barkhausen institut

Microkernel Construction

Capabilities

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06/04/2026

- **Introduction**
  - **Global Names and ACL**
- Capabilities in General
- Capabilities in NOVA

Motivation

1. How do you find/access resources?

2. How do you restrict access to resources?

Global Names

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- Example: semaphores, processes, devices, … on UNIX

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Pros & Cons

- 🙂 Simple
- 😕 Name clashes: people need to agree on names.
- 😕 What if a malicious process registers a name first?
- 😕 All resources are visible: just try to access them

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🙁 Makes it hard to restrict specific subjects

🙁 POLA is more difficult to achieve

🙁 Requires (global) names

🙁 Confused deputy problem

Confused Deputy Problem

- Compiler service: `compile <source> <object>`
- Service stores billing information in file `"bill"`
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Solution

Client opens files and passes file descriptors (capabilities) to service

- Introduction
- **Capabilities in General**
  - **Overview**
  - Operations
  - Implementation Considerations and Variants
- Capabilities in NOVA

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- Give each subject a local namespace
- Operations to exchange objects between namespaces
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🙂 Makes it easy to restrict specific subjects

🙂 Separation of subsystems, composable, independent

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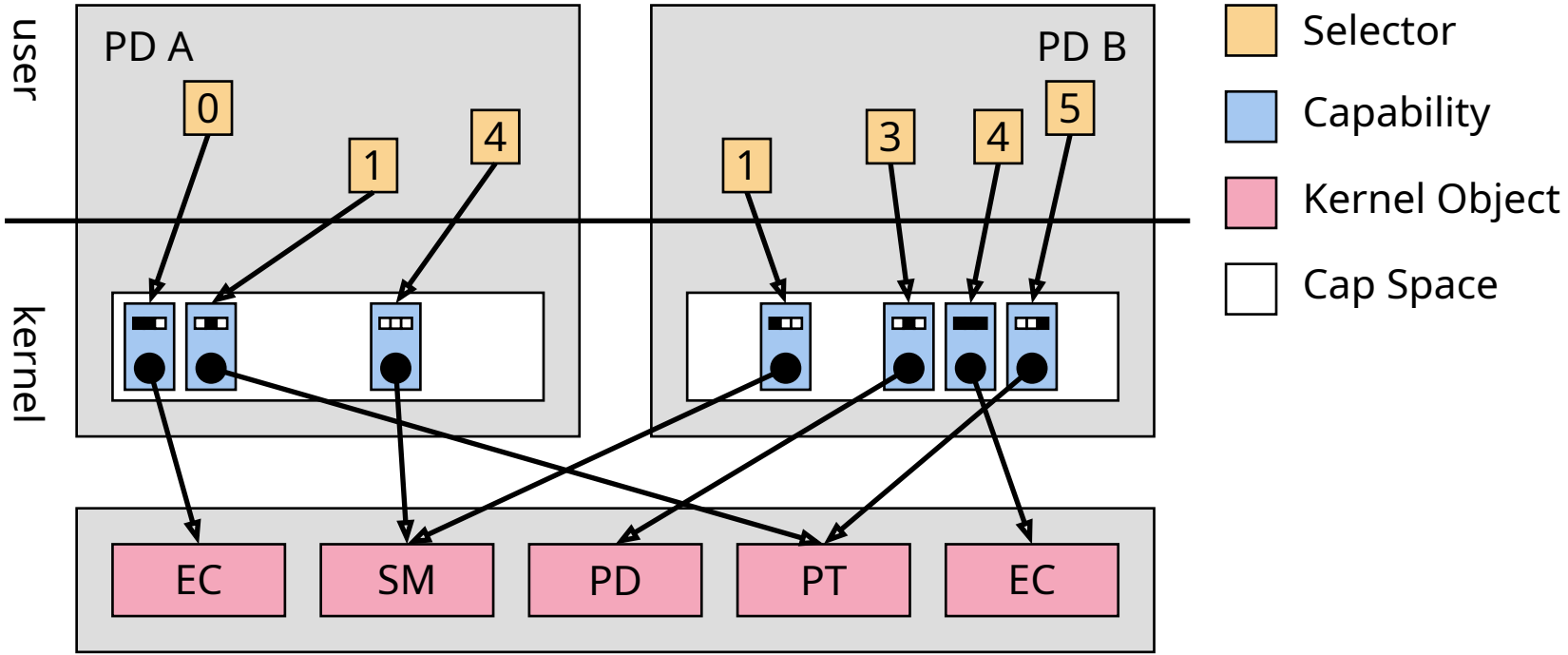
😕 Need to give permissions explicitly

😕 Exchanging, especially revoking, capabilities is difficult

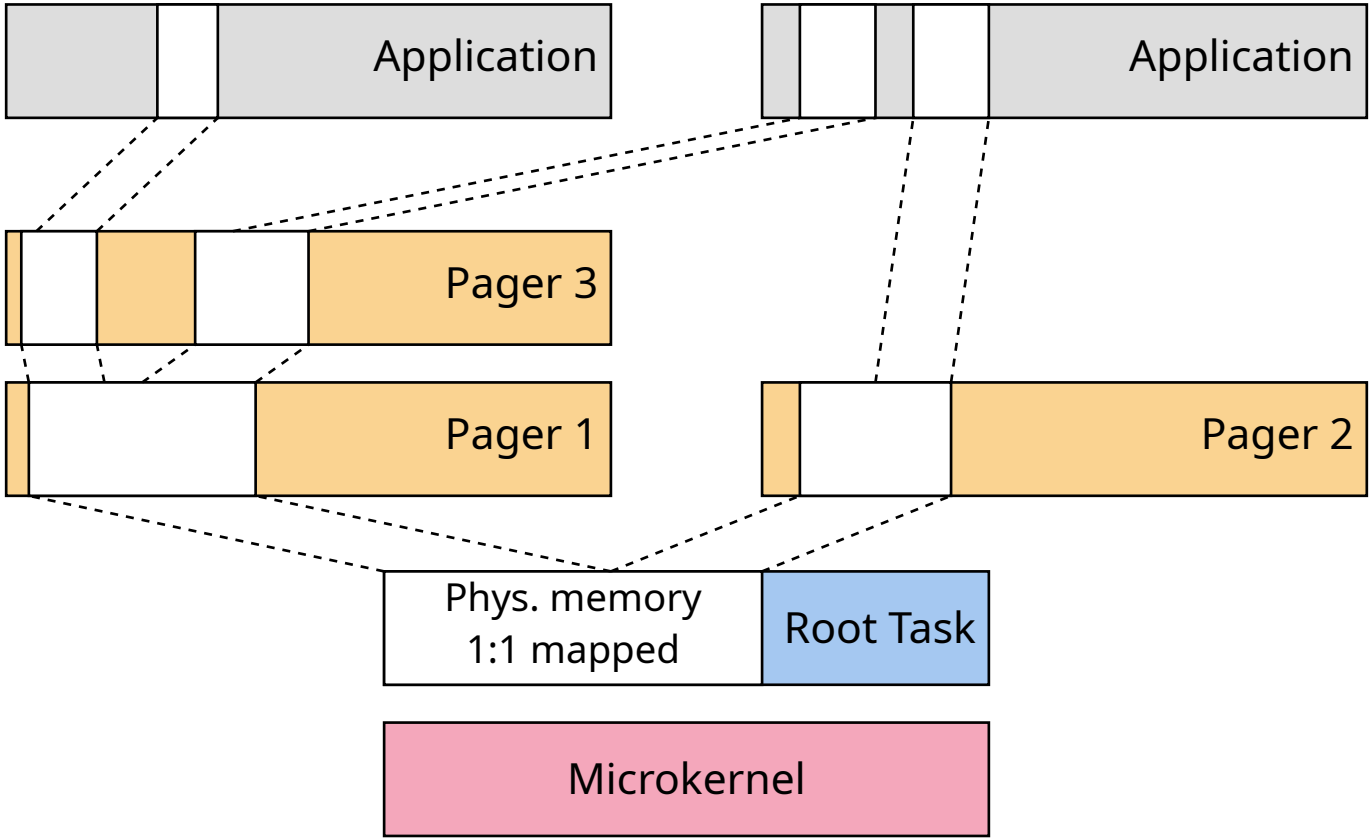
Capabilities Overview



Operations

- Map/delegate:
  - Copy capability from one Cap Space to the other
- Grant:
  - Move capability from one Cap Space to the other
- Revoke:
  - Remove capability, recursively
- Lookup:
  - Search capability by selector and return its permissions
- Translate:
  - Translate selector from one Cap Space to the other

Hierarchical Organization



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- **Capabilities in General**
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  - **Implementation Considerations and Variants**
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Revocability

Fully Selective (examples: NOVA, M³ , memory caps in L4Re)

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Semi Selective (example: distributed capability system in FractOS)

- Like the previous, but revocable subtrees can be created
- Creates a new object that can be revoked separately

Requirements

- Finding capabilities by selector
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  - Easier approach (not fully selective): list

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- Finding child capabilities (delegation, derivation)
  - Tree required for fully selective revocation
  - Without any further measures: unbounded recursion
  - Easier approach (not fully selective): list
- Delegation is performance critical
  - Challenging in distributed capability systems
  - FractOS does not track delegations, but invalidates objects at owner

Concurrency and Interuptibility

Concurrency

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Interruptibility

- What if a large capability tree is revoked?
- System should remain usable
- Ideally, revoke should be interruptible

Locking Strategies

NOVA

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L4Re

- locks entire revoke operation
- but lock is per object/frame

Capabilities in Other Systems

Files

- File descriptor is equivalent of selector
- File table is similar to capability space
- FDs can be passed between processes, but is seldomly used
- Revocation not possible
- Only used for a subset of kernel resources

