Microkernel Construction

Capabilities

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06/02/2022

Outline

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

Motivation

- How do you find/access resources?
- How do you restrict access to resources?

Global Names

- One global namespace for (one type of) resources
- Example: semaphores, processes, devices, ... on UNIX

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

Access Control Lists

- Attach a list of permissions (subjects) to each object
- Permission depends on who you are, not what you have

Pros & Cons

+ No need to give permissions explicitly
+ Makes it easy to restrict access to specific objects
− 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”
- Client executes: `compile foo bill`
- Service has access to bill file, client does not
- Problem: service is acting on behalf of the client, but opens files with *its own* permissions
- One solution: the client opens files and passes file descriptors (capabilities) to service

Outline

- Introduction
- Capabilities in General
  - Overview
  - Operations
- Capabilities in NOVA

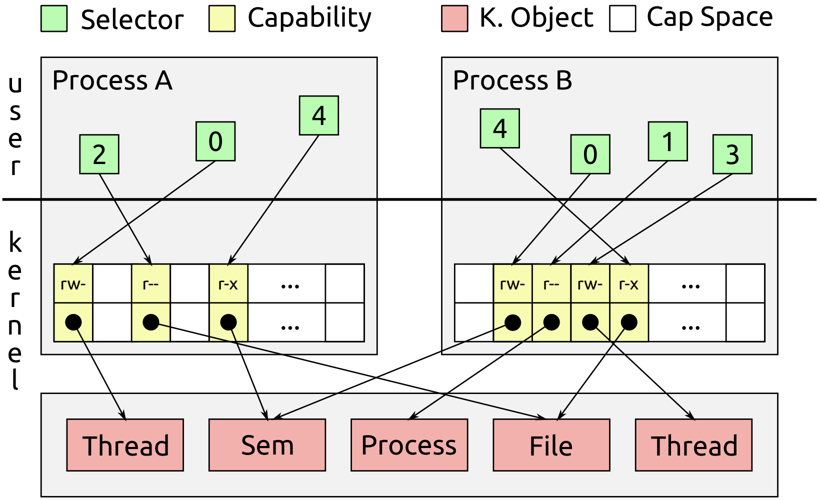
Capabilities

- Give each subject a local namespace
- Operations to exchange objects between namespaces
- Permission depends on what you have

Pros & Cons

+ Makes it easy to restrict specific subjects
+ Separation of subsystems, composable, independent
+ POLA is easy to achieve
− Need to give permissions explicitly
− Exchanging, especially revoking, capabilities is difficult

Overview

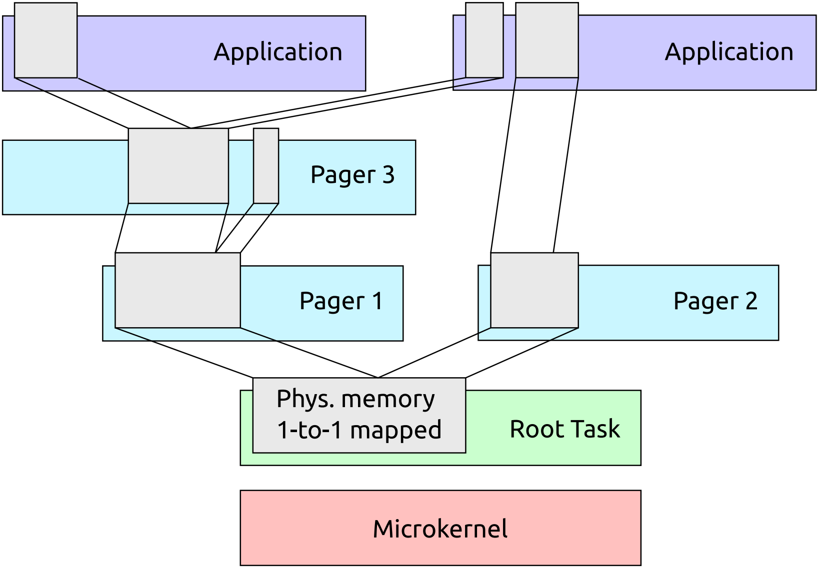


Selector
Capability
K. Object
Cap Space
user
kernel
Process A
2
0
4
rw-
r--
r-x
...
Process B
4
0
1
3
rw-
r--
rw-
r-x
...
Thread
Sem
Process
File
Thread

