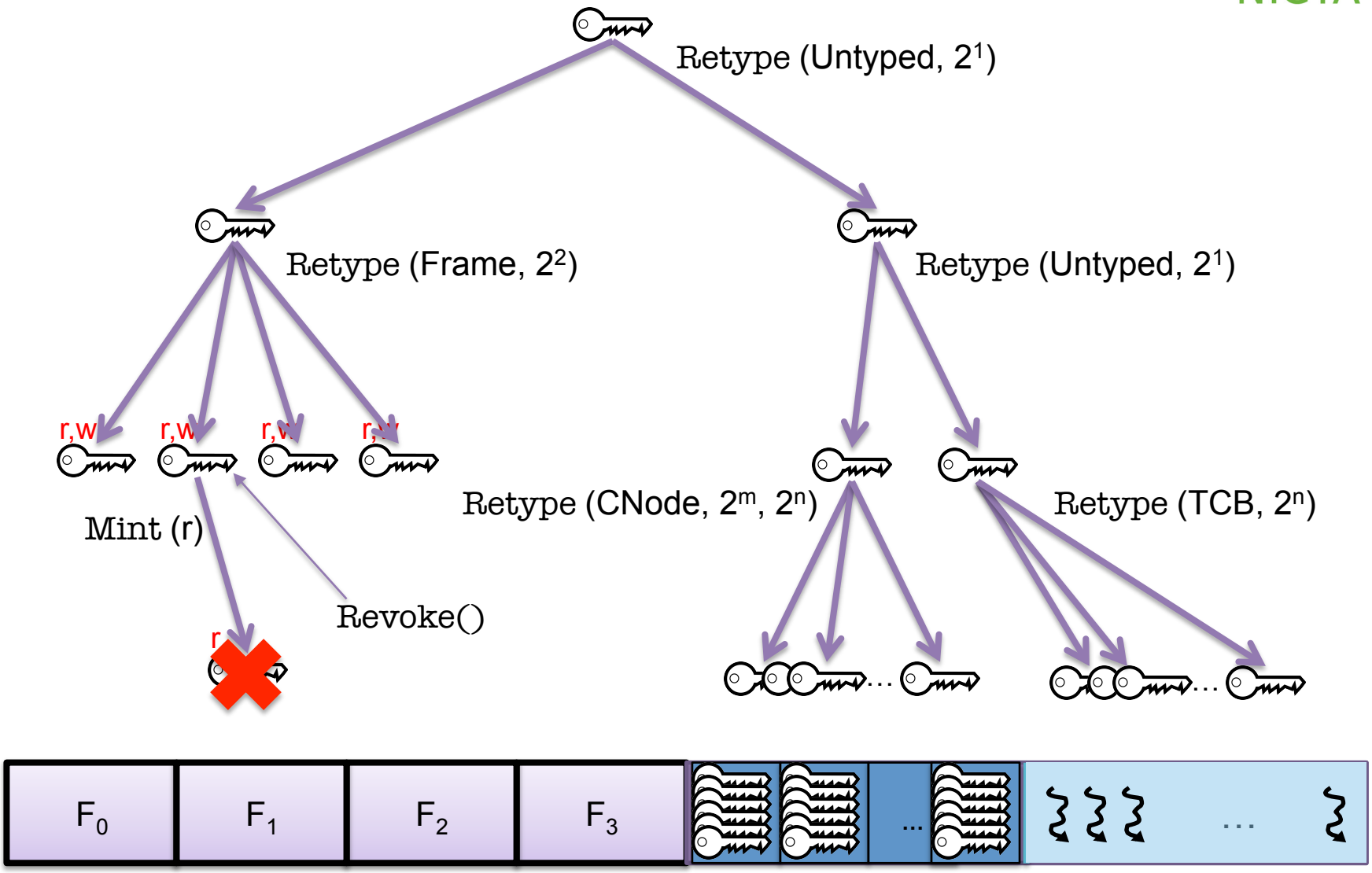
seL4 Capabilities



- Stored in cap space (*CSpace*)
  - Kernel object made up of *CNodes*
  - each an array of cap "slots"