POSIX Capabilities

- not associated with any object
- define whether a process has certain permissions
  (example: open port under 1024)
- main purpose: restrict power of root

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- Capabilities in General
- **Capabilities in NOVA**
  - **Capability Spaces**
  - Mapping Database
  - Delegate, Translate, and Revoke
  - Data Types
  - Receive Windows

Capability Spaces

Each protection domain (Pd) has

- `Space_obj`: object capabilities
- `Space_mem`: memory capabilities (pages)
- `Space_pio`: I/O port capabilities

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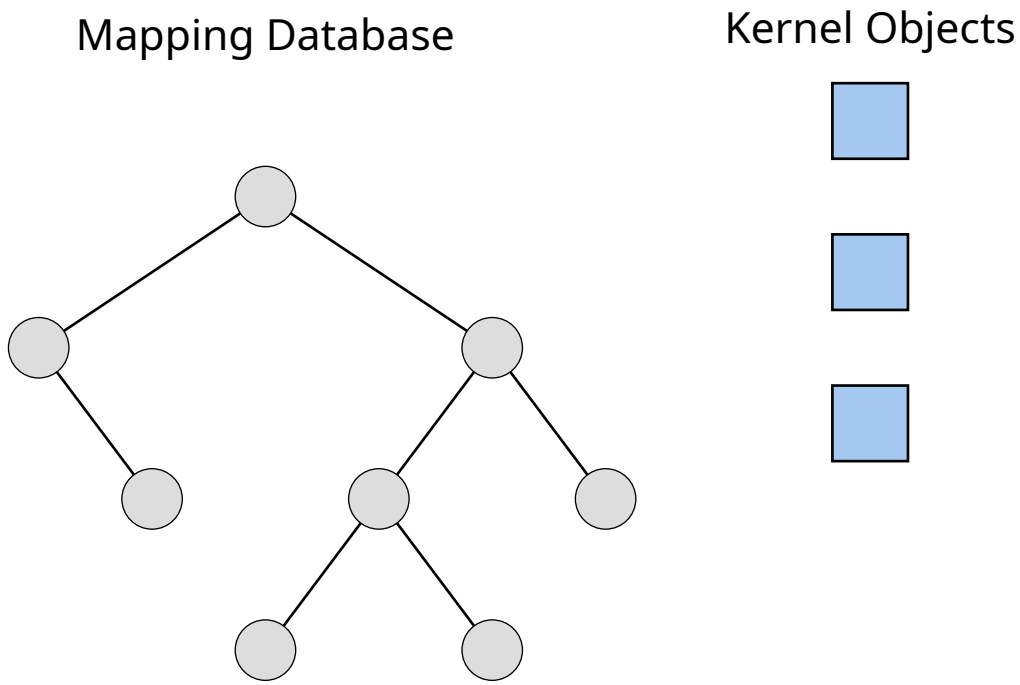
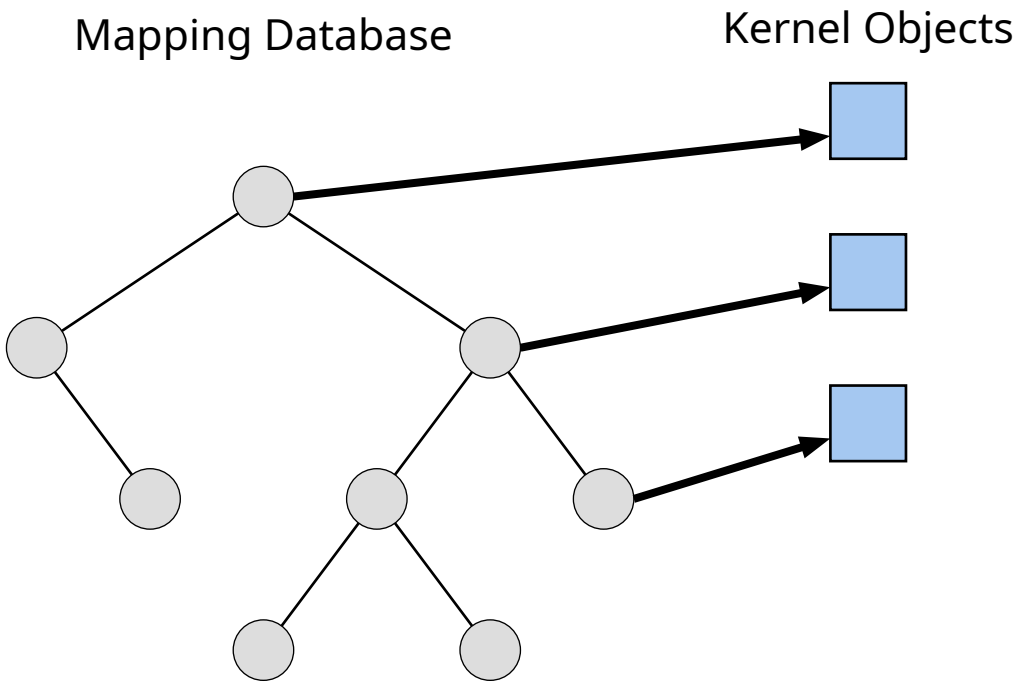
Similarities and differences

- Shared: capability delegation, revocation, ...
- Differences:
  - Object caps are created and used via system calls
  - Port and memory caps are referring to existing resources
  - Passed to root task, distributed in the system via delegation
  - Memory capabilities lead to page table entries
  - Port capabilities lead to bits set in the I/O bitmap

