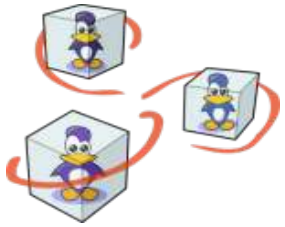
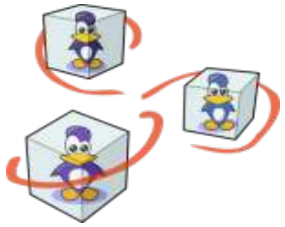


Kerrighed Internal

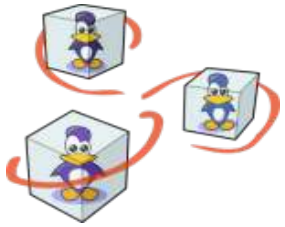
Renaud Lottiaux, Pascal Gallard
Paris Team, Irisa / Inria
July 7, 2005

Kerrighed
Linux clusters made easy



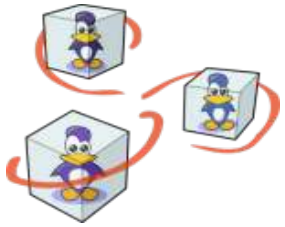
Context

- Today clusters :
  - Set of PCs
  - Fast interconnection network
  - One instance of a regular OS on each node
- View of a fully distributed machine
  - Distributed resources
    - Memory, disk, CPU, ...
  - Poor distributed services
    - NFS, RPC, ...
- No standard OS designed for clusters



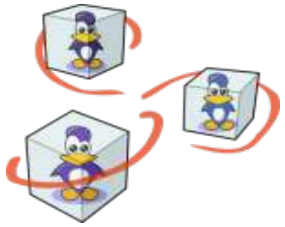
Kerrighed goals

- Goal : create an OS dedicated to clusters
  - Ease the use of clusters
  - Achieve high performance
- Target HPC Applications
  - Scientific applications
  - Message passing (MPI, PVM, sockets, ...)
  - Shared memory (Pthread, Open-MP, ...)
  - Sequential applications



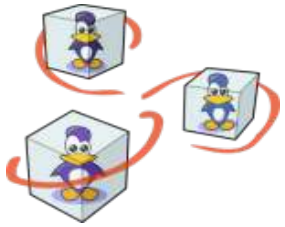
Kerrighed Design Philosophy

- Avoid mechanisms and code redundancy
- Build a strong software architecture
- Integrate most previous works ideas in the same OS
  - Analyze existing and previous works
  - Factorize similar ideas within the same abstraction
  - Instantiate abstractions in distributed services
- Introduce new works



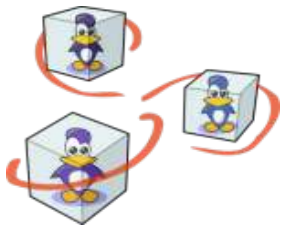
Factorization examples (1)

- Previous works (memory management)
  - Shared virtual memory (TreadMarks, ...)
  - Cooperative file cache (XFS, ...)
  - Memory injection (GMS, ...)
- Factorization : Containers
- Instantiation
  - Thread memory sharing cluster wide
  - Cluster wide IPC system V
  - Global file cache
  - ...

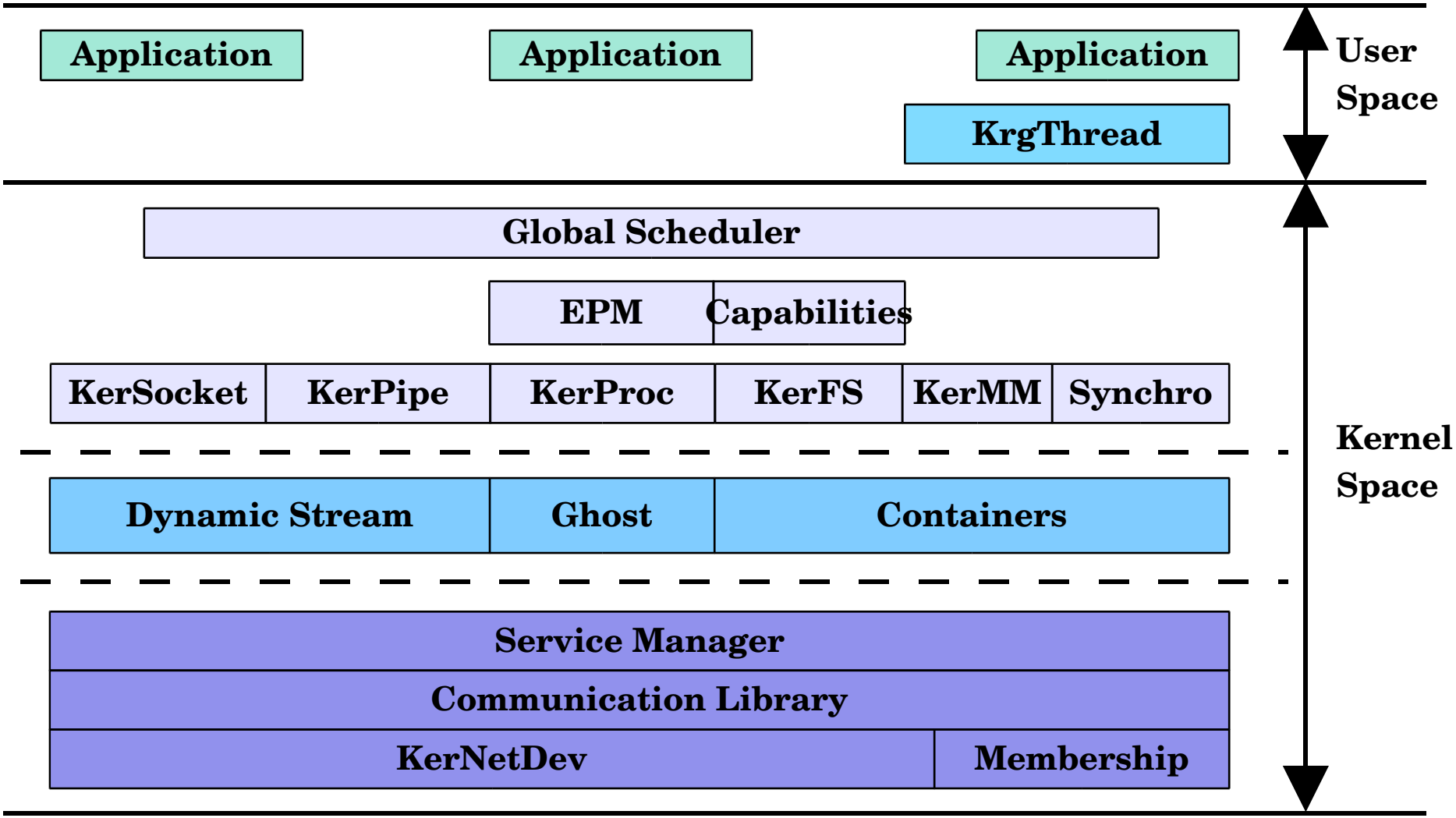


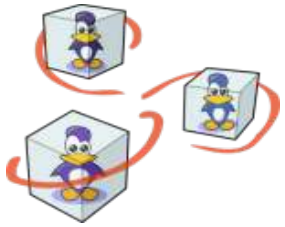
Factorization examples (2)

- Previous works
  - Process migration (Mosix, ...)
  - Process placement (Bproc, ...)
  - Process checkpointing (Condor, ...)
- Factorization : Process ghosts
- Instantiation
  - Distant process/thread creation
  - Process/thread migration
  - Process/thread checkpoint/restart



Global View of the Kerrighed Software Architecture





Outline

- Global Process Management
- Containers
- Global memory management
- Dynamic streams
- Capabilities
- Kerrighed in Action !

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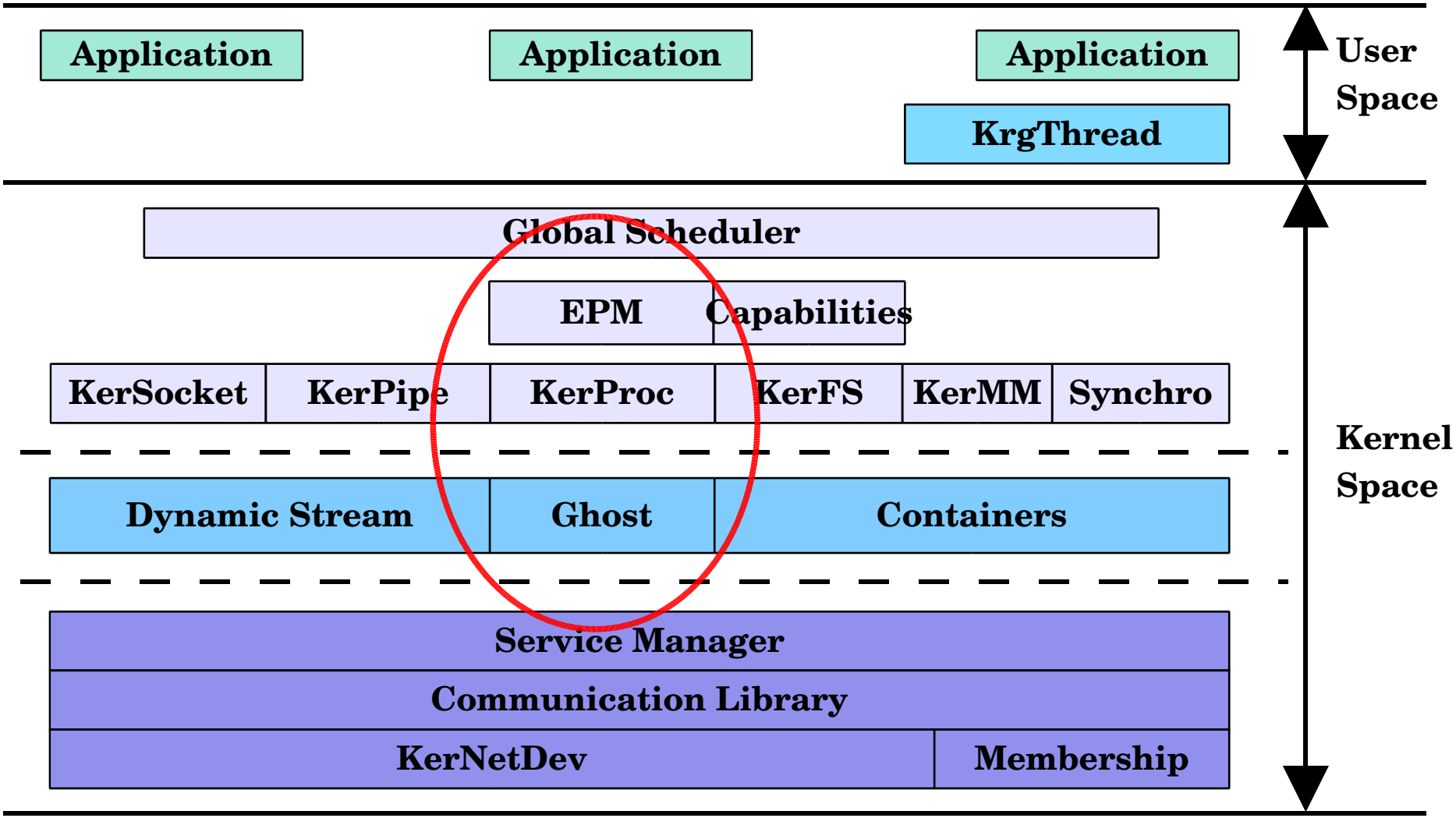
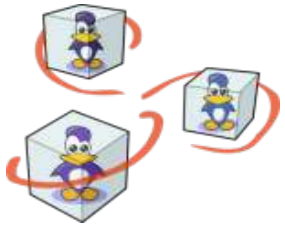
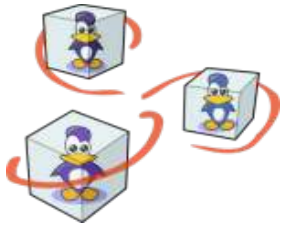