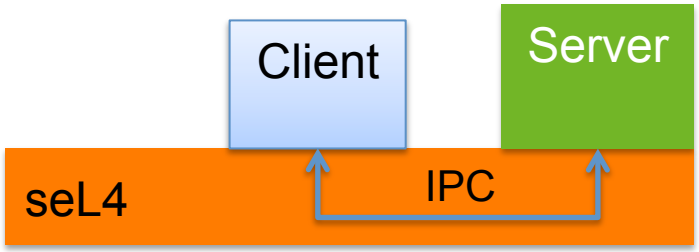
- Main operations on caps:
  - *Retype*: on **Untyped** only, creates other objects
  - *Invoke*: perform operation on object referred to by cap
    - Possible operations depend on object type
  - *Copy*/*Mint*/*Grant*: create copy of cap with *same*/*lesser* privilege
  - *Move*/*Mutate*: transfer to different address with same/lesser privilege
  - *Delete*: invalidate slot
    - Only affects object if last cap is deleted
  - *Revoke*: delete any derived (eg. copied or minted) caps

Memory Management Mechanics: Retype

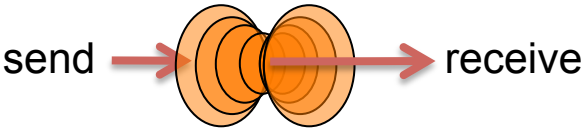


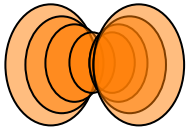
Inter-Process Communication (IPC)

- Fundamental microkernel operation
  - Kernel provides no services, only mechanisms
  - OS services provided by (protected) user-level server processes
  - invoked by IPC



- seL4 IPC uses a handshake through *endpoints*:
  - Transfer points without storage capacity
  - Message must be transferred instantly
    - One partner may have to block
    - Single-copy user → user by kernel