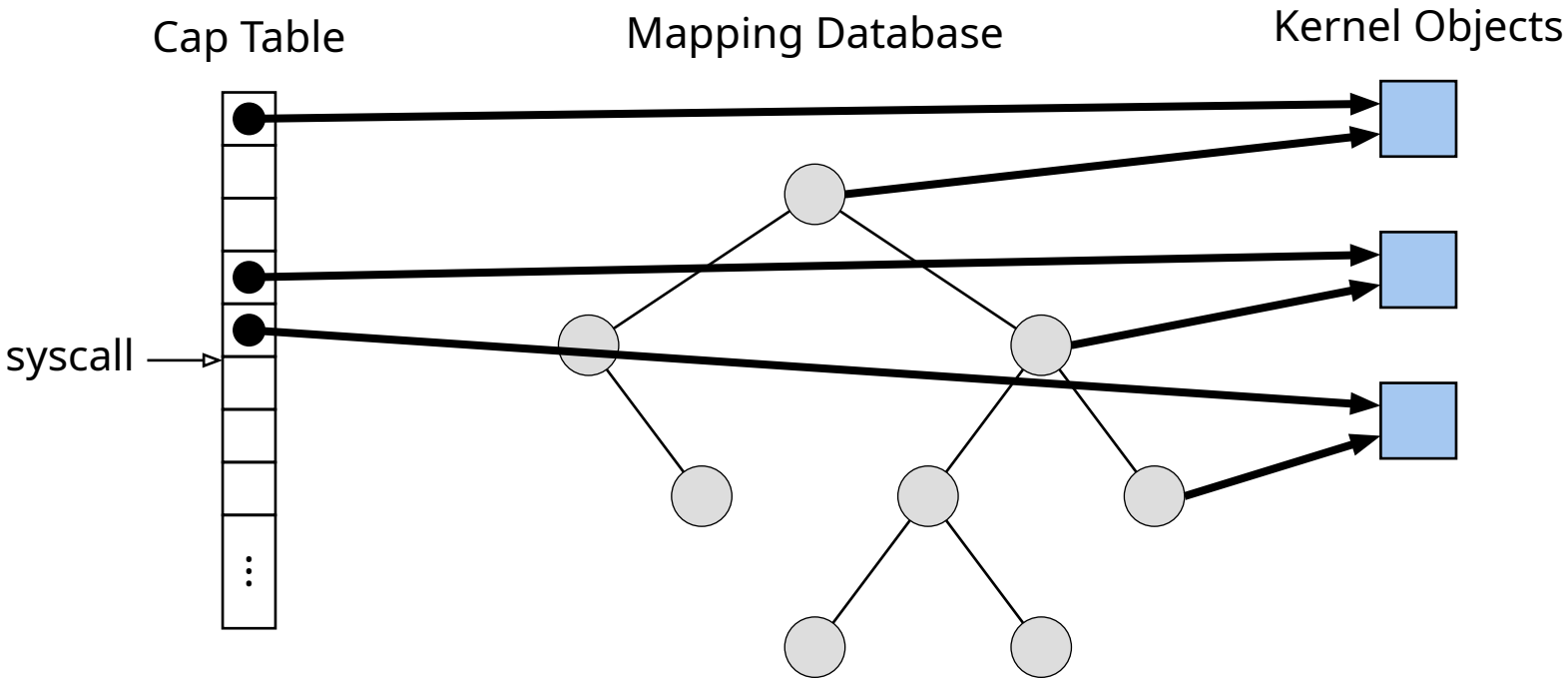
Object Capability Space



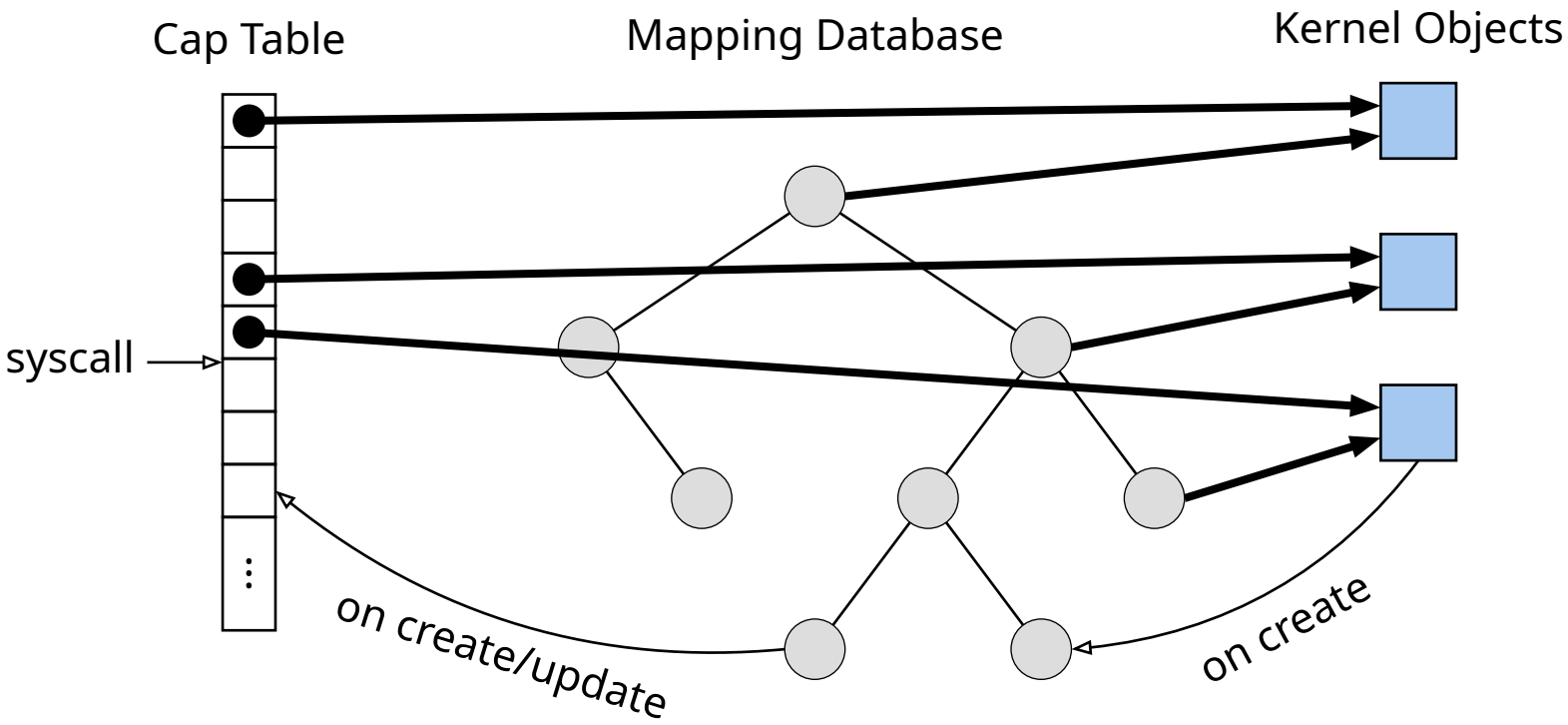
Object Capability Space



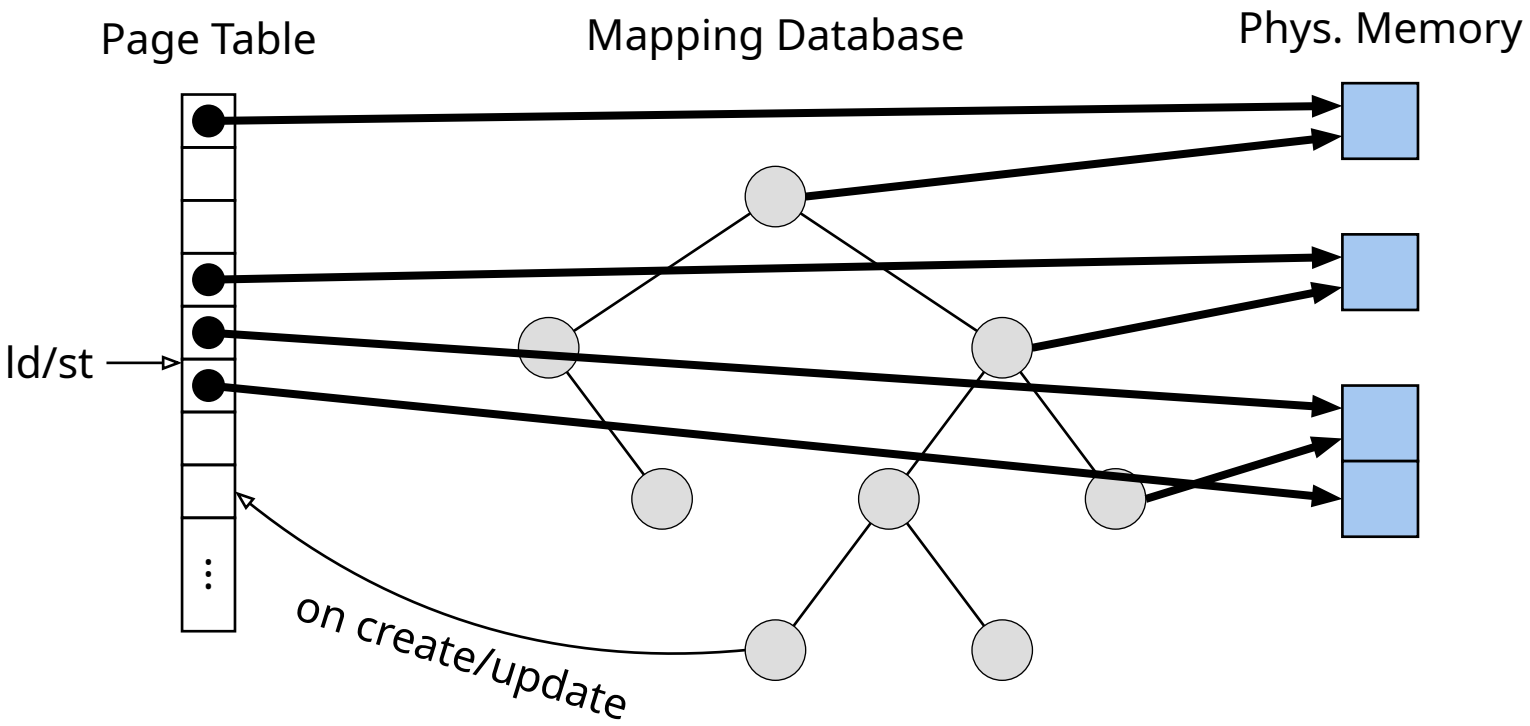
Object Capability Space



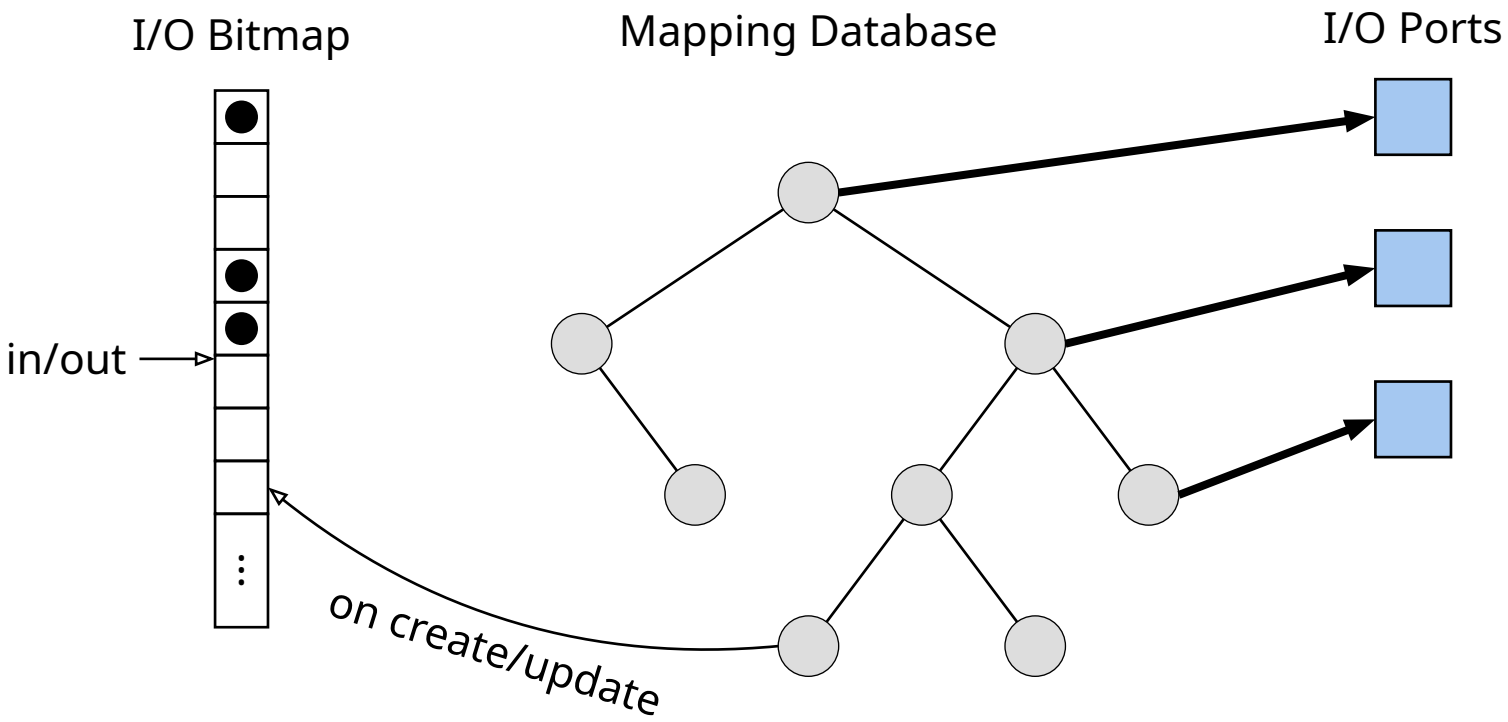
Object Capability Space