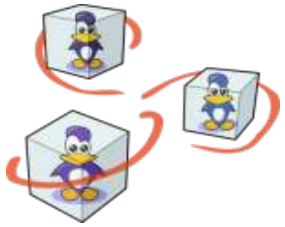
Global Process Management

- To achieve global process management we need
  - To name processes cluster wide
    - We use a cluster wide pid
      - Kill a remote task
      - Killall cluster wide
      - Global *ps*, global *top*
      - ...
  - To schedule processes cluster wide
    - We use process migration



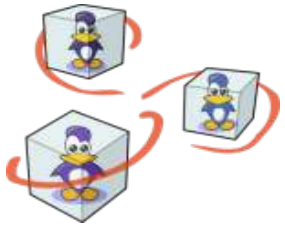
Process Migration in Kerrighed

- Migrate a process means migrating
  - Process context
  - Process memory
  - Open files
  - Active open streams (pipe, socket, ...)
  - ...
- Everything is fully distributed
  - No deputation
  - No home node



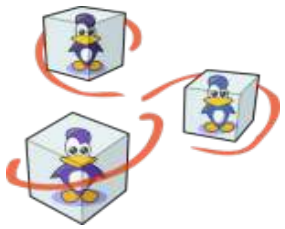
Process Migration in Kerrighed (2)

- 4 Main mechanisms
  - Ghost
    - Migrate process context
  - Containers
    - Migrate memory space
  - Dynamic streams
    - Migrate open streams
  - KerFS
    - Migrate open files

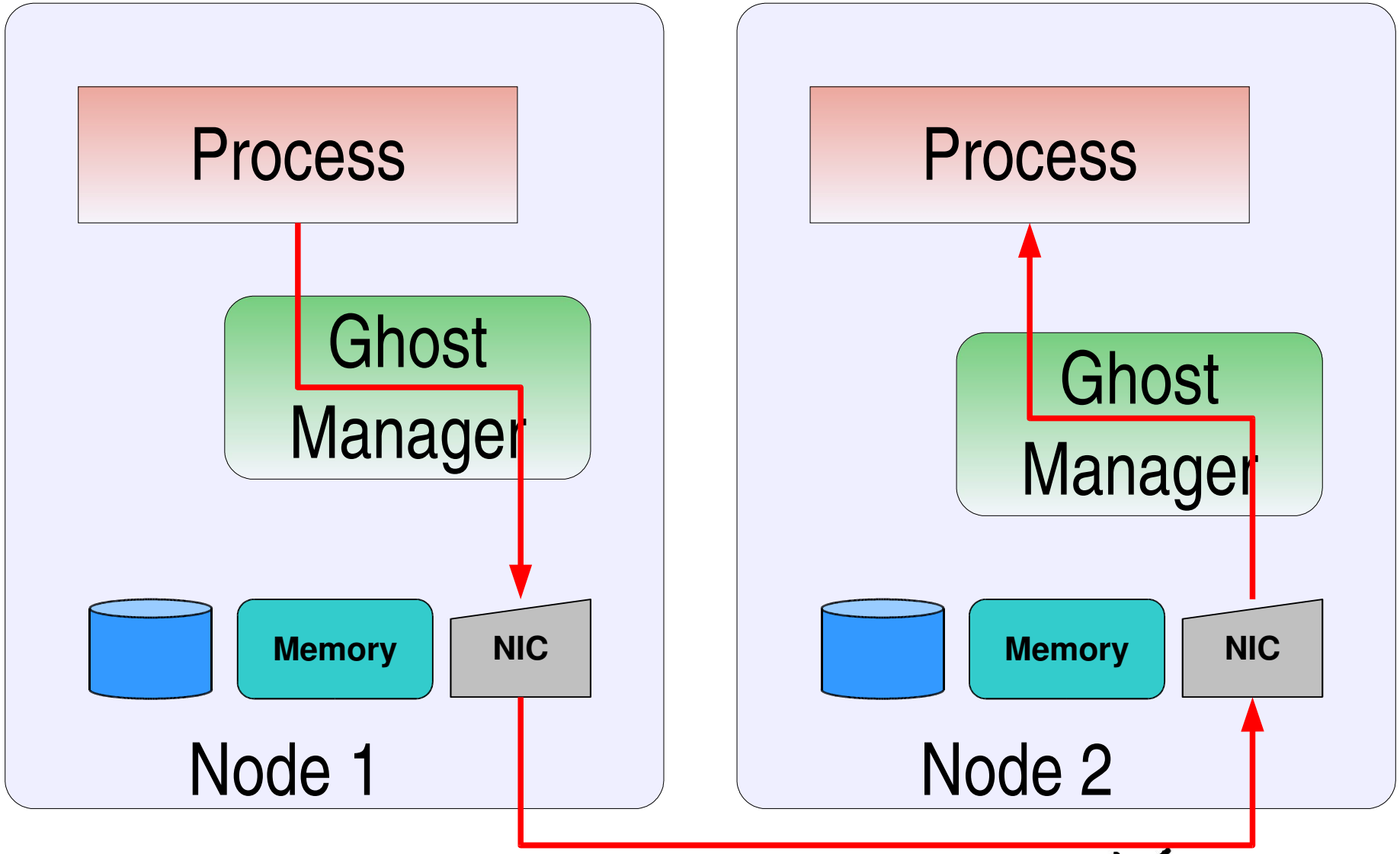


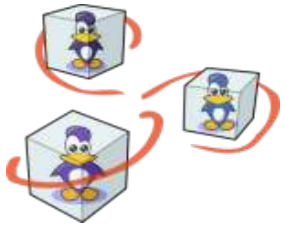
Process ghosts

- Generic mechanism to handle kernel data structures
  - Duplication
  - Migration
  - Checkpoint / restart
- Create an image of data structures and send it :
  - On disk
  - Over the network
  - In memory
- Ghost creation is independent of destination support



Migration / Duplication

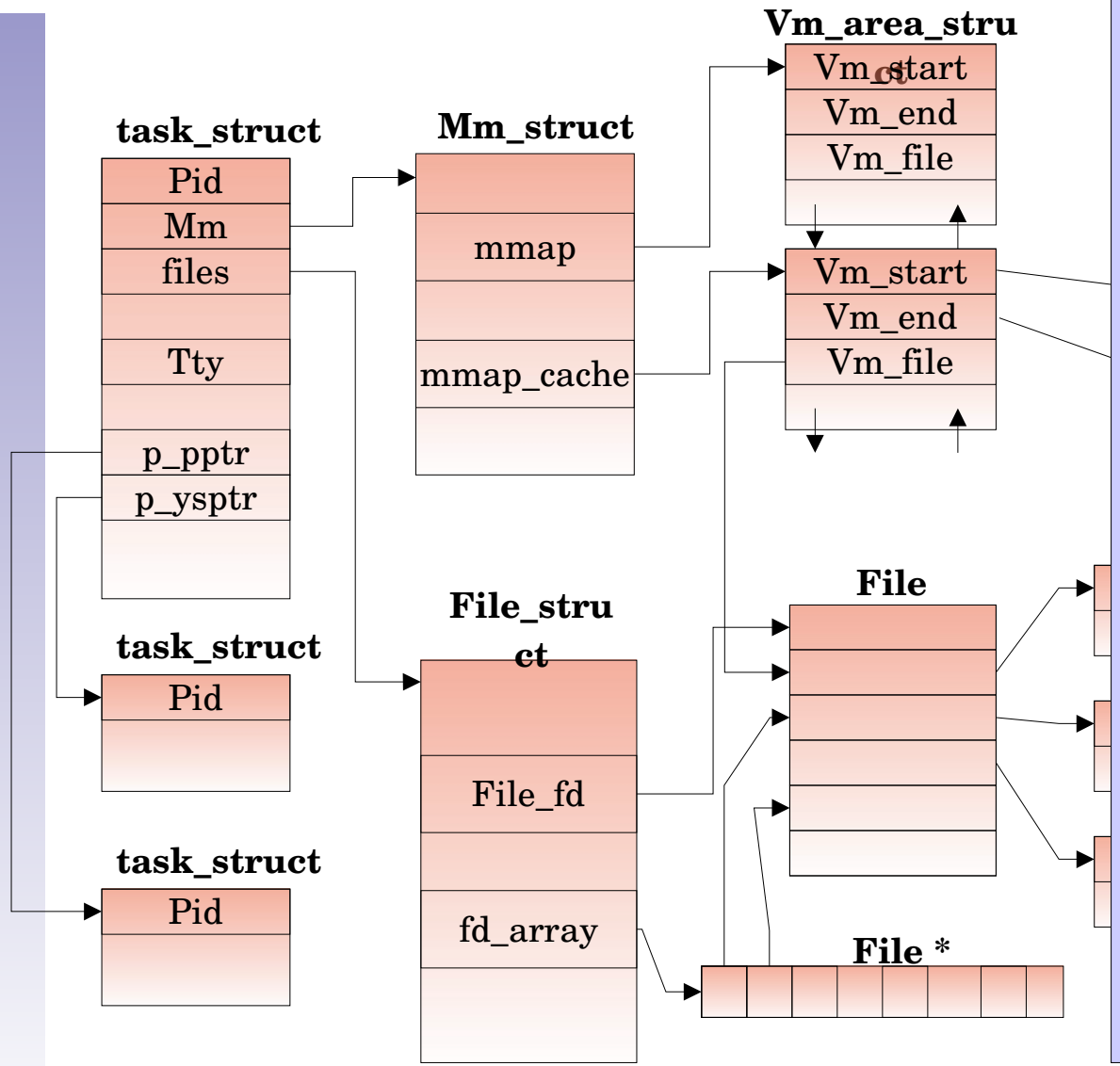




Ghost Architecture

- A ghost is defined by
  - A cluster wide ghost identifier
  - An associated device
    - Network
    - Memory
    - Disk
  - A ghosting action
    - Migration
    - Duplication
    - Checkpoint
    - Restart