IPC Endpoints

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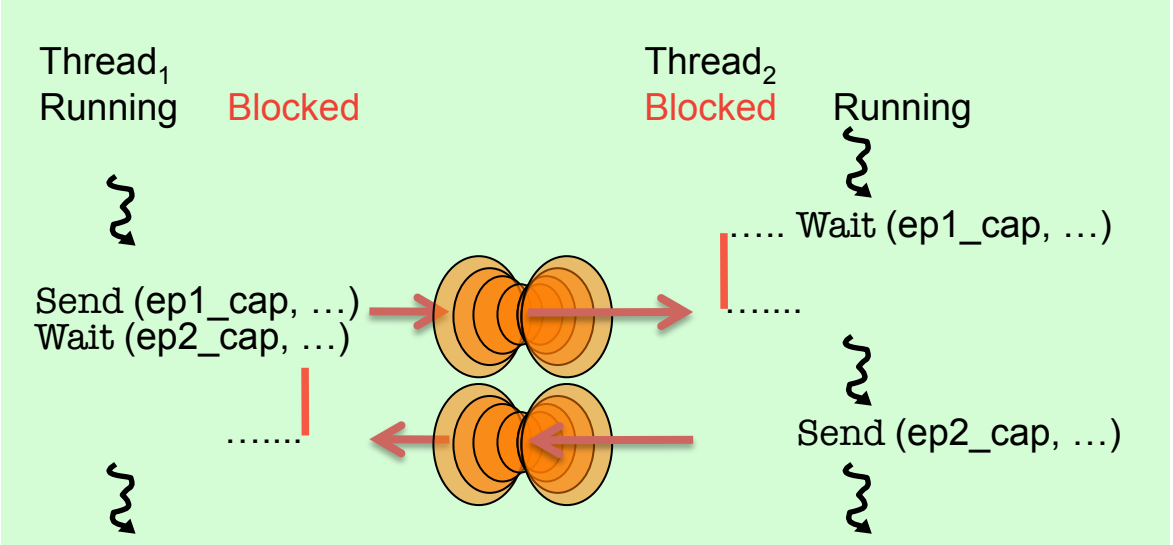
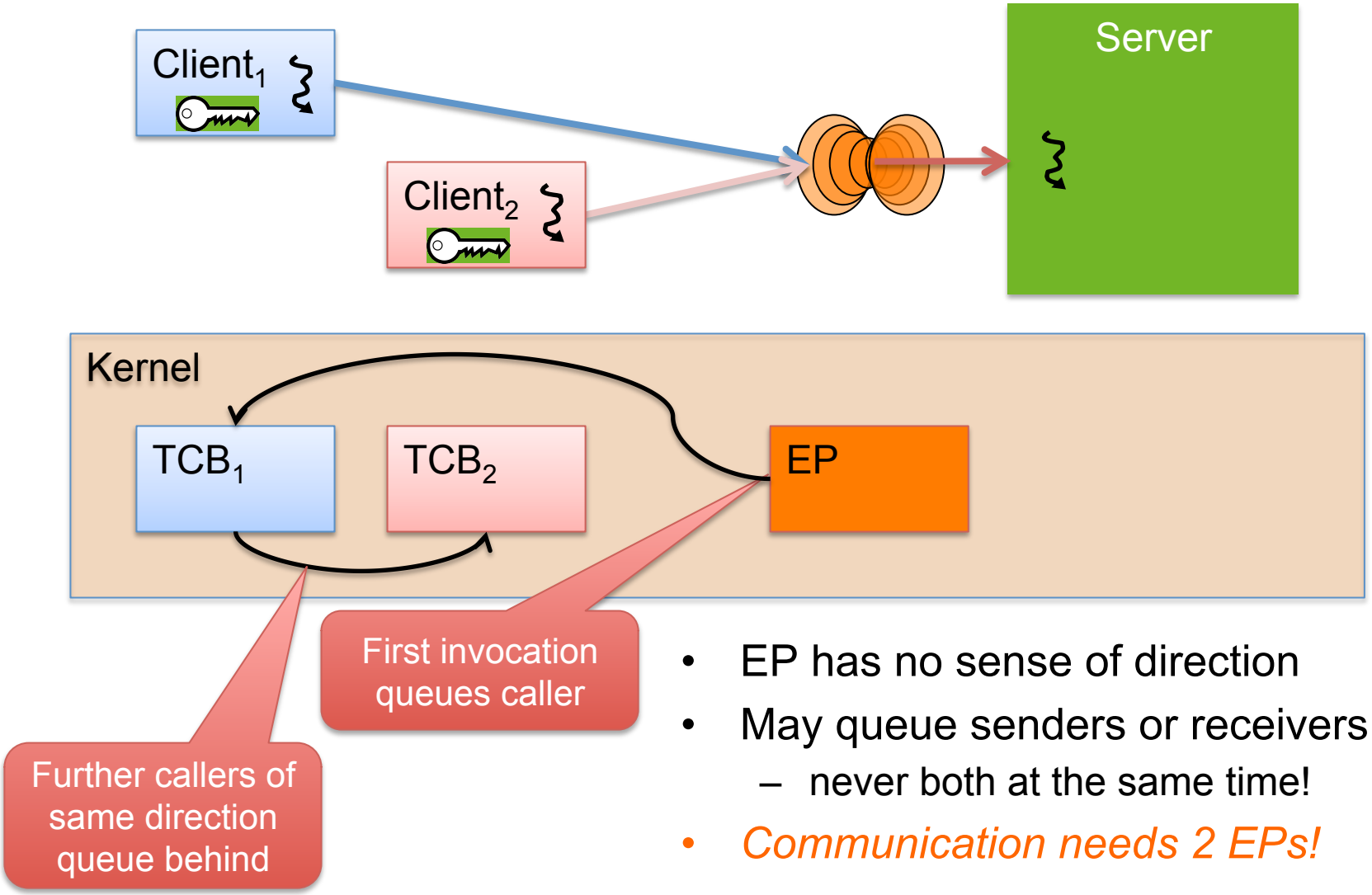
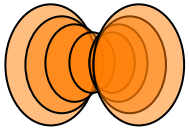