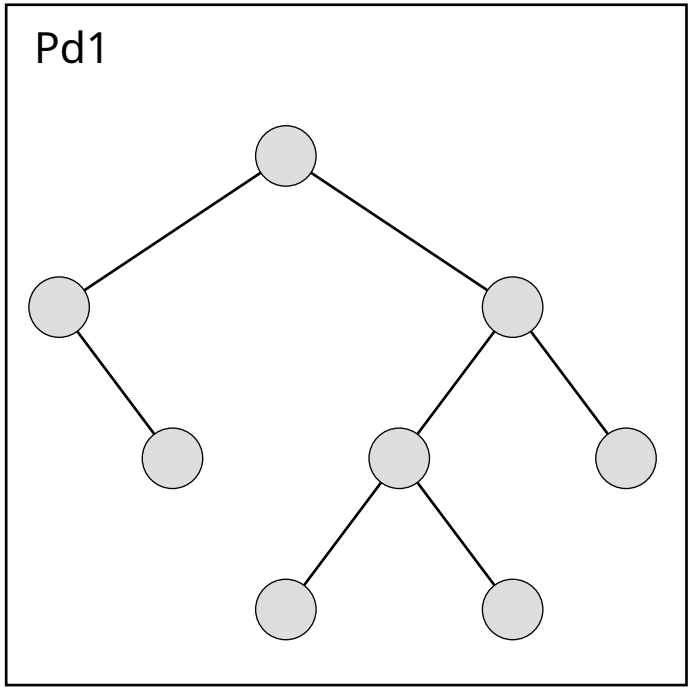
Mapping Capability Space

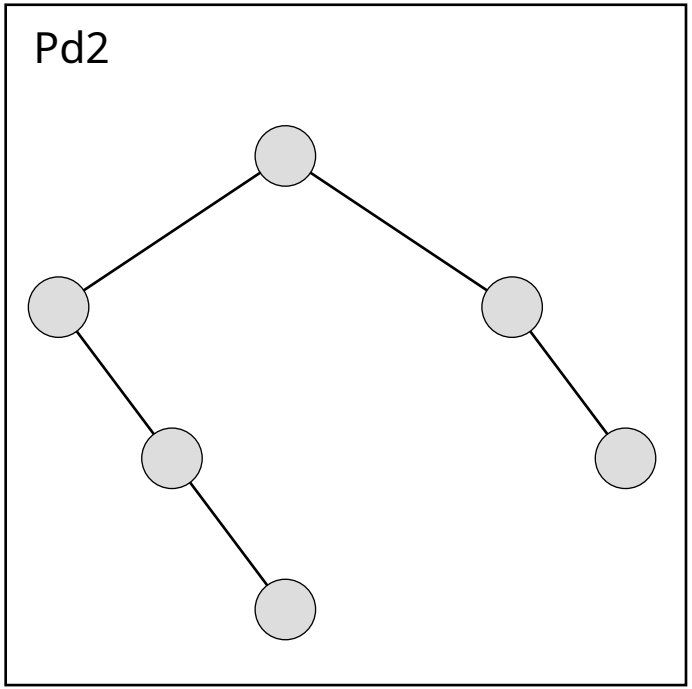


I/O Capability Space



Mapping Database





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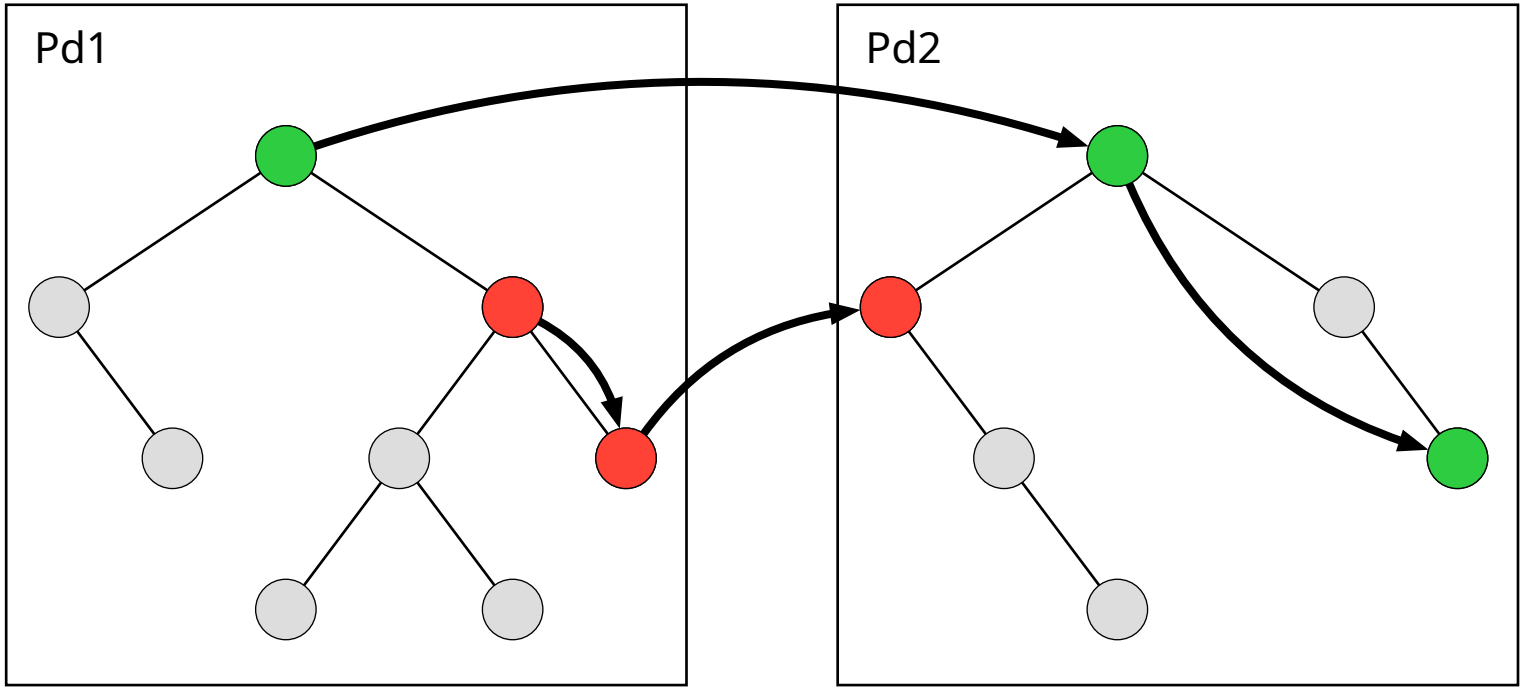
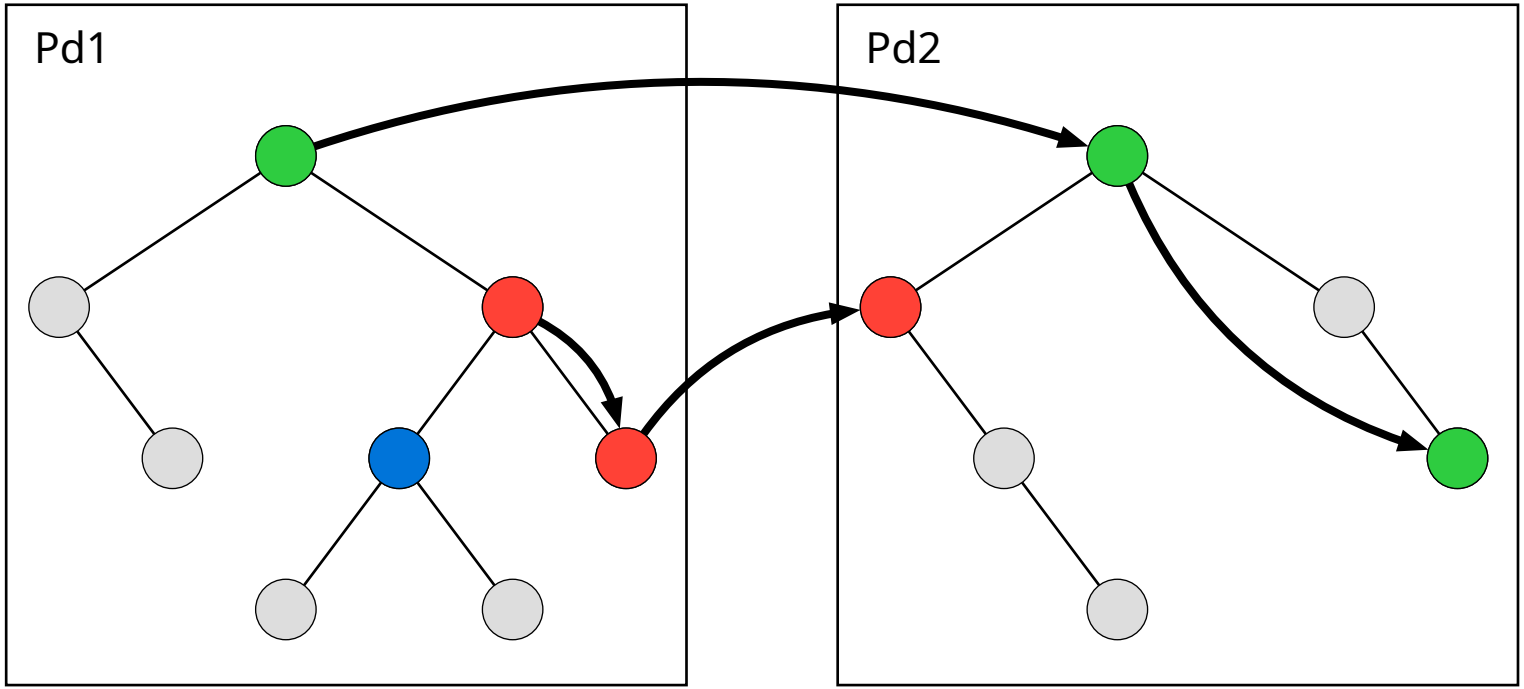