“Ghosting” a task structure

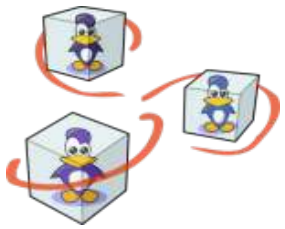



```
export_task_struct(
    ghost_t *ghost,
    struct task_struct *tsk)
{
 ghost_write (ghost, tsk,
      sizeof(task_struct));

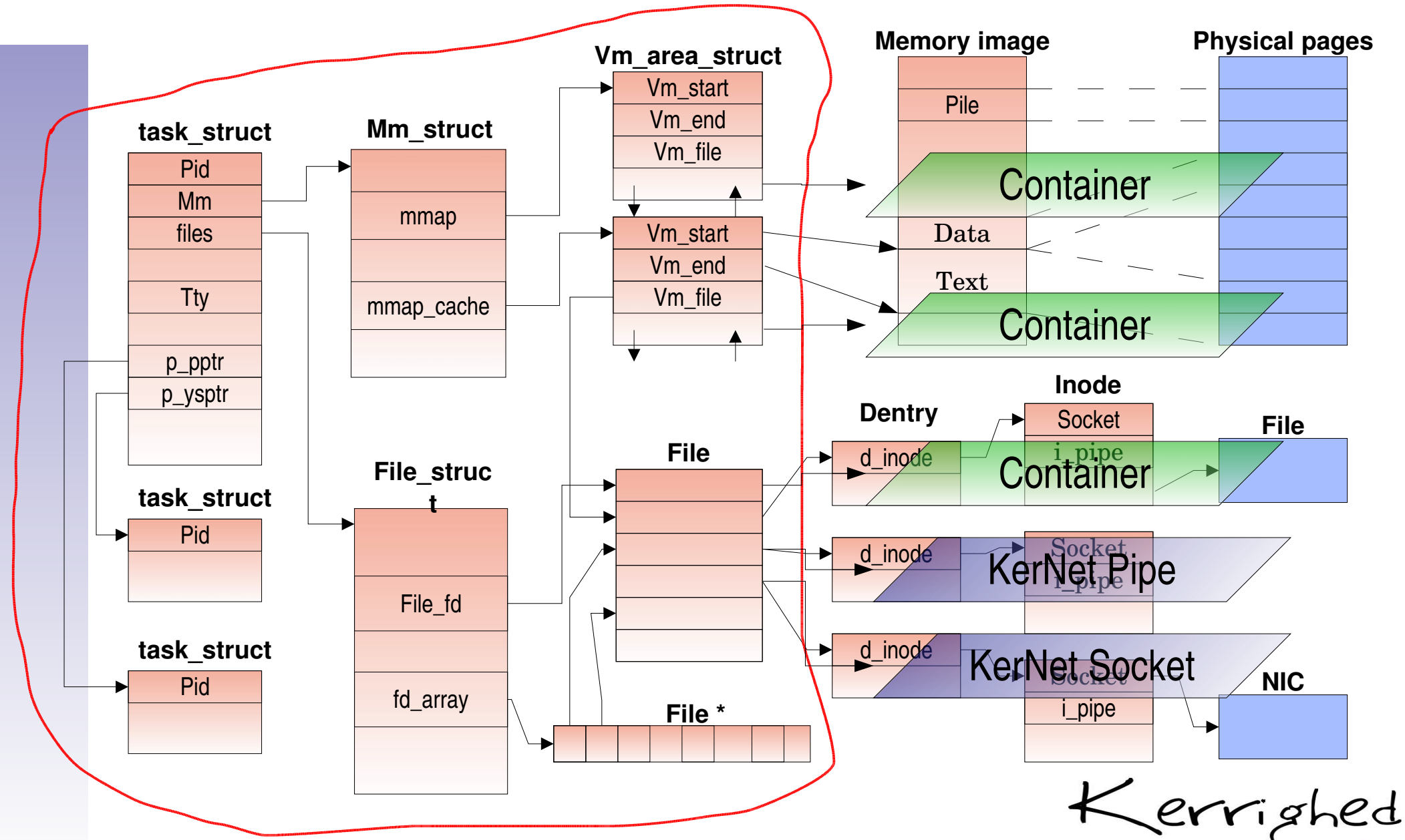
 make_ghost_of_mm(ghost,
      tsk->mm);

 make_ghost_of_files (ghost,
      tsk->mm);

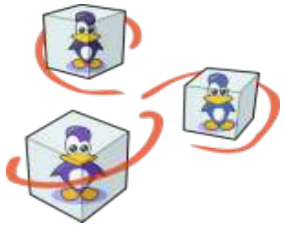
  ...
}
```



The Ghost Frontier



Kerrighed
Linux clusters made easy



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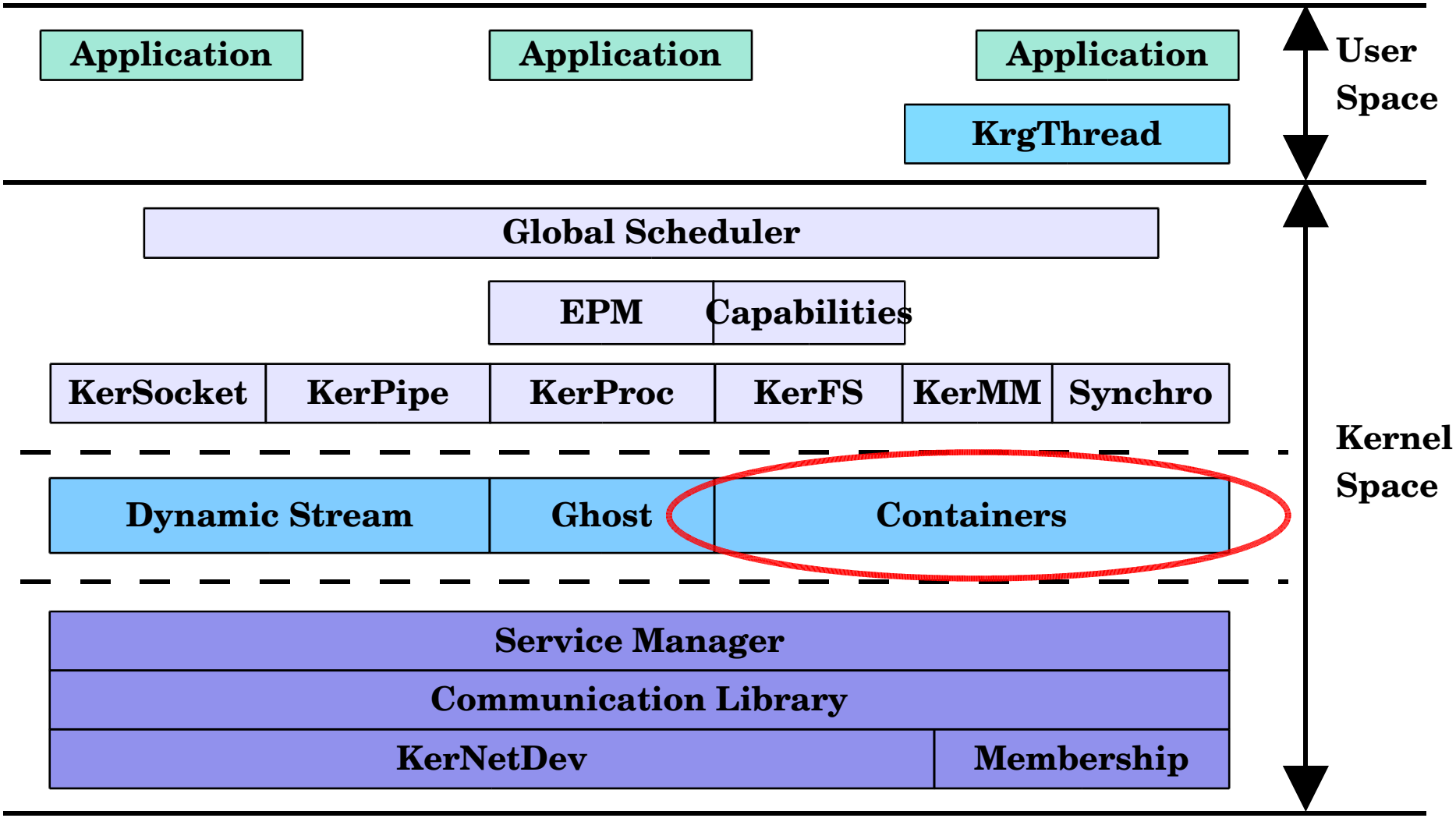
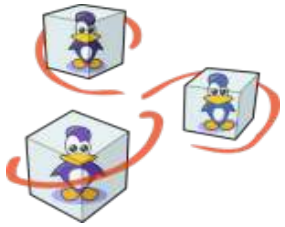
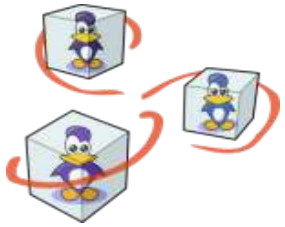




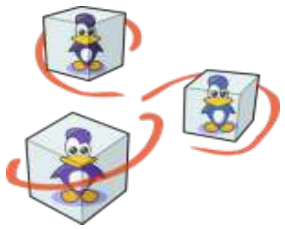
Definition of container

- Containers
  - Generic mechanism to share data cluster wide
  - Share data between cluster nodes at OS level
  - Transparent access to remote data
  - Ensure coherency of shared data
  - Efficient access to data
- Linkers
  - Interface between containers and host OS

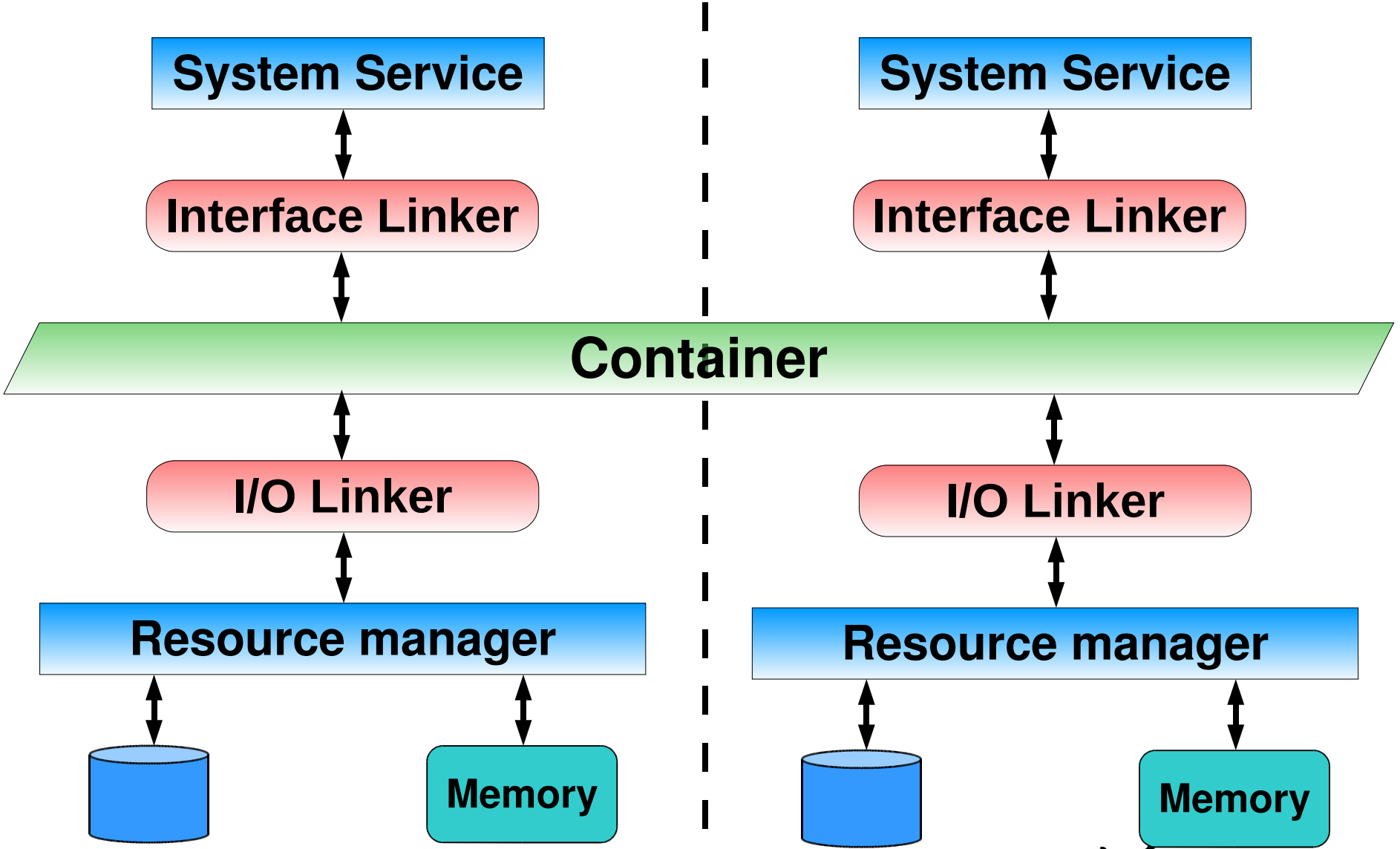


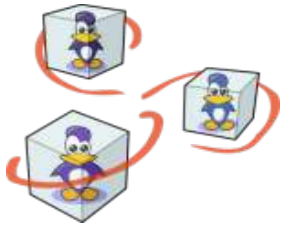
Containers : a Generic Data Sharing Mechanism