- Threads must rendez-vous for message transfer
  - One side blocks until the other is ready
  - Implicit synchronisation
- Message copied from sender's to receiver's *message registers*
  - Message is combination of caps and data words
    - presently max 121 words (484B, incl message "tag")

IPC Endpoints are Message Queues



- EP has no sense of direction
- May queue senders or receivers
  - never both at the same time!
- *Communication needs 2 EPs!*



Client-Server Communication

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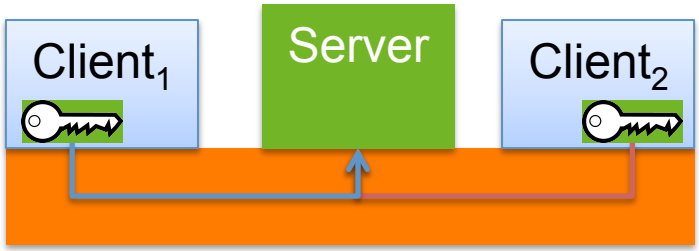
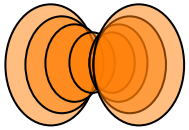
- Asymmetric relationship:
  - Server widely accessible, clients not
  - How can server reply back to client (distinguish between them)?

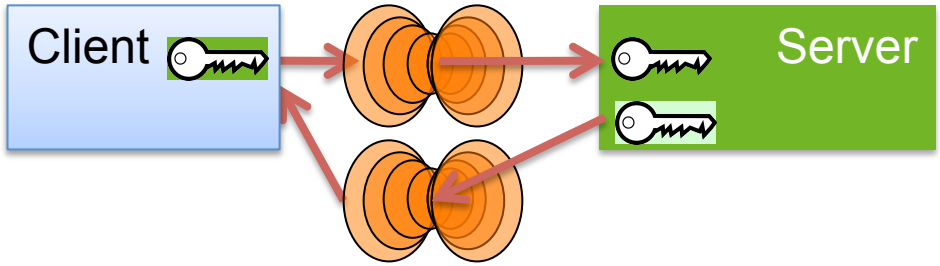


- Client can pass (session) reply cap in first request
  - server needs to maintain session state
  - forces stateful server design

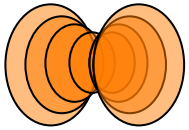
- seL4 solution: Kernel provides single-use *reply cap*
  - only for `Call` operation (`Send+Wait`)
  - allows server to reply to client
  - cannot be copied/minted/re-used but can be moved
  - one-shot (automatically destroyed after first use)



Call RPC Semantics



Client	Kernel	Server
		Wait(ep,&rep)
Call(ep,…)		
	mint rep	
	deliver to server	
		process
		Send(rep,…)
	deliver to client	
	destroy rep	
process		*process*



Identifying Clients

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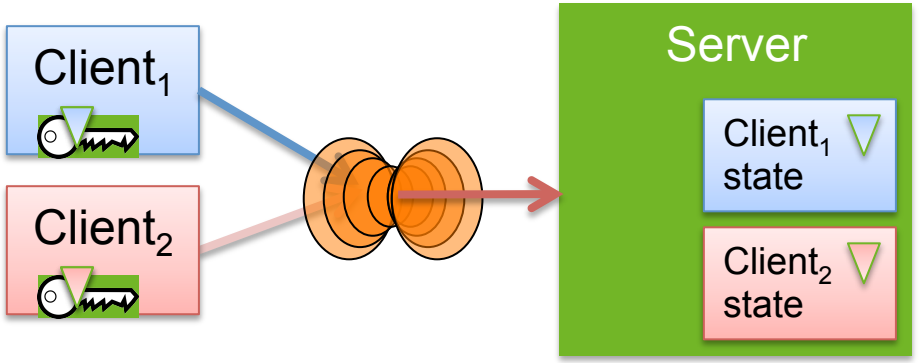
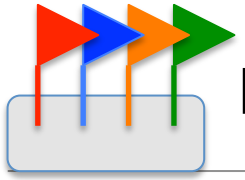
Stateful server serving multiple clients