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



Outline

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

Capability Spaces

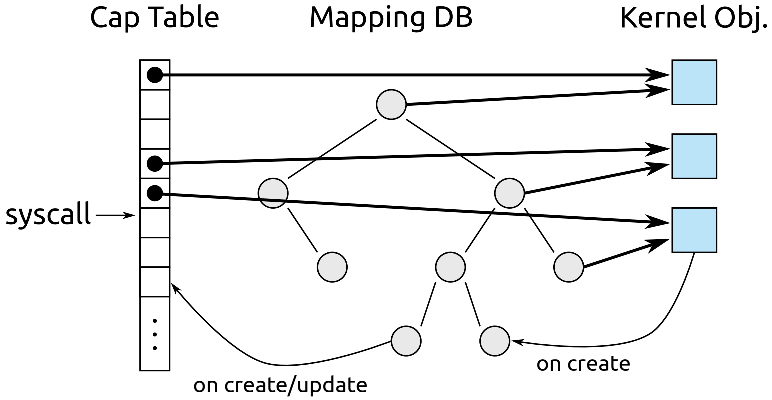
Each protection domain (Pd) has

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

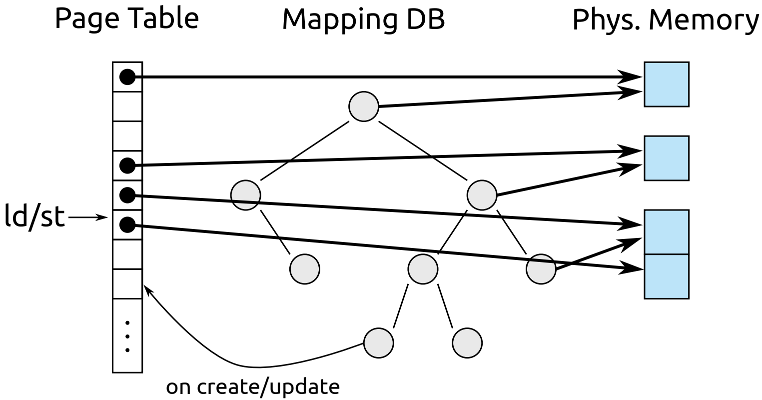
Similarities and differences