- Data hosting and sharing
  - A container hosts a set of objects
  - Objects : memory pages, data structure
  - Unit of sharing : 1 object
  - Node local memory = cache of container objects
- Object coherence management
  - MESI-like coherence algorithm
    - Single writer / multiple reader
    - Invalidation on write



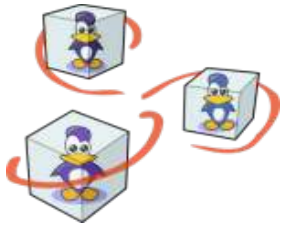
Containers Architecture





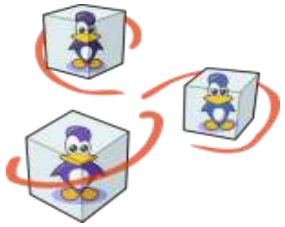
Container interface

- High level interface (used by interface linkers)
  - ctnr_find_object (Container id, object id)
    - Check if an object is present in local memory
  - ctnr_get_object (Container id, object id)
    - Place an object copy in local memory
  - ctnr_grab_object (Container id, object id)
    - Place an unique object copy in local memory
  - ctnr_put_object (Container id, object id)
    - Release an object



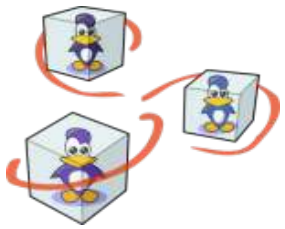
Container interface (2)

- ctnr_remove_object (Container id, object id)
  - Remove an object from a container, cluster wide
- ctnr_sync_object (Container id, object id)
  - Synchronize an object with its physical device

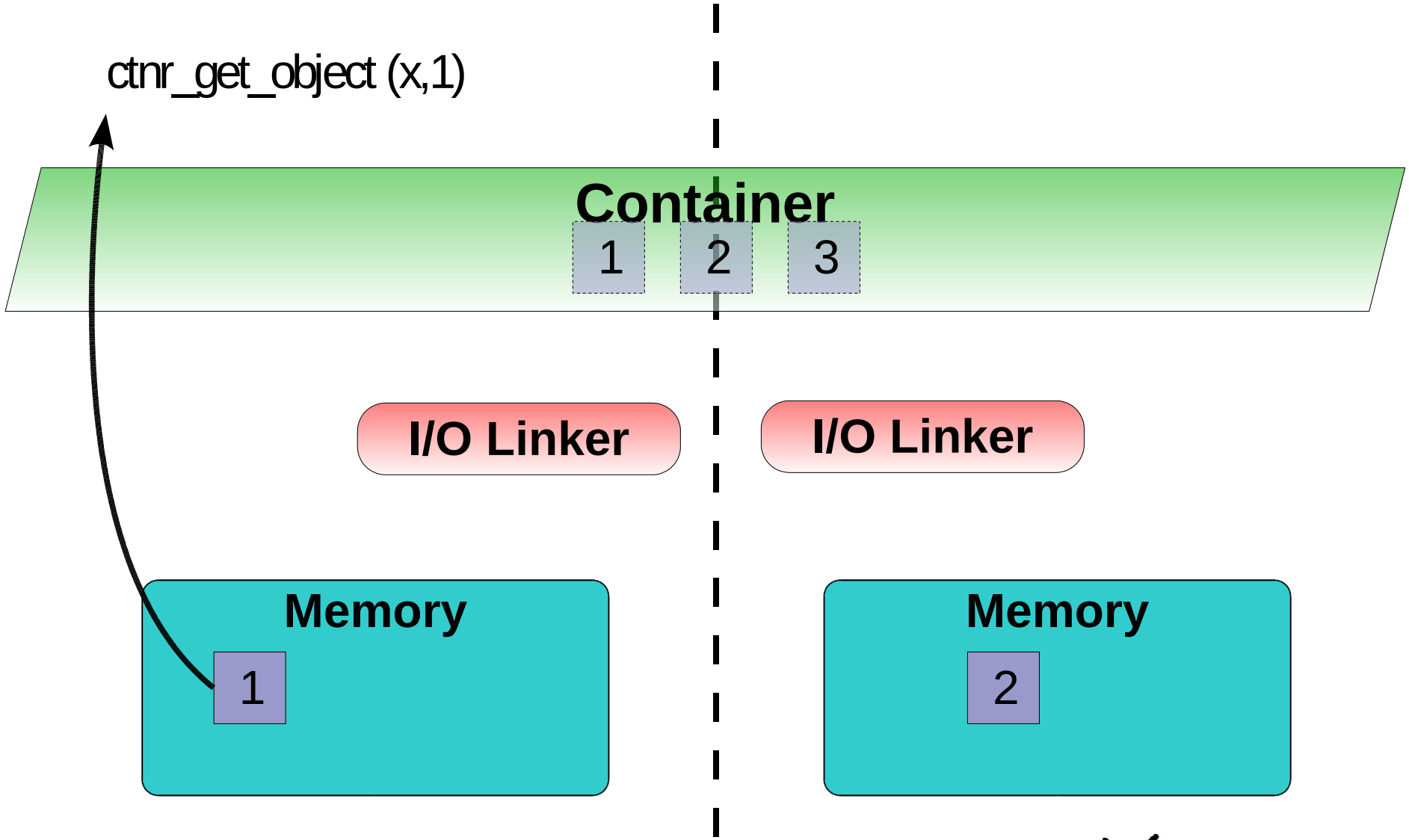


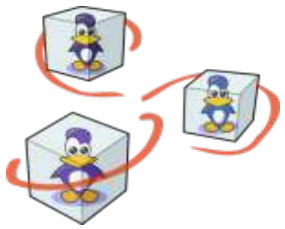
Data input/output in Containers

- Interface offered by I/O linkers
  - First_touch(...)
    - Allocate and initialize data
  - Invalidate_object(...)
    - Evict a data from local memory (used by the coherence protocol)
  - Remove_object(...)
    - Remove a data from a container (container destroy or data removal)
  - Free_object(...)
    - Free a page from local memory (used to free a container)
- One kind of container per object type to share



Get Page Example





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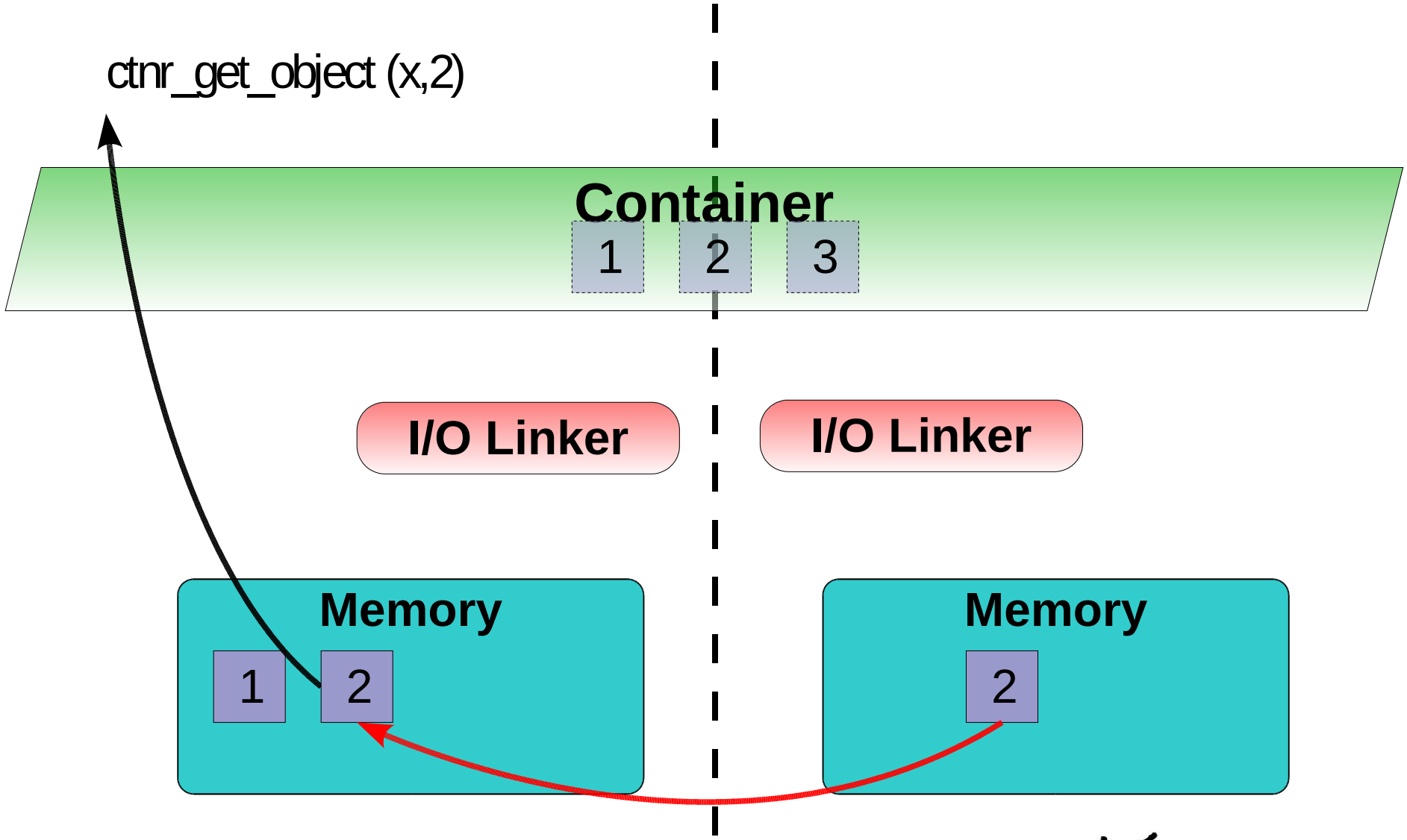