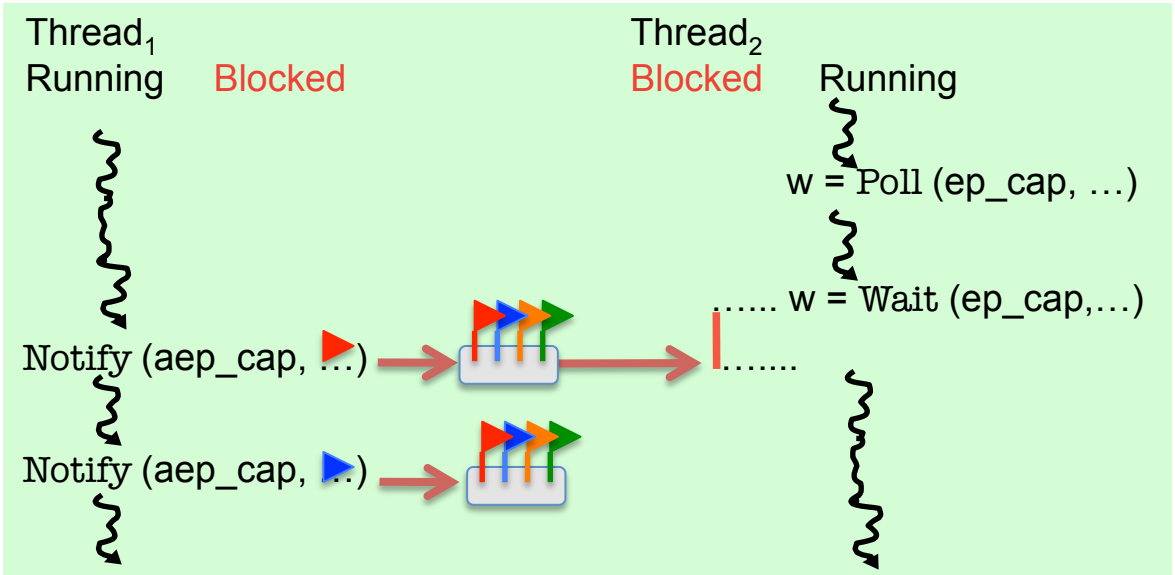
- Must respond to correct client
  - Ensured by reply cap
- Must associate request with correct state



- Could use separate EP per client
  - endpoints are lightweight (16 B)
  - but requires mechanism to wait on a set of EPs (like select)
- Instead, seL4 allows to individually mark ("badge") caps to same EP
  - server provides individually badged caps to clients
  - server tags client state with badge (through `Mint()`)
  - kernel delivers badge to receiver on invocation of badged caps



Notification Endpoints



- Logically, AEP is an array of binary semaphores
  - Multiple signalling, select-like wait
  - Not a message-passing IPC operation!
- Implemented by *data word* in AEP
  - Send OR-s sender's *cap badge* to data word
  - Receiver can poll or wait
    - waiting returns and clears data word
    - polling just returns data word

seL4 Address Spaces (VSpaces)