Mapping Database – Delegate



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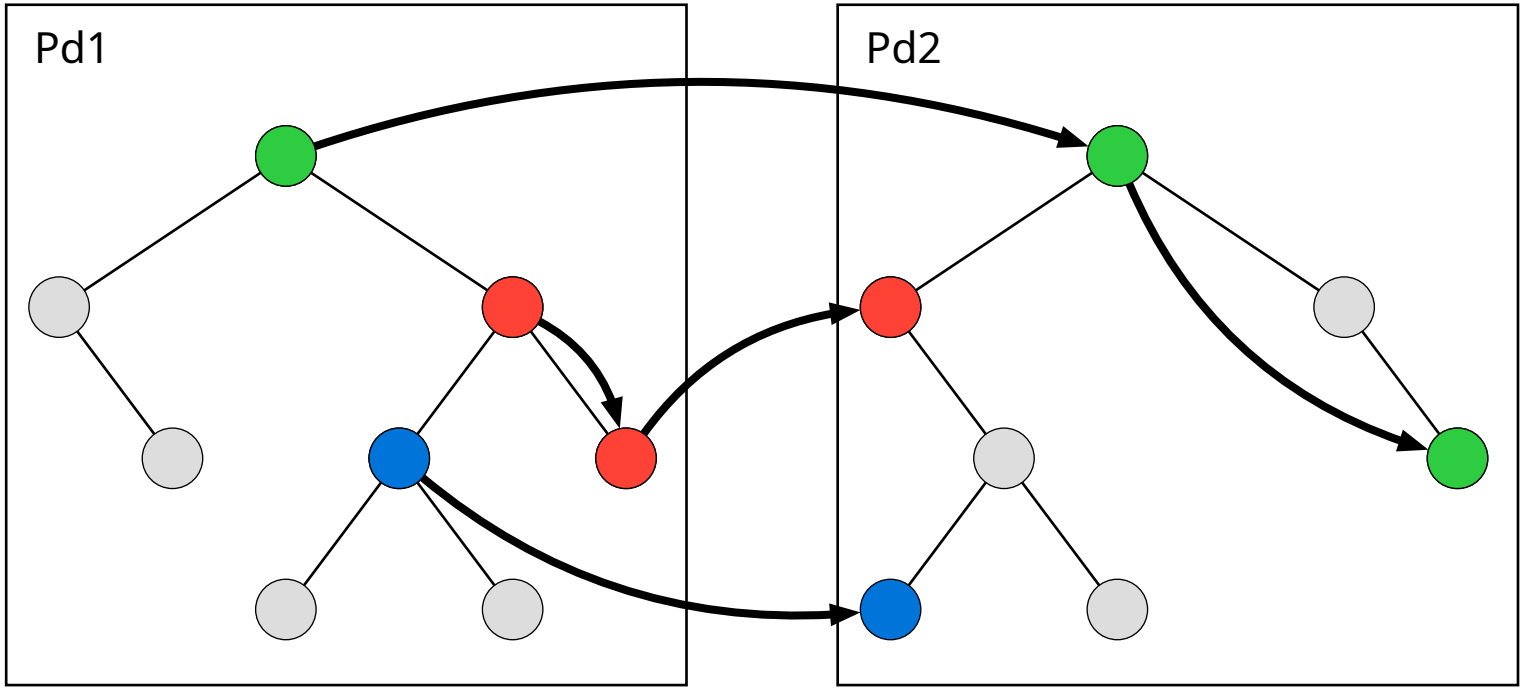
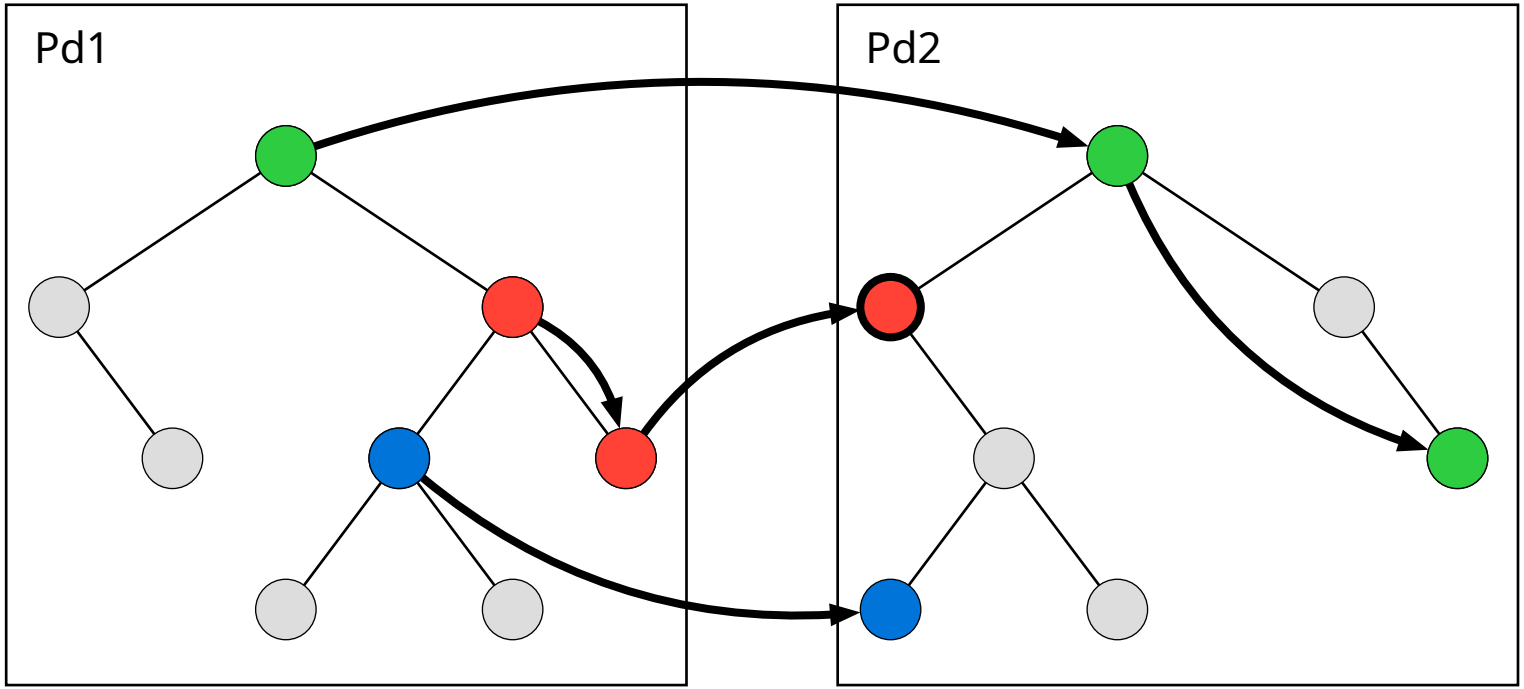