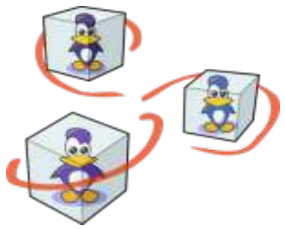

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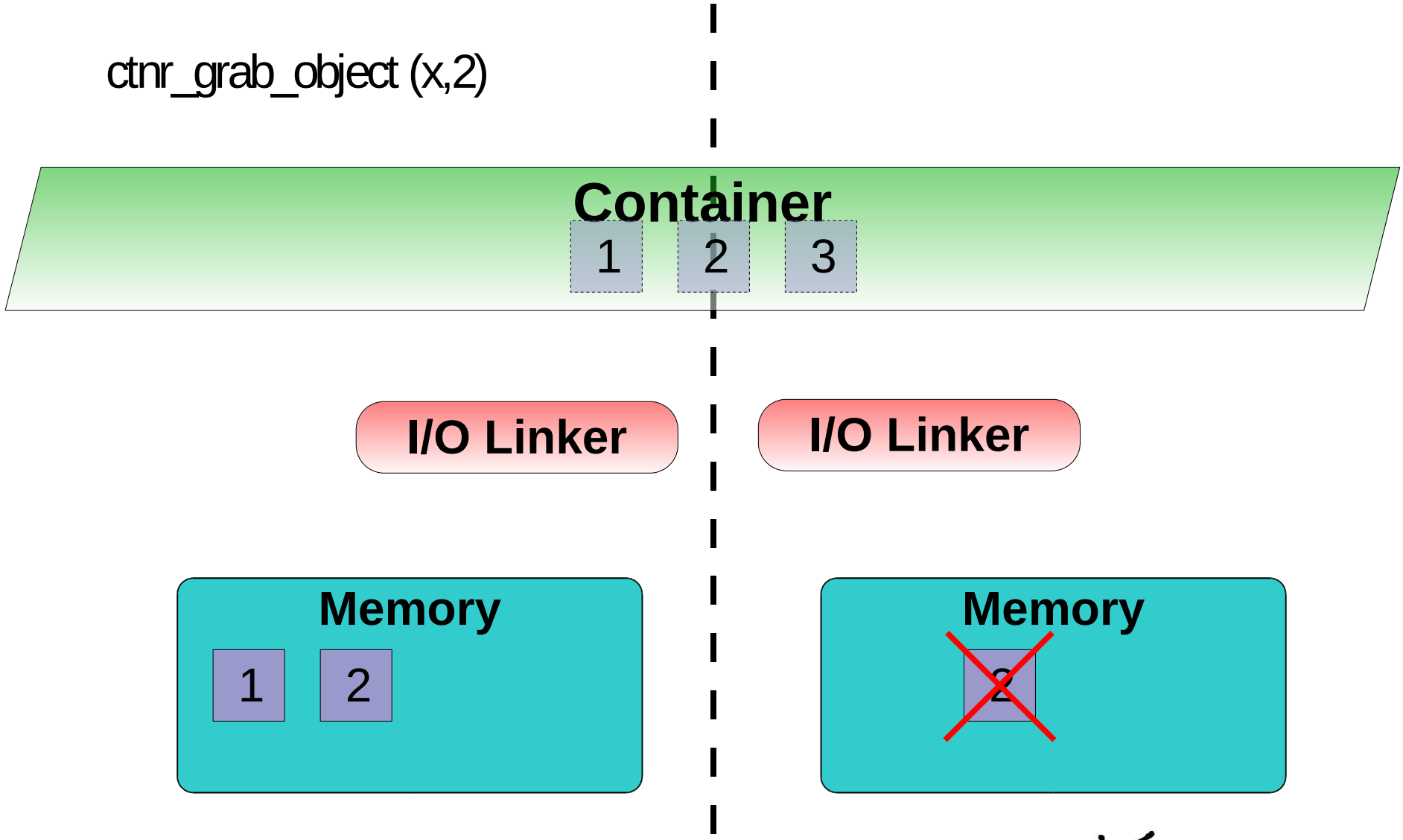

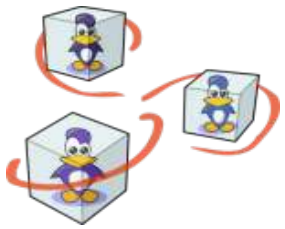

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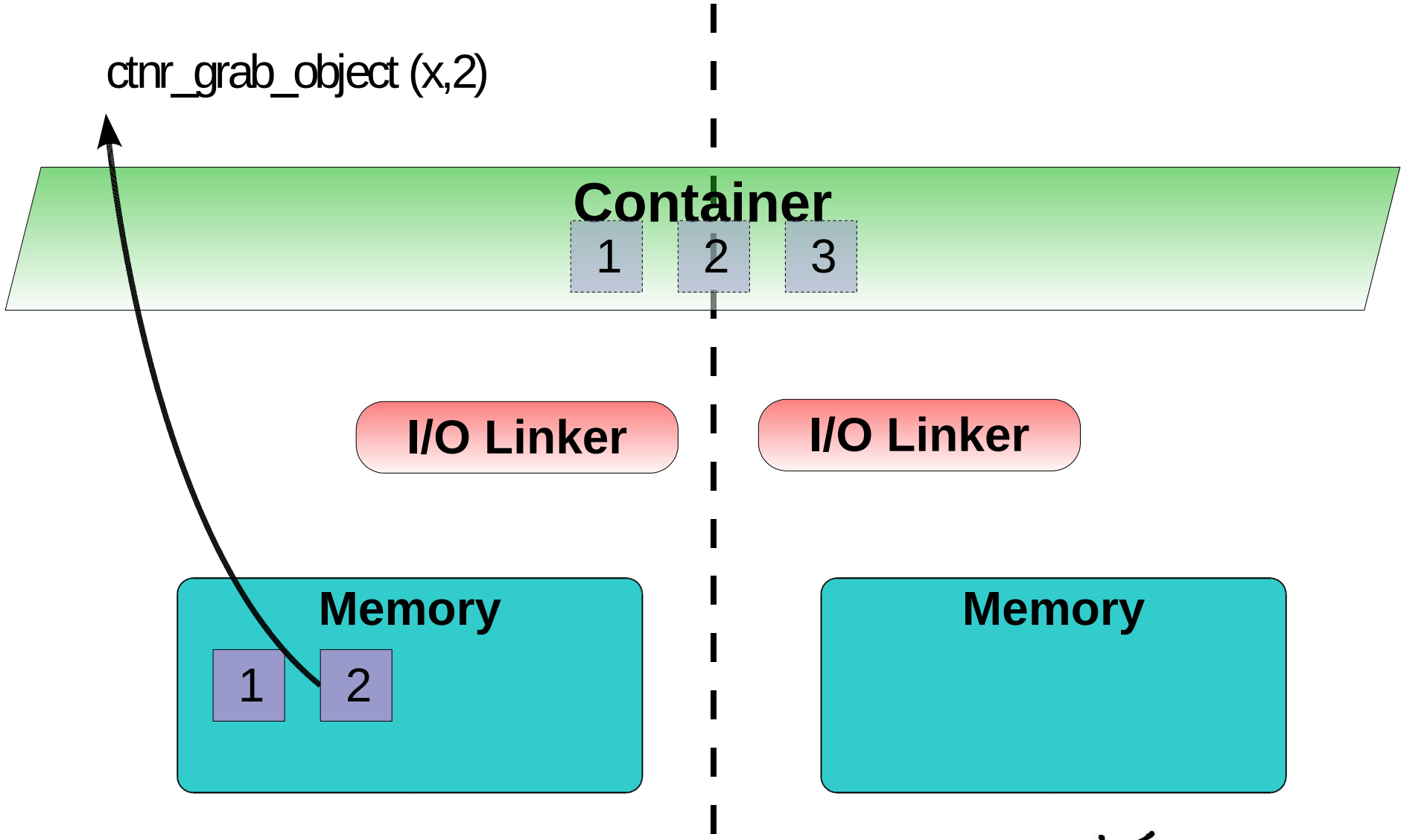

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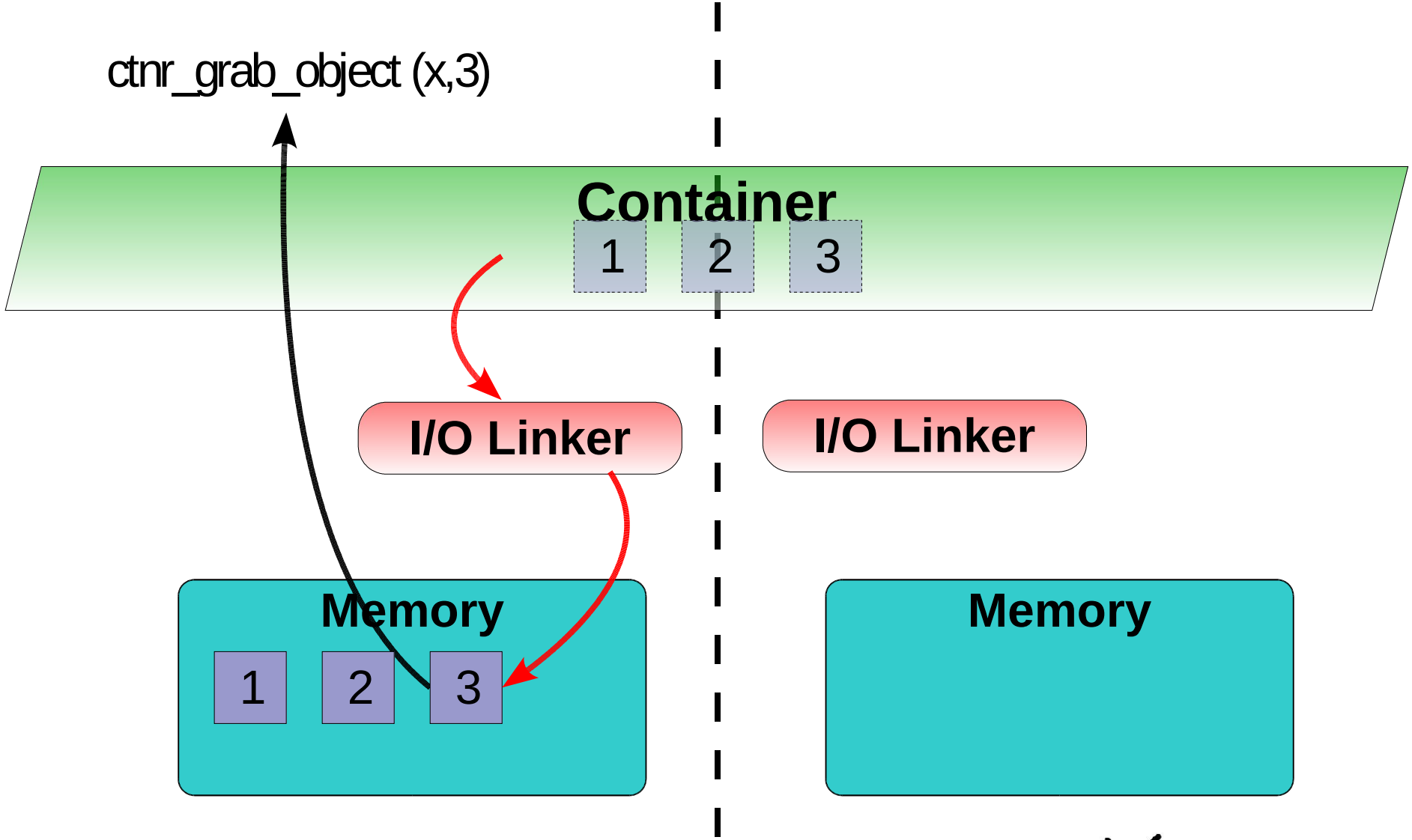
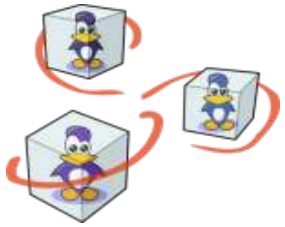
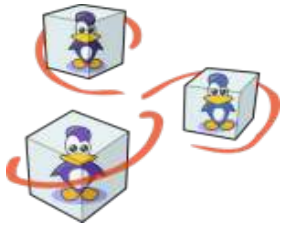




Container use in Kerrighed

- Used as a basic bloc to implement
  - Process memory migration
  - Memory sharing cluster wide
    - Thread memory
    - IPC system V segments
  - File cache sharing cluster wide
  - Inodes sharing cluster wide
  - Cluster wide locks
  - Signal sharing
  - Etc...