- 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

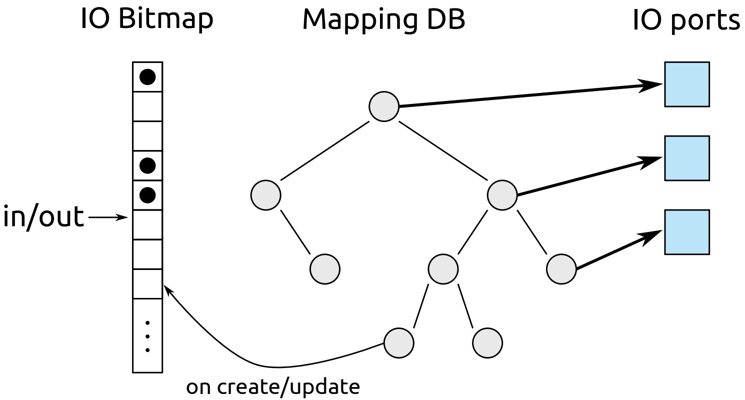
Object Capability Space



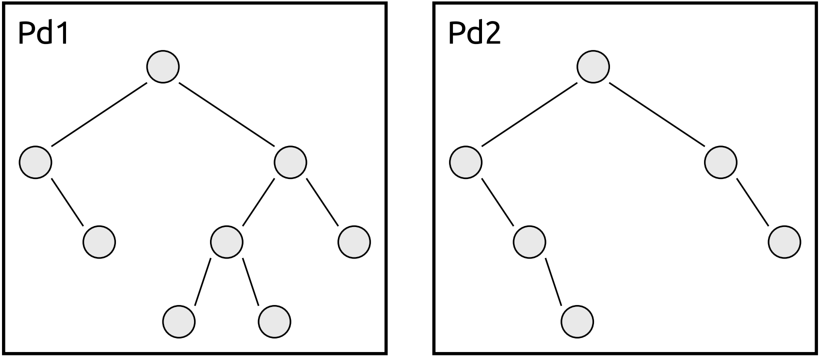
Memory Capability Space

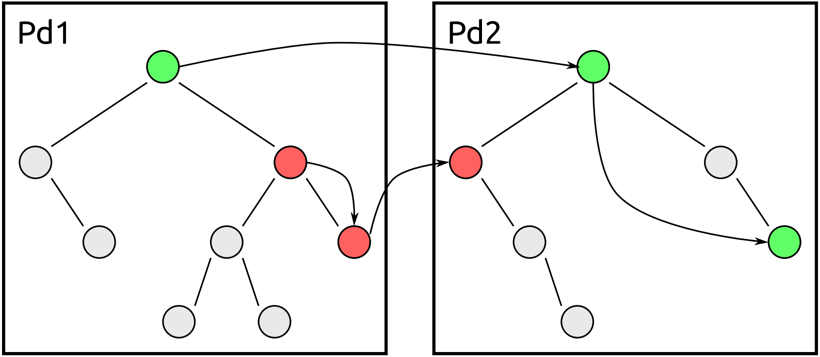


I/O Capability Space

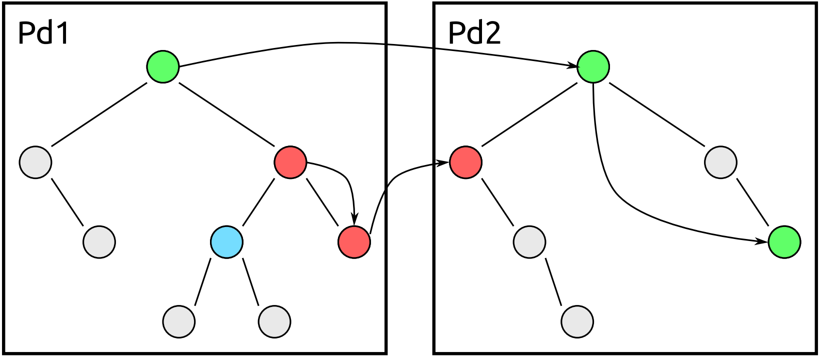


Mapping Database

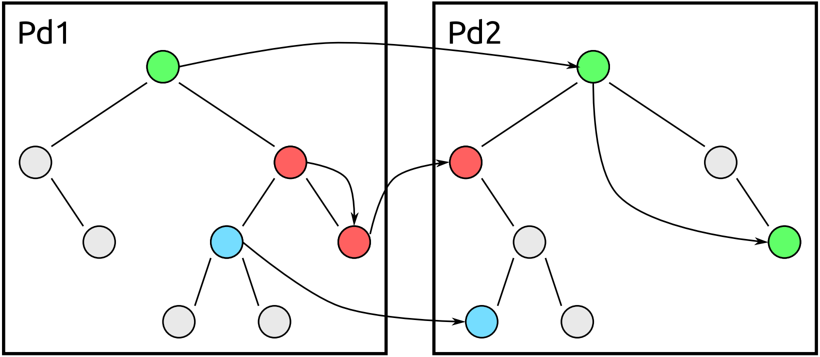