Mapping Database – Translate



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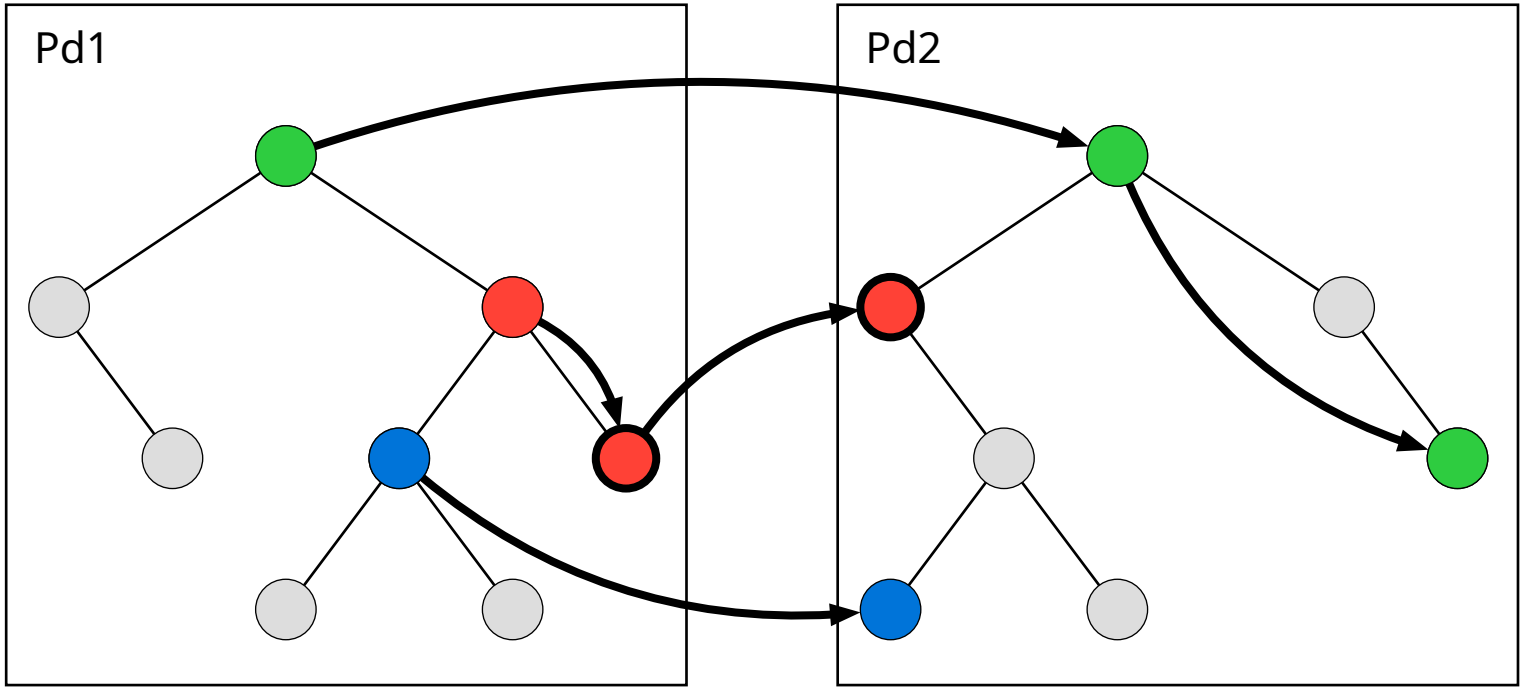
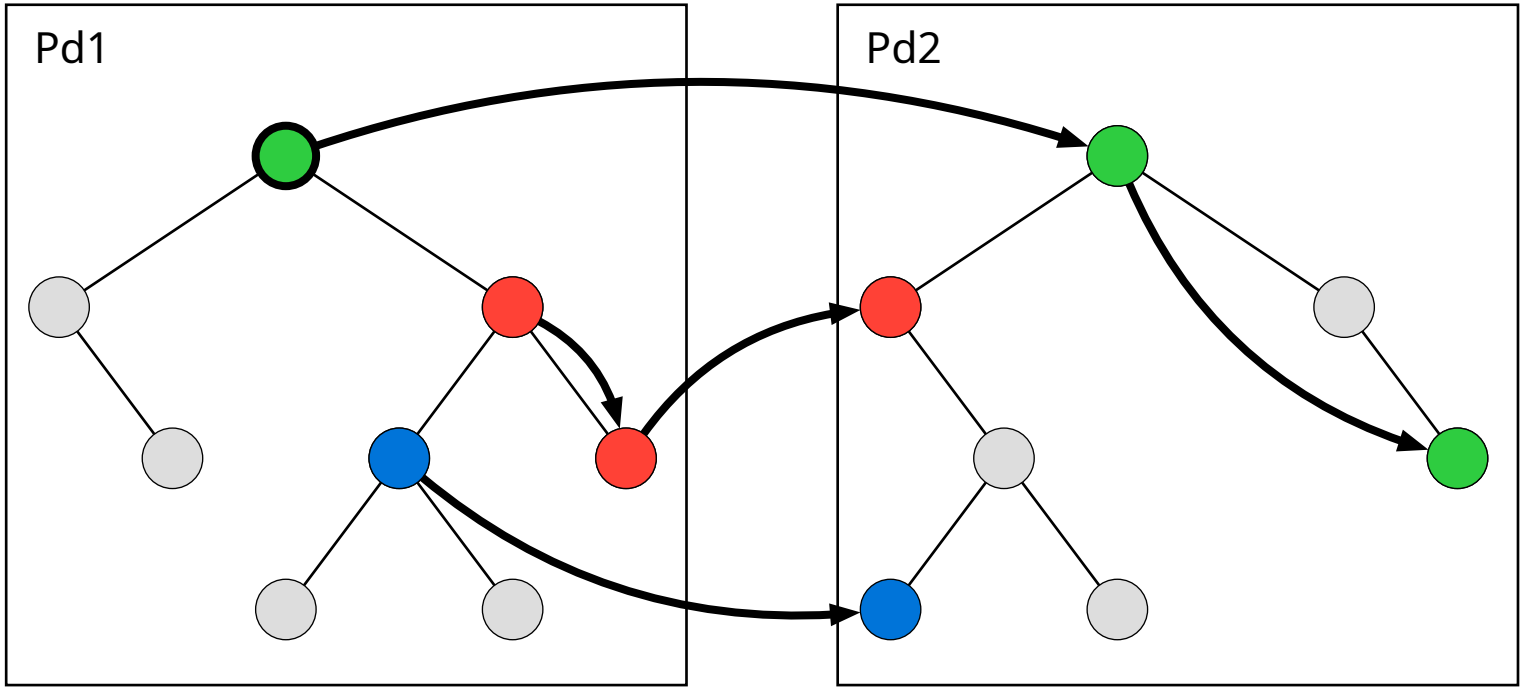


Mapping Database – Revoke



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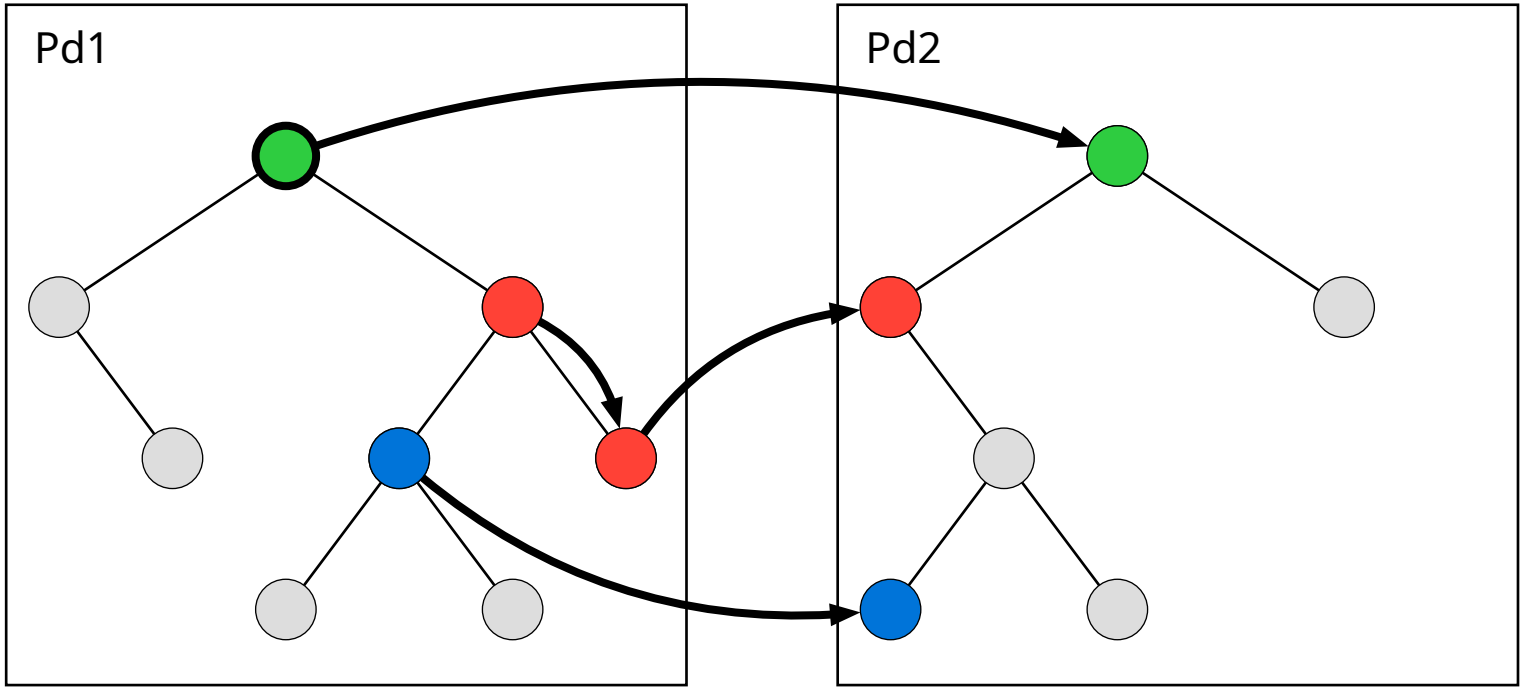