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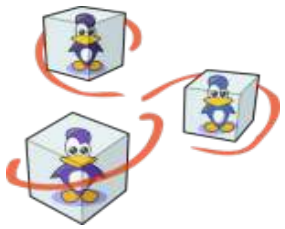

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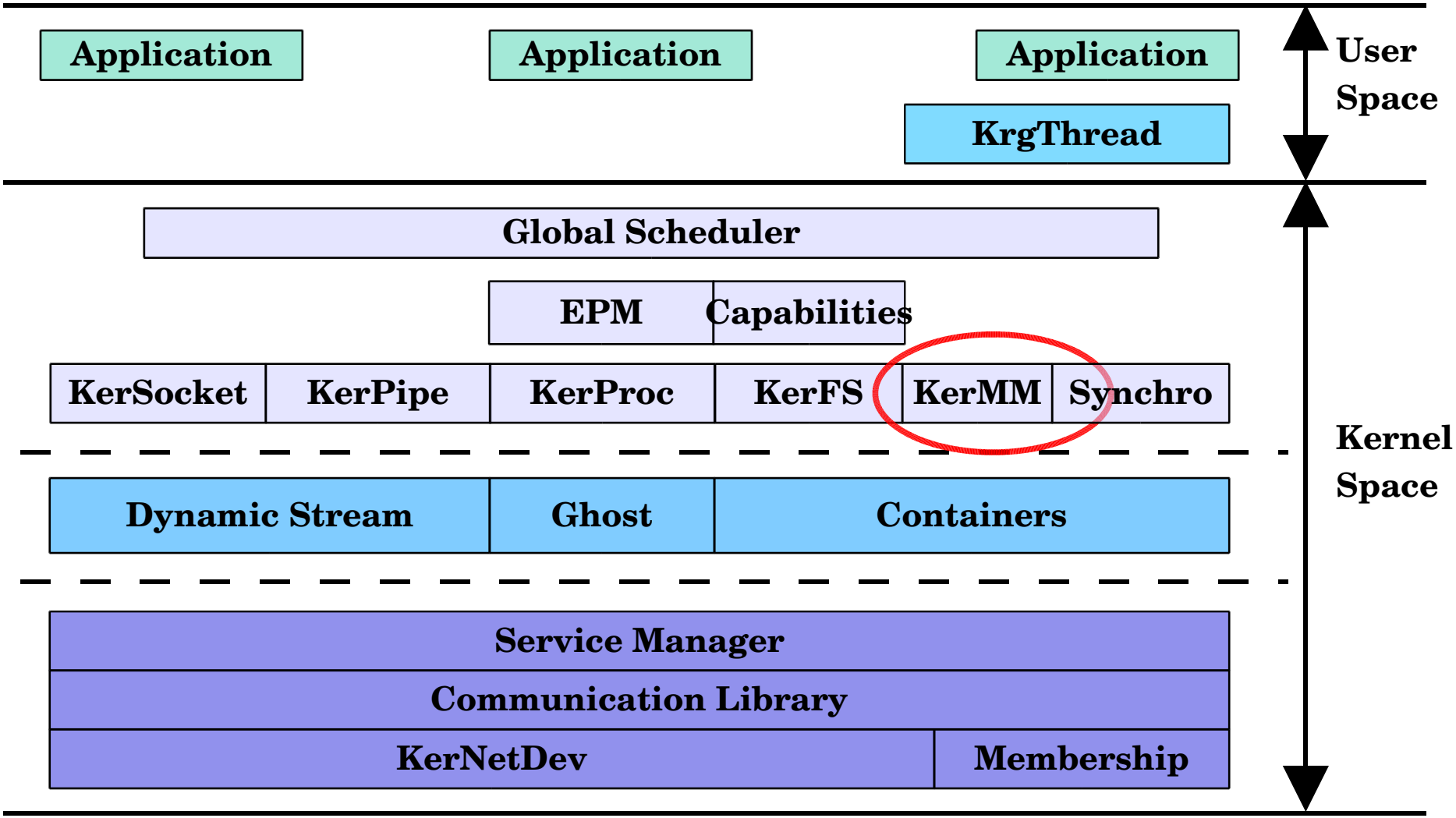
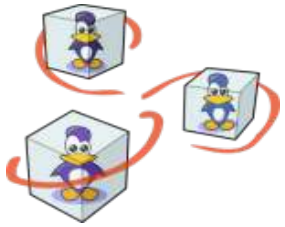




Global Memory Management

- Enable memory sharing cluster wide
  - Intra-application virtual memory sharing
    - Threads memory
    - System V memory segments
  - Inter-nodes physical memory sharing
    - Remote memory paging
- Manage distributed address space
  - Address space migration
  - Threads address space management
    - Mmap, munmap, ...
    - Stack, heap

Global Memory Sharing

- Rely on **containers** for data sharing
- KerMM defines :
  - A memory IO linker
  - A memory interface linker
- Thread memory and System V memory segment
  - Same memory sharing mechanism
  - Dedicated interface link/unlink mechanisms

Memory IO Linker

```
IO_Link ( ctnr, vma )
  For each physical page in VMA
  {
    obj = alloc_ctnr_object (cntr, objid, page);
    ctnr_insert_object (ctnr, obj) ;
  }
```

```
First_Touch ( p )
  page := Alloc_Page () ;
  Return page ;
```

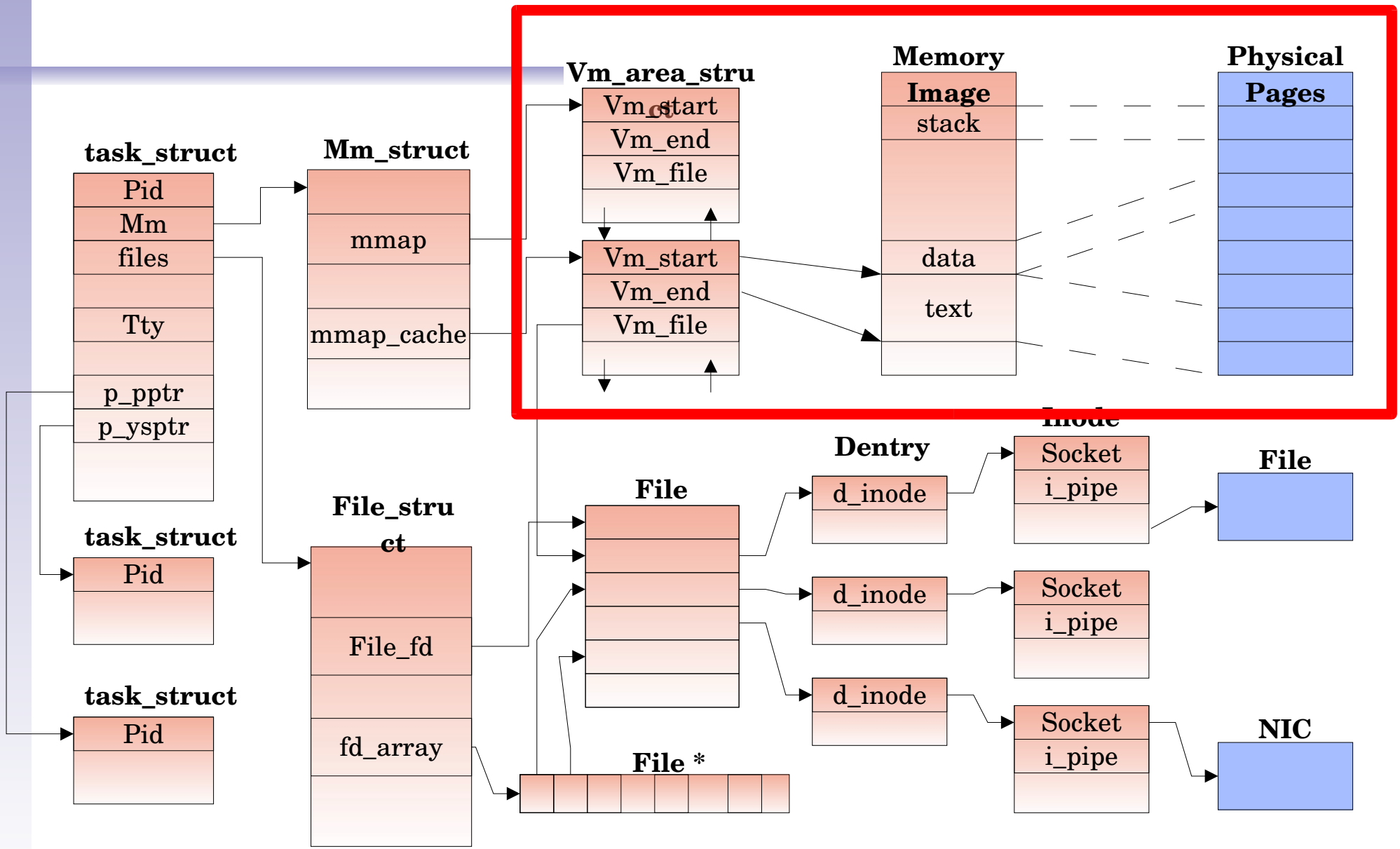
```
Invalidate_Page ( p )
  NOP ;
```

```
Flush_Page ( p )
  NOP ;
```