Pd1
Pd2

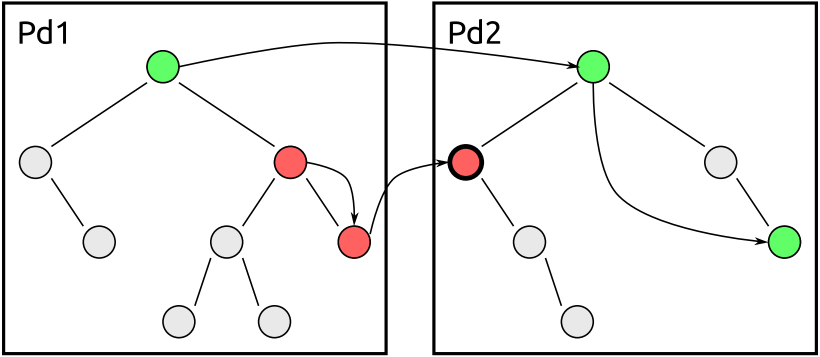
Mapping Database – Delegate

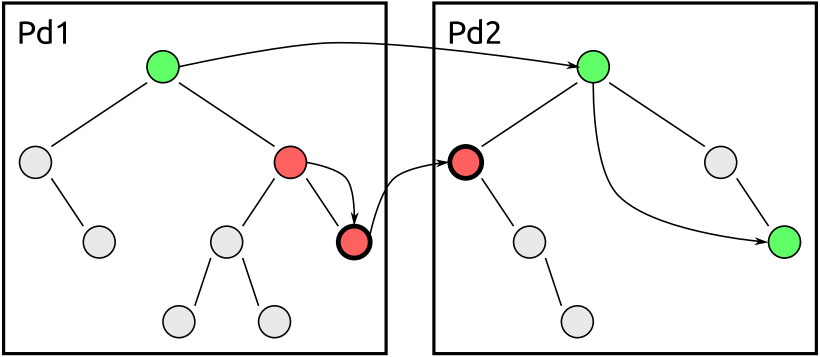


Mapping Database – Delegate

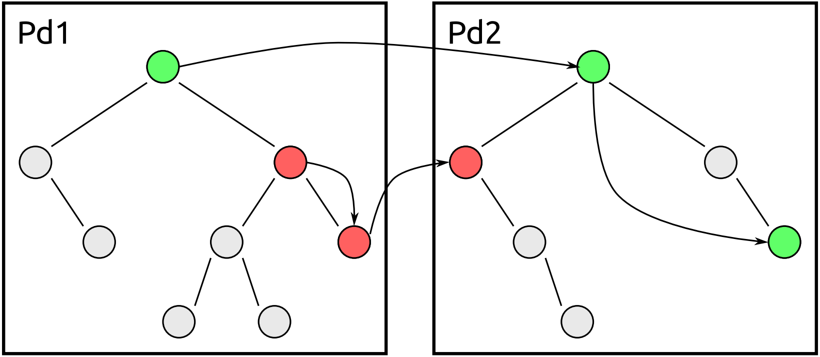


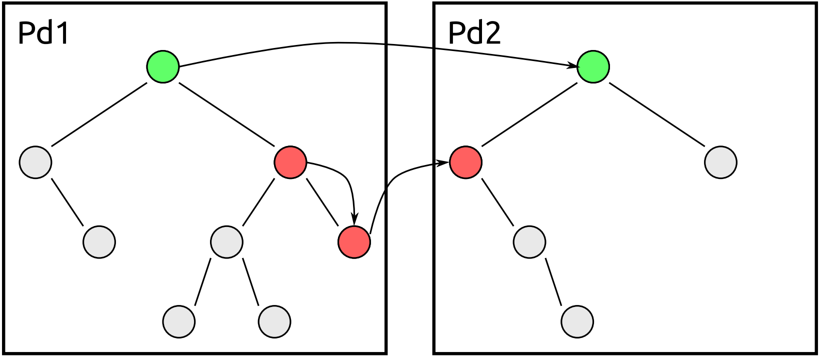
Mapping Database – Translate



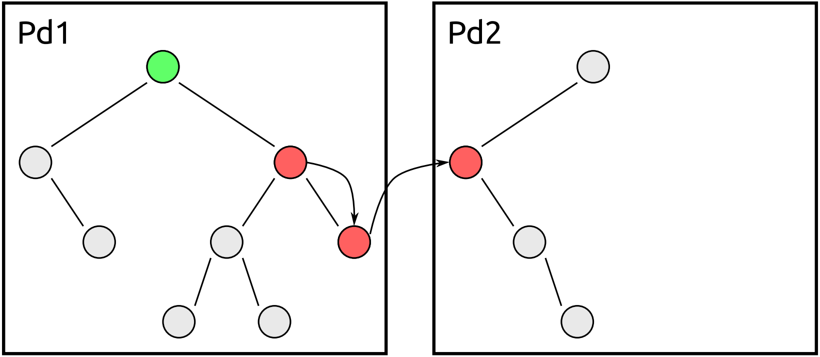

Pd1
Pd2

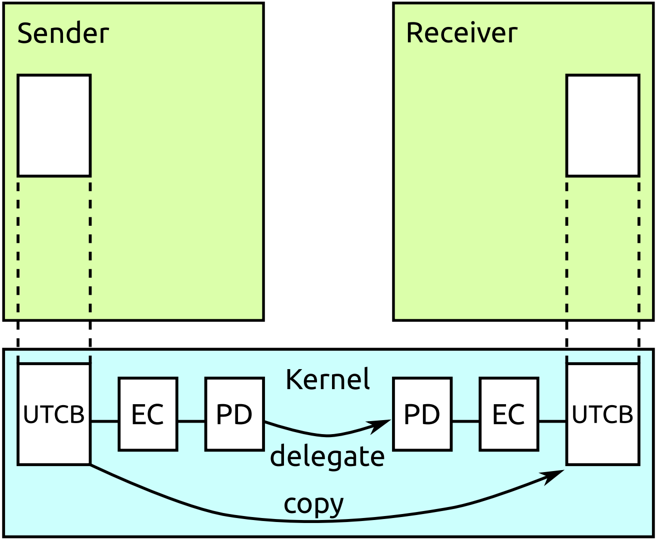