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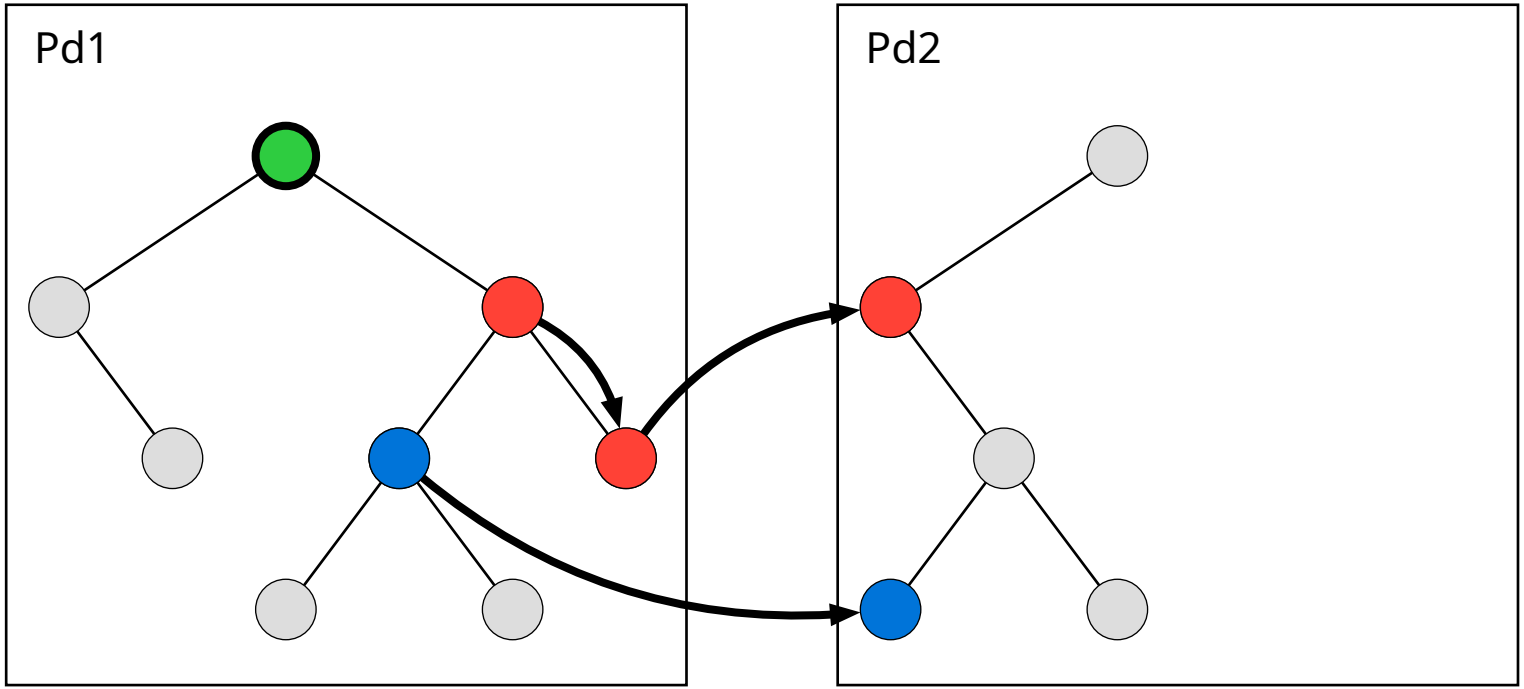
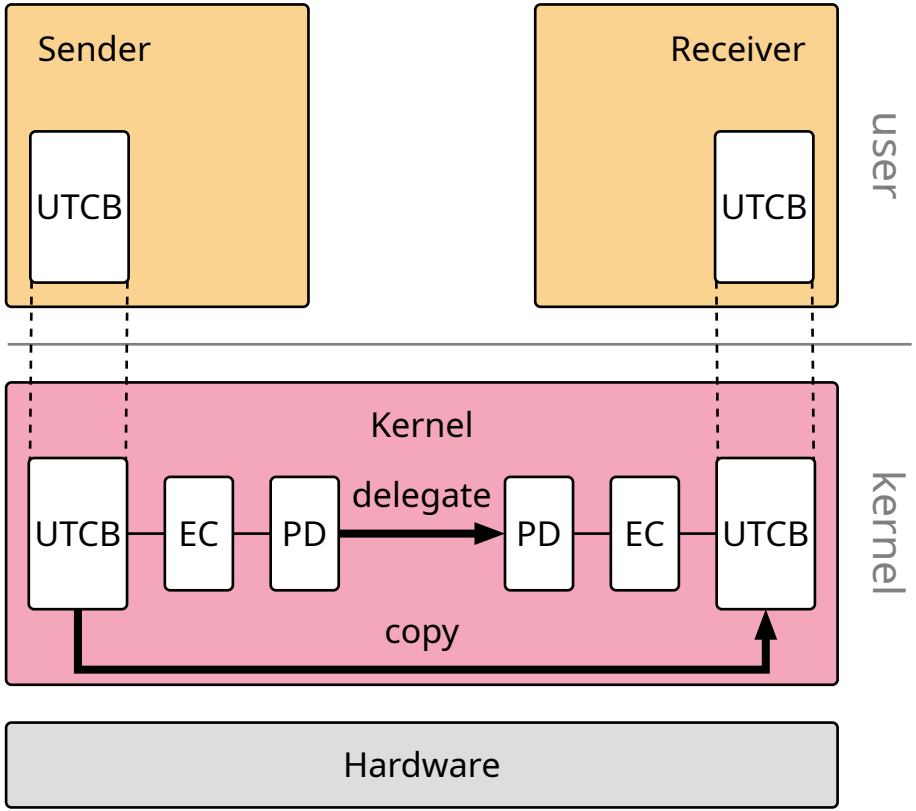
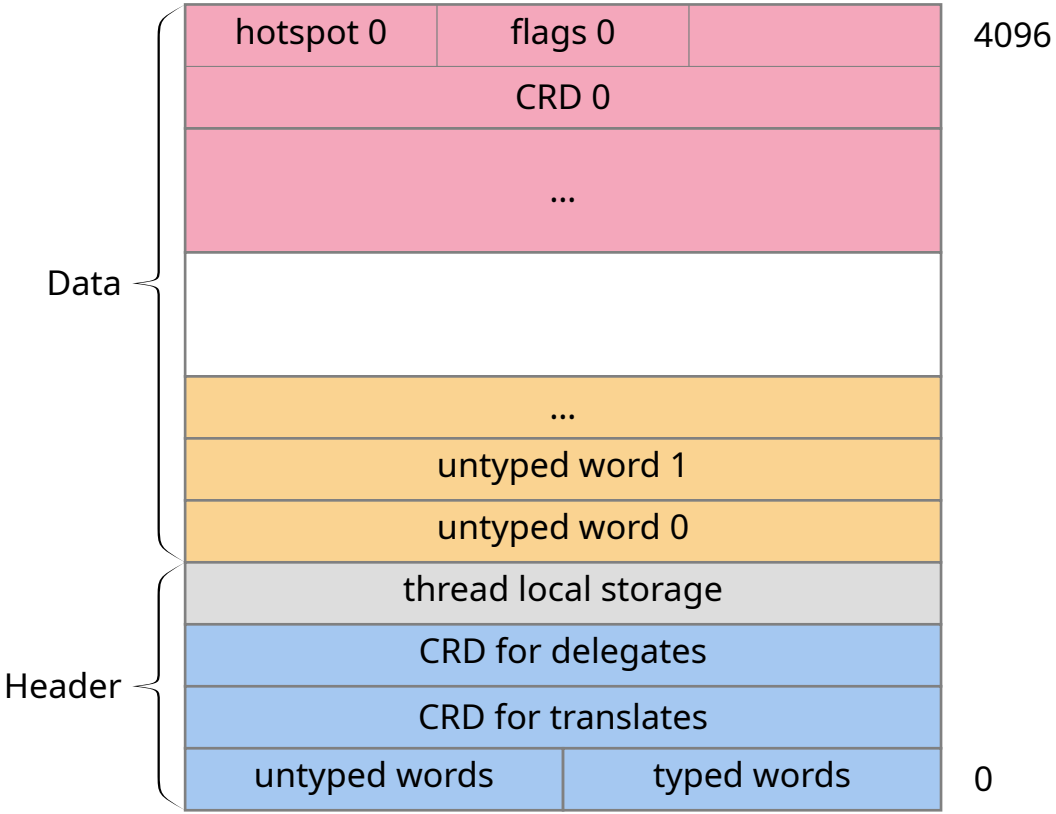


IPC With Delegate

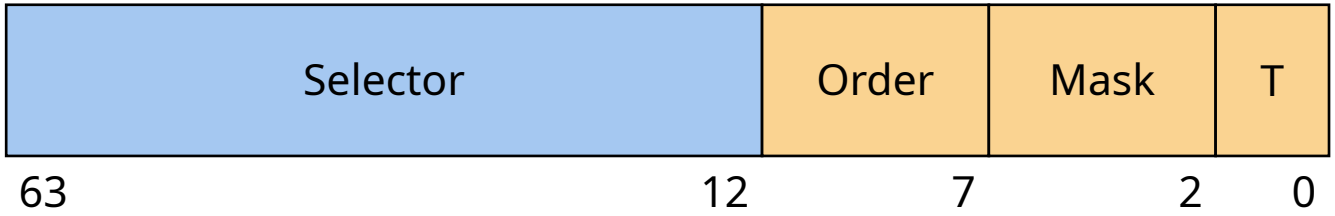


- EC has exactly one UTCB
- EC belongs to exactly one PD
- Kernel copies between UTCBs
- Kernel delegates from sender PD to receiver PD