Memory Interface Linker

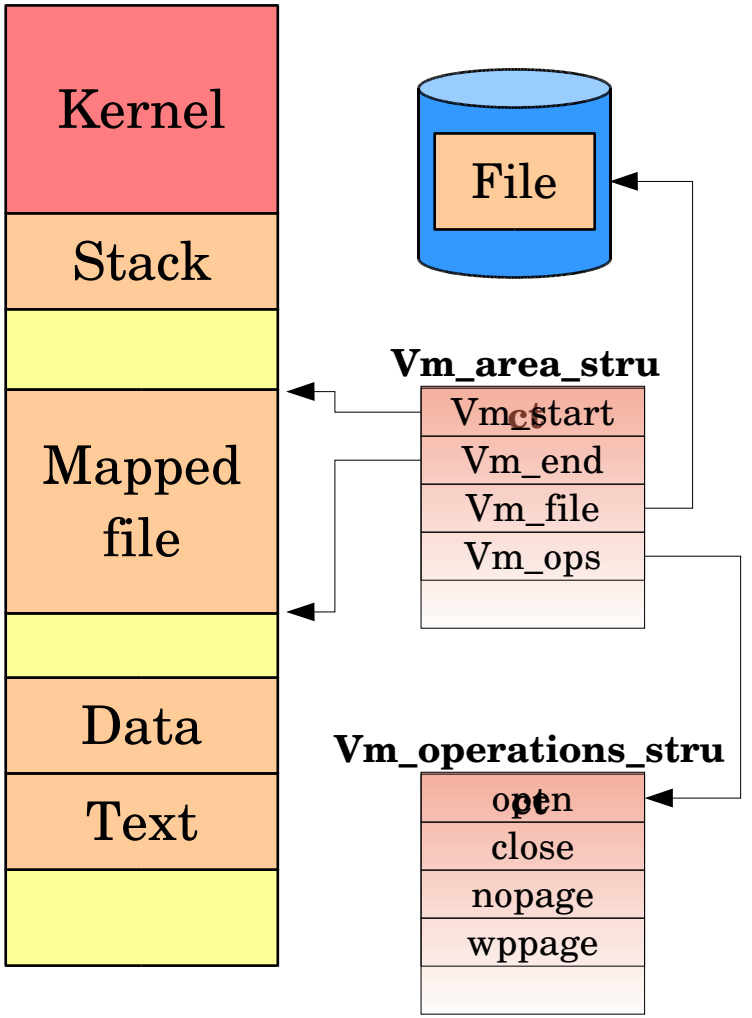
- Goals
  - Link a memory segment to a container
  - Divert page faults to the linked container
- Done at the Virtual Memory Area (VMA) level

Integration in the Linux Kernel

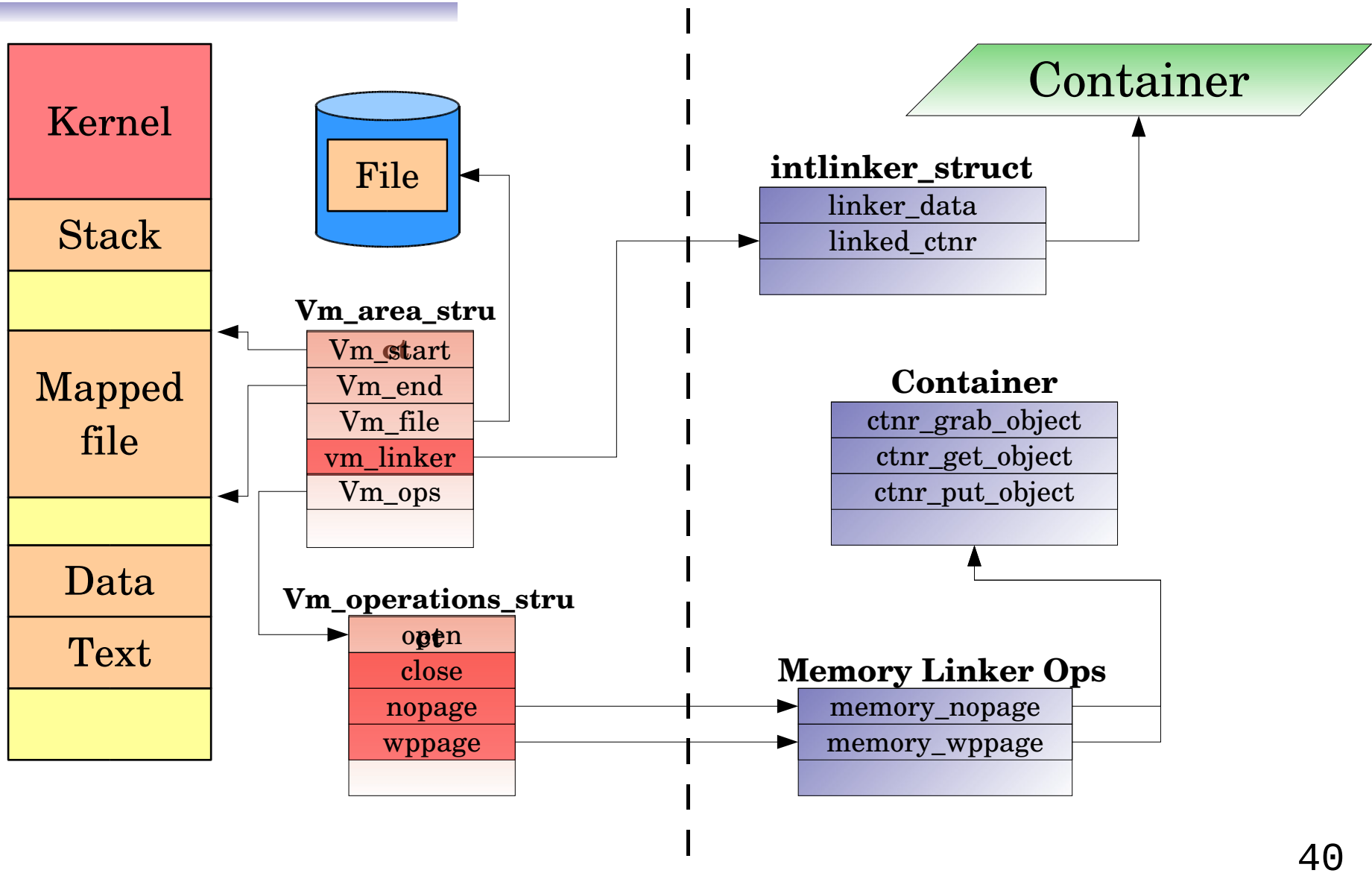


Memory Interface Linker (2)

- A VMA is defined by
  - Begin/end address
  - Access wrights
  - Linked file
  - Memory operations
- Memory operations :
  - VMA closing
  - First access to a page
  - Copy on write
  - ...



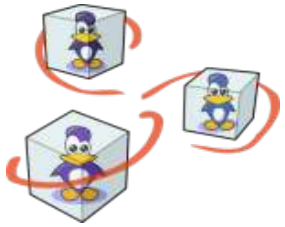
Memory Interface Linker (3)



Memory Interface Linker (4)

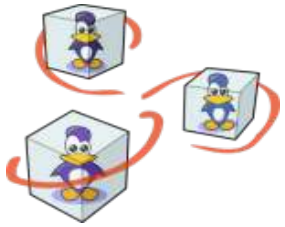
```
memory_nopage ( ctnr, vma, address )
  if (write access)
    page = ctnr_grab_object (ctnr, pageid) ;
  else
    page = ctnr_get_object (ctnr, pageid) ;
  return page ;
```

```
memory_wppage ( ctnr, vma, address )
  page = ctnr_grab_object (ctnr, pageid) ;
  return page ;
```



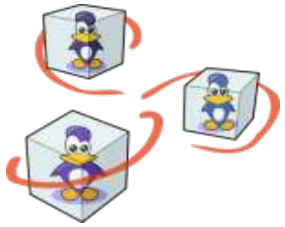
Outline

- Global Process Management
- Containers
- Global memory management
- Dynamic streams
- Capabilities
- Kerrighed in Action !



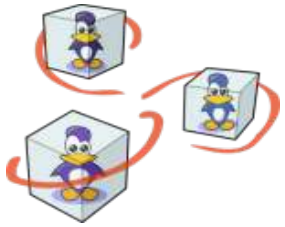
What's the problem ?

- Migrating process may communicate!
- Communications are **inside** of the cluster
- Communications by
  - system calls
  - direct memory access



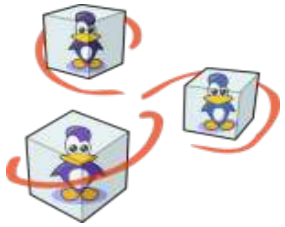
What's the problem ?

- Migrating process may communicate!
- Communications are **inside** of the cluster
- Communications by
  - system calls
    - Unix socket (share a memory page)
    - Pipe/FIFO (share a memory page)
    - INET socket (link to an IP address)



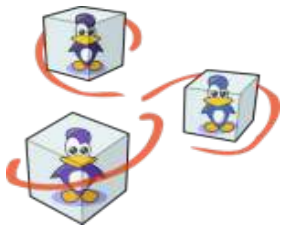
Data streams

- Data streams:
  - data: just bytes running from one node to one node
  - meta-data: any useful informations needed to handle the stream (usually manages by the protocol)
- Meta-data provide:
  - protocol dependent details
  - location of the extremities of the stream



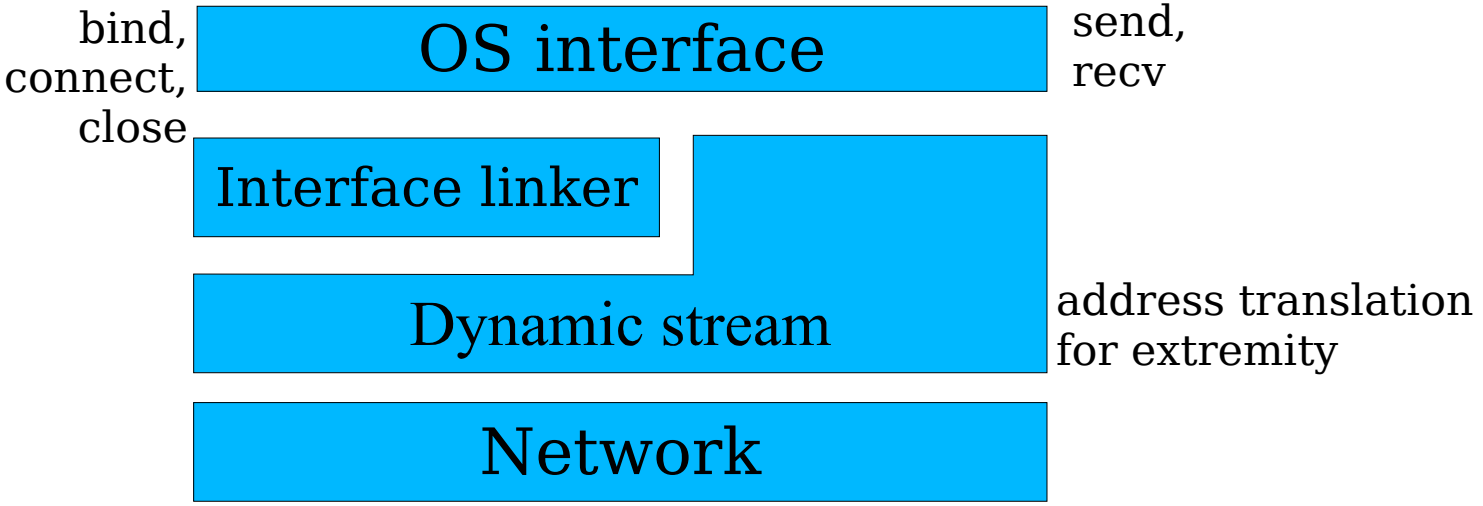
Data streams in SSI

- How to locate an extremity ?
- How to detect the migration of an extremity ?
- How to be efficient ?