Mapping Database – Revoke



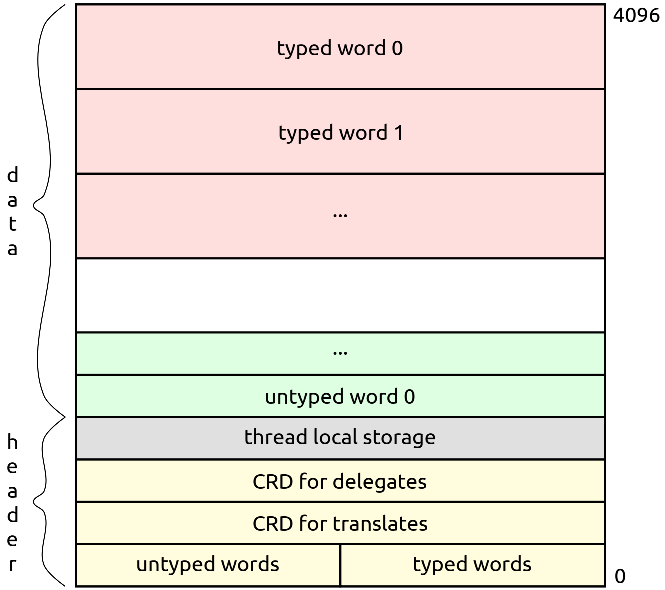

Pd1
Pd2

Mapping Database – Revoke




Sender
Receiver
Kernel
UTCB
EC
PD
delegate
PD
EC
UTCB
copy

UTCB Layout



typed word 0
typed word 1
...
...
untyped word 0
thread local storage
CRD for delegates
CRD for translates
untyped words
typed words
4096
0
data
header