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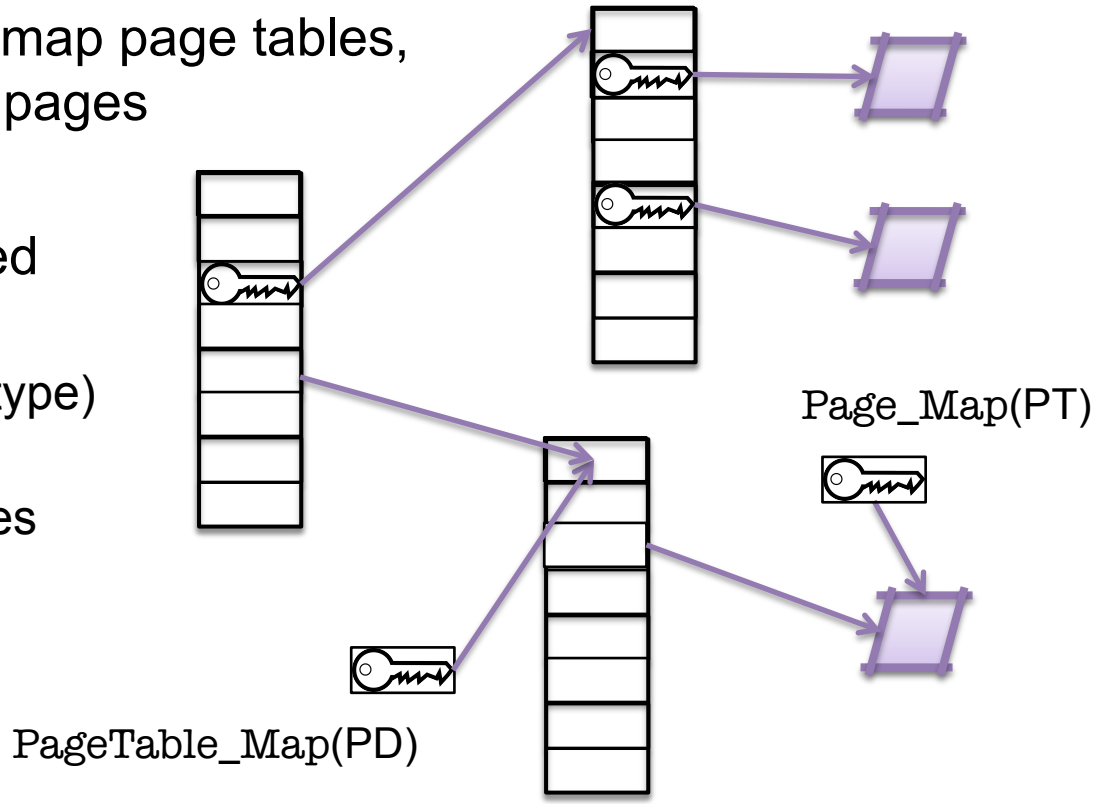
- Very thin wrapper around hardware page tables
  - Architecture-dependent
  - ARM and (32-bit) x86 are very similar

- Page directories (PDs) map page tables, page tables (PTs) map pages

- A VSpace is represented by a PD object:
  - Creating a PD (by Retype) creates the VSpace
  - Deleting the PD deletes the VSpace



seL4 Roadmap

Presently Released

- Verified implementation
  - seL4.ARMv6
  - Properties:
    - Execution safety: to binary
    - Functional correctness: to binary
    - Integrity: to binary
    - Confidentiality (excluding timing channels): to binary
    - User-level system initialization: on model

- Unverified implementation:
  - seL4/ARMv7: various boards, incl. Zynq
  - seL4/ARMv7a: A15 virtualisation support (branch)
  - seL4/x86: VT-x, VT-d (**experimental** branch)

Roadmap: Mainline Kernel (Subject to Change)

Sep'15: seL4/x64 implementation release
Q4'15: seL4/ARMv8 32-bit
Q4'15: seL4 for multicore ARM and x86

Q2'16: seL4/ARMv8 64-bit
Q2'16: seL4 for multicore ARM and x86 64-bit
Q3'16: seL4 real-time & mixed-criticality scheduling [NEW API]
Q3'16: SMP VMM
Q4'16: seL4 strict temporal partitioning [NEW API]

Q1'17: verified ARM virtualisation support
Q1'17: verified seL4/x64

Q2'18: verified RT kernel
???: verified multicore kernel

Summary

1. seL4 is the world's most demonstrably secure OS kernel
2. Security is no excuse for bad performance!

http://seL4.systems

gernot@nicta.com.au

http://microkerneldude.wordpress.com

@GernotHeiser