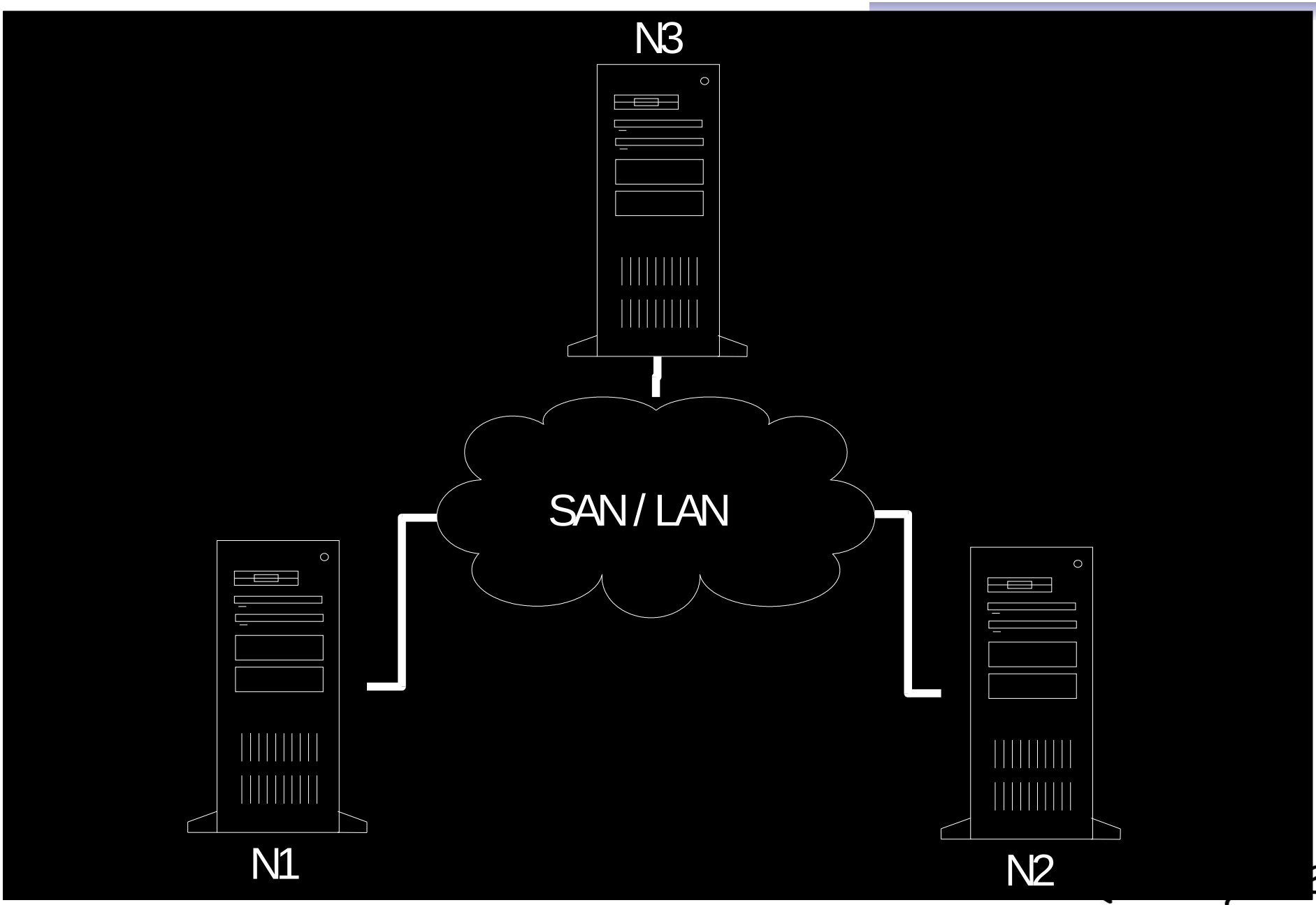


Here is the answer!

- Split the communication layer:
  - dynamic stream: define how to follow the extremities of a stream
  - Protocol linker: link Kerrighed protocol to the regular Linux OS interface



Communicating process migration



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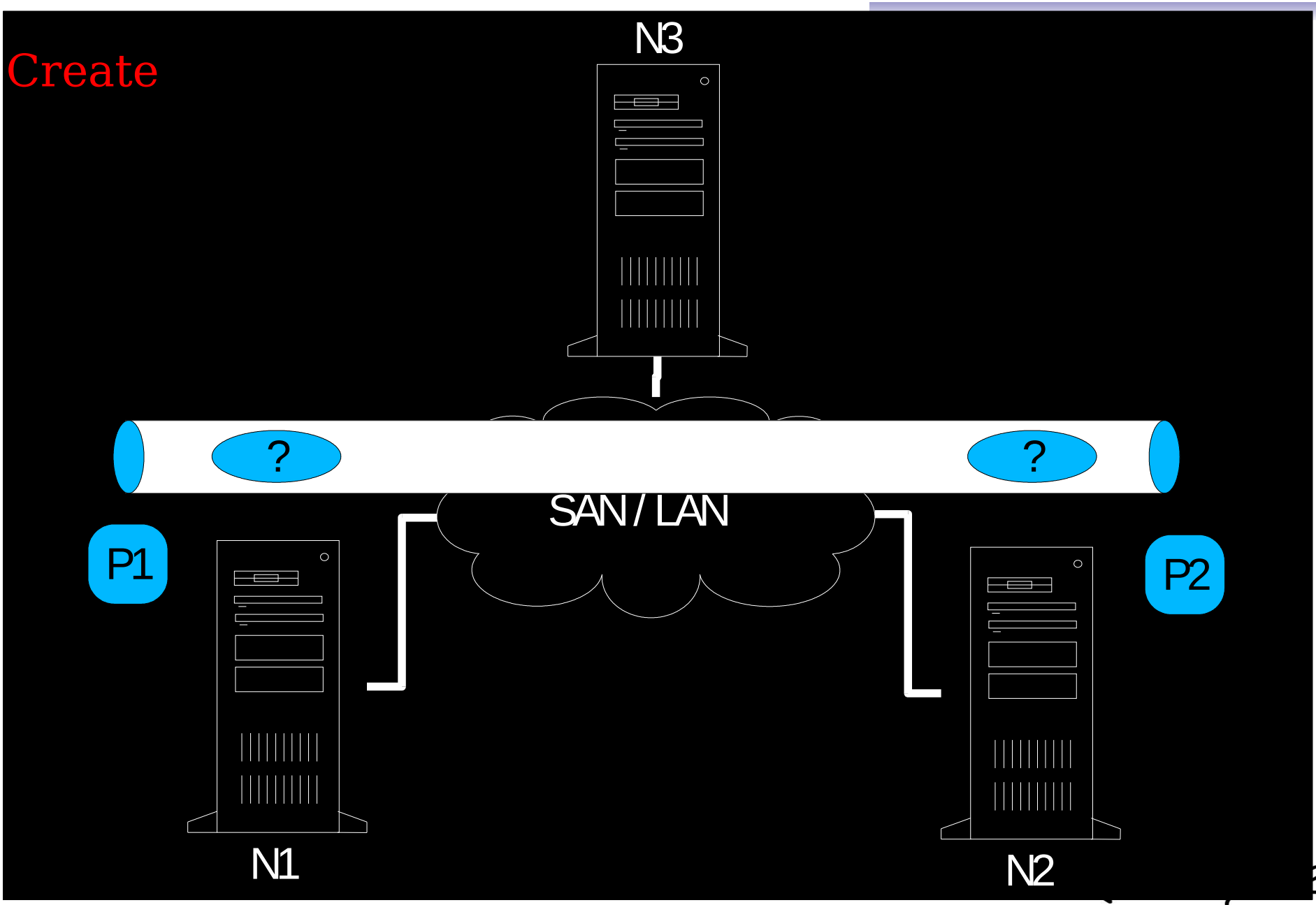

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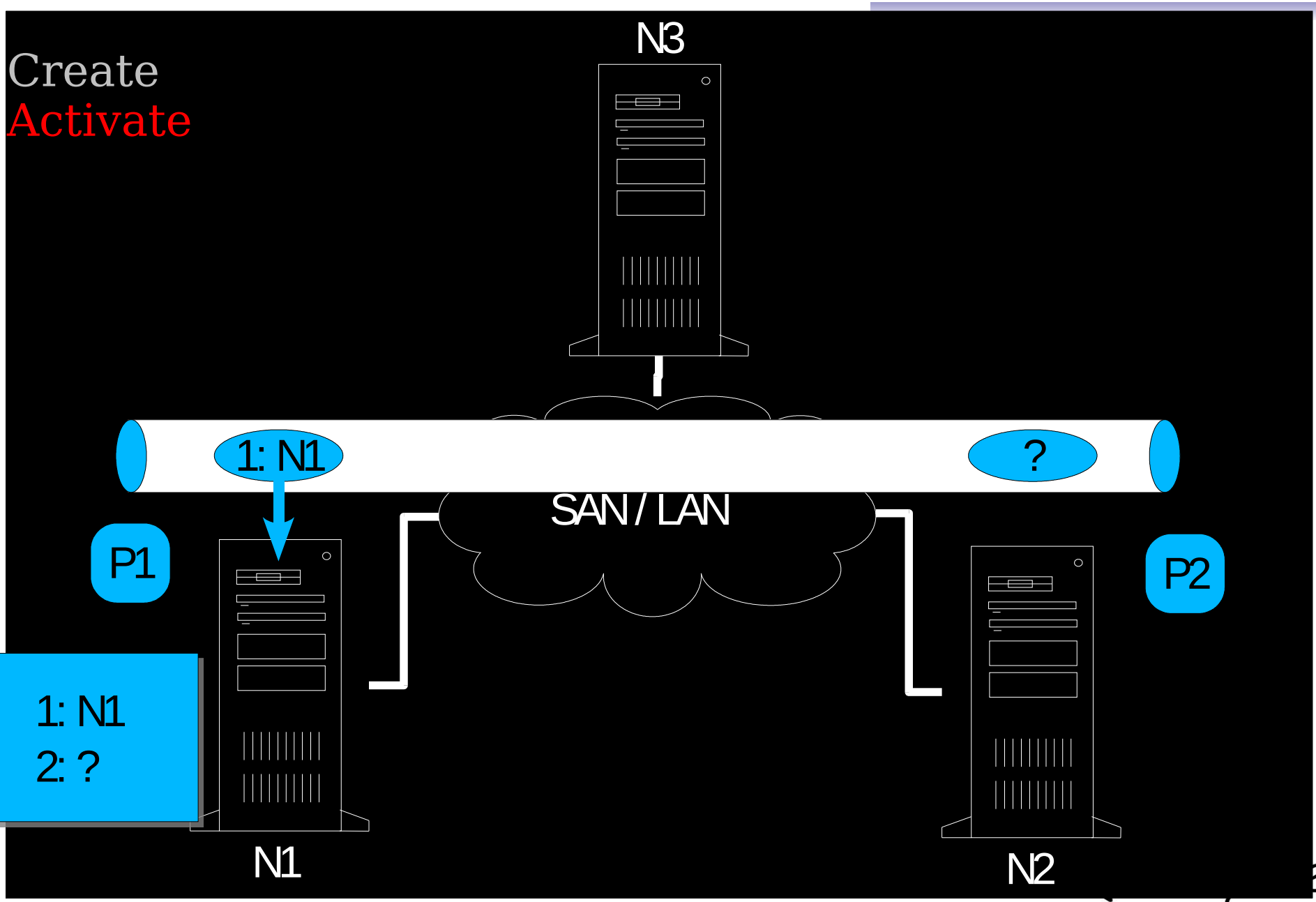

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