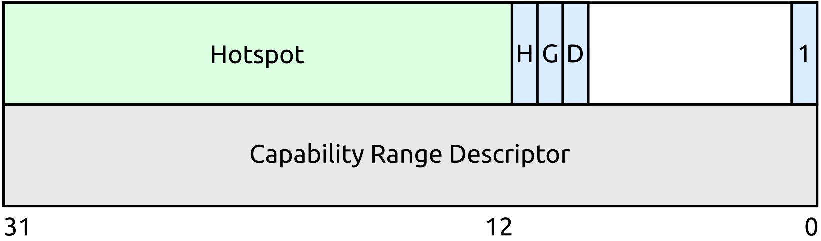
Capability Range Descriptor

Selector	Order	Mask	T
31 … 12	7	2	0

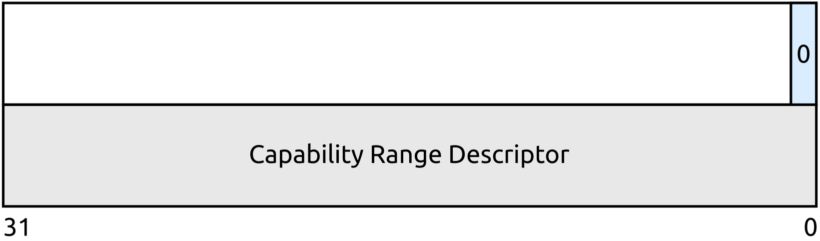
- Order specifies the number of capabilities (2^{order})
- Selector specifies the first capability
- Selector has to be size aligned, i.e., a multiple of 2^{order}
- **wrong**: order=2, selector=6, okay: order=2, selector=8
- Mask allows to reduce permissions
- T specifies capability space (objects,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

Typed Words

Delegate:



Translate:



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?

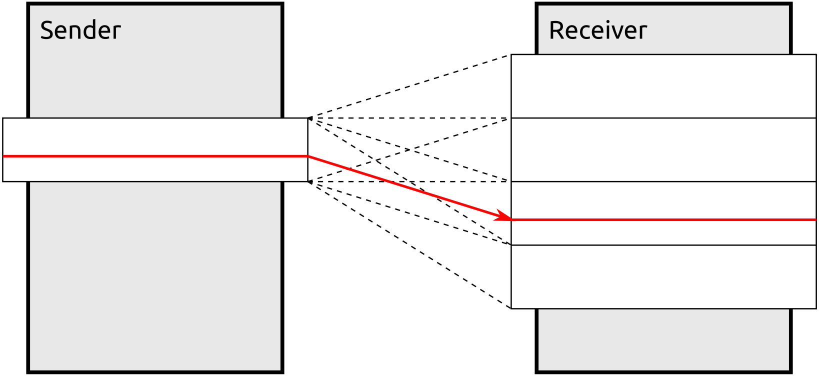


Figure: Send window is smaller than receive window

Matching Send and Receive Window (2)