UTCB Layout

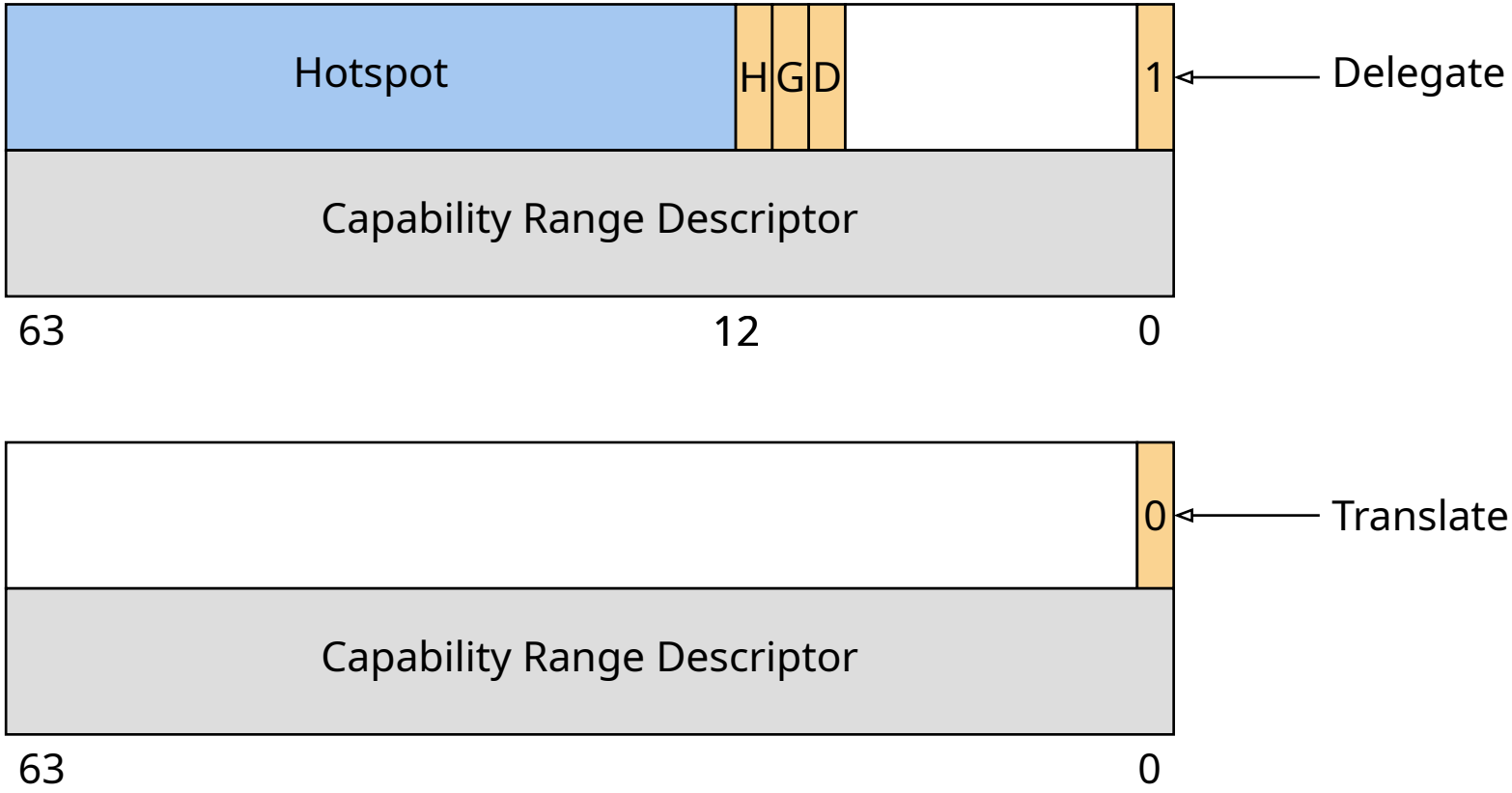

hotspot 0
flags 0
4096
CRD 0
...
Data
...
untyped word 1
untyped word 0
thread local storage
CRD for delegates
Header
CRD for translates
untyped words
typed words
0

Capability Range Descriptor



- Order specifies the number of capabilities (2^{order})
- Selector specifies the first capability
- Selector has to be size aligned, i.e., a multiple of 2^{order}
  - **wrong**: order=2, selector=6
  - **okay**: order=2, selector=8
- Mask allows to reduce permissions
- T specifies capability space (objects, memory, I/O)

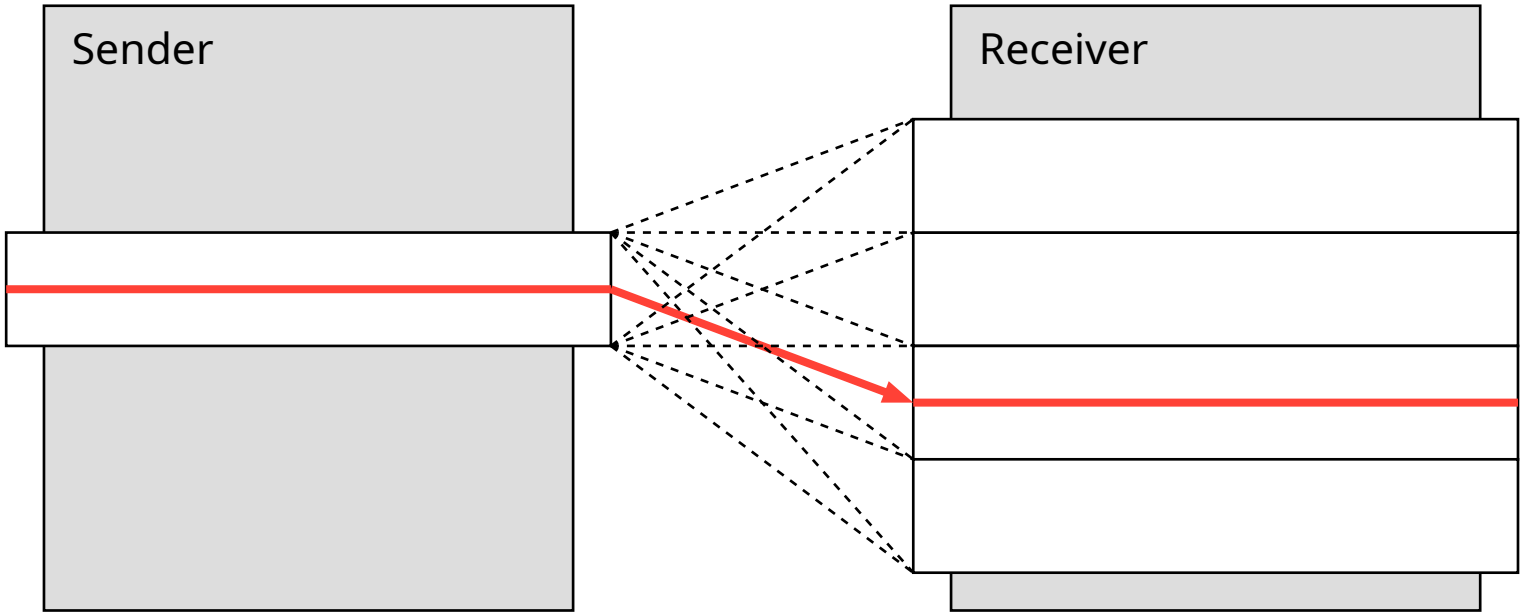
Typed Words


Hotspot
H
G
D
1
Delegate
Capability Range Descriptor
63
12
0
0
Translate
Capability Range Descriptor
63
0

Capability Delegation: Order of Events

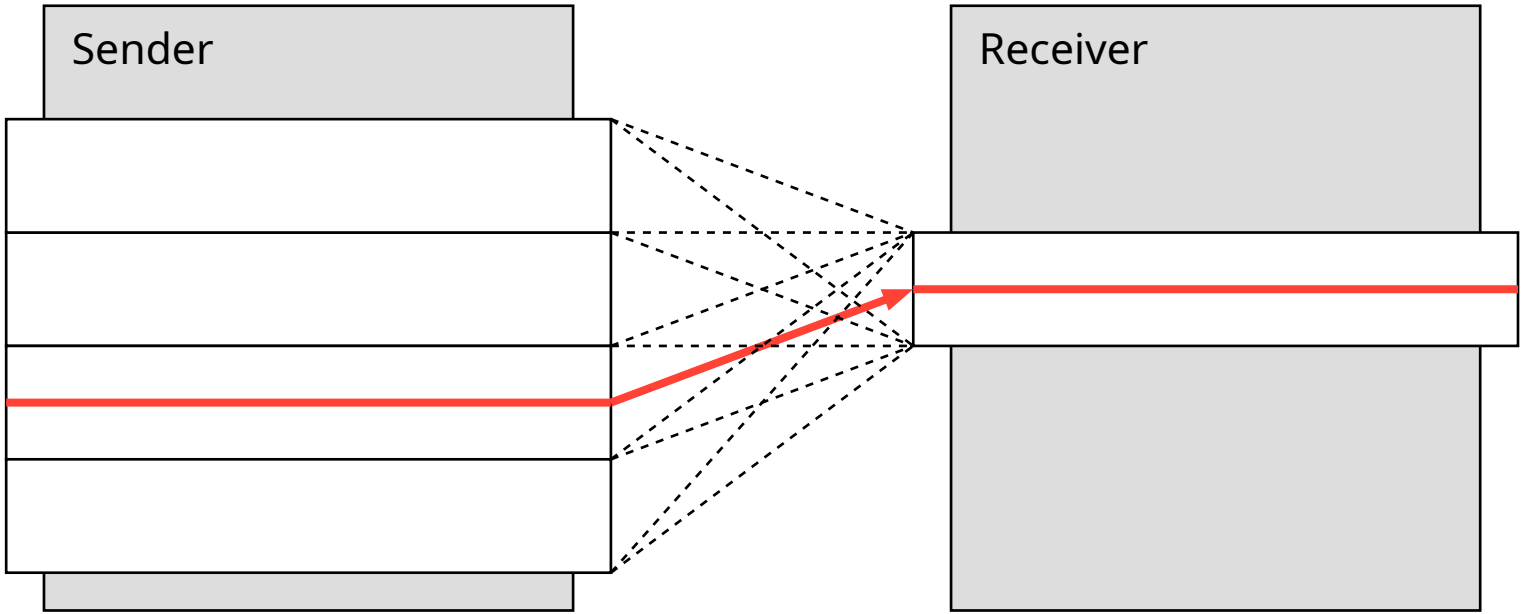
- Receiver sets up receive window (writes CRD into UTCB)
- Receivers waits for IPC
- Sender puts typed item into UTCB
- Sender calls portal
- Kernel delegates typed item
- Kernel puts typed item into UTCB, telling receiver about caps
- Kernel switches to receiver
- But: what if receive window and sent caps don’t match?

Matching Send and Receive Window (1)



Send window is smaller than receive window

Matching Send and Receive Window (2)



Send window is larger than receive window