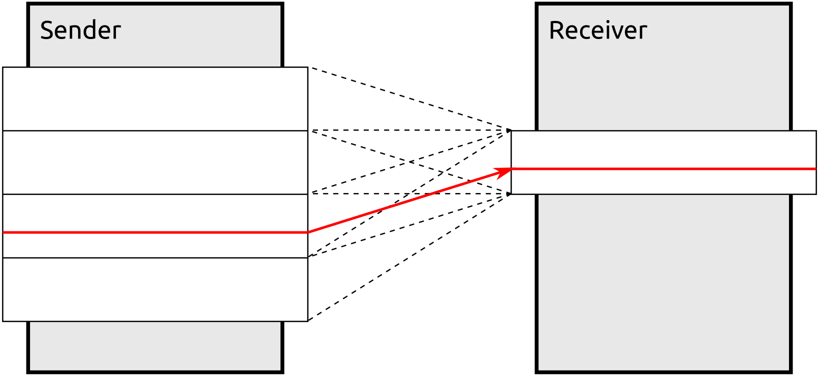


Figure: Send window is larger than receive window

Delegation Code (1)

```
void Pd::xfer_items (Pd *src, Crd xlt, Crd del,
                     Xfer *s, Xfer *d, unsigned long ti)
{
  for (Crd crd; ti--; s--) {
    crd = *s;
    switch (s->flags() & 1) {
      case 0:
        xlt_crd (src, xlt, crd);
        break;
      case 1:
        del_crd (src, del, crd, s->flags(), s->hotspot());
        break;
    }
    if (d)
      *d-- = Xfer (crd, s->flags());
  }
}
```

Delegation Code (2)

```
void Pd::del_crd (Pd *pd, Crd del, Crd &crd,
                  mword sub, mword hot)
{
  mword a = crd.attr() & del.attr();
  mword sb = crd.base(), so = crd.order();
  mword rb = del.base(), ro = del.order(), o = 0;

  switch (del.type()) {
    case Crd::MEM:
      o = clamp (sb, rb, so, ro, hot);
      delegate<Space_mem>(pd, sb, rb, o, a, sub);
      break;
    ...
  }

  crd = Crd (del.type(), rb, o, a);
}
```

Delegation Code (3)

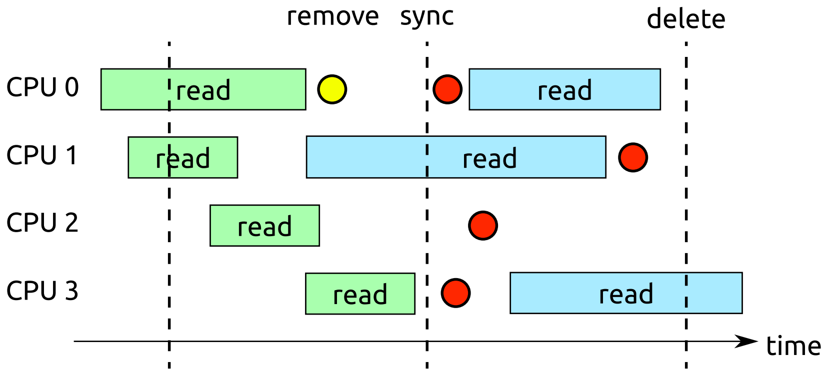
```
template <typename S>
void Pd::delegate (Pd *snd, mword snd_base, mword rcv_base,
                   mword ord, mword attr, mword sub)
{
  Mdb *mdb;
  for (mword addr = snd_base;
       (mdb = snd->S::tree_lookup (addr, true));
       addr = mdb->node_base + (1UL << mdb->node_order)) {
    Mdb *node = new Mdb (static_cast<S *>(this), ...);

    if (!S::tree_insert (node))
      ...
    if (!node->insert_node (mdb, attr))
      ...

    S::update (node);
  }
}
```

Deleting Mapping DB Nodes and Kernel Objects

- When revoking, kernel objects should be destructed
- But what if somebody accesses them at the same time?
- We could lock them during each access
- But this is expensive
- We don't care that much when exactly they are destructed
- Can't we destruct them if nobody accesses them anymore?

Read-Copy-Update

- Basically: copy-on-write with lazy delete
- Don't change objects, but copy them and change the copy
- Don't delete objects immediately, but when readers are done
- In case of NOVA: no copy-on-write, but only lazy delete
- On revoke, object is removed first
- Then, the object is registered for deletion
- Timer IRQ is used to delete only if all readers are gone


remove
sync
delete
CPU 0
read
read
CPU 1
read
read
CPU 2
read
CPU 3
read
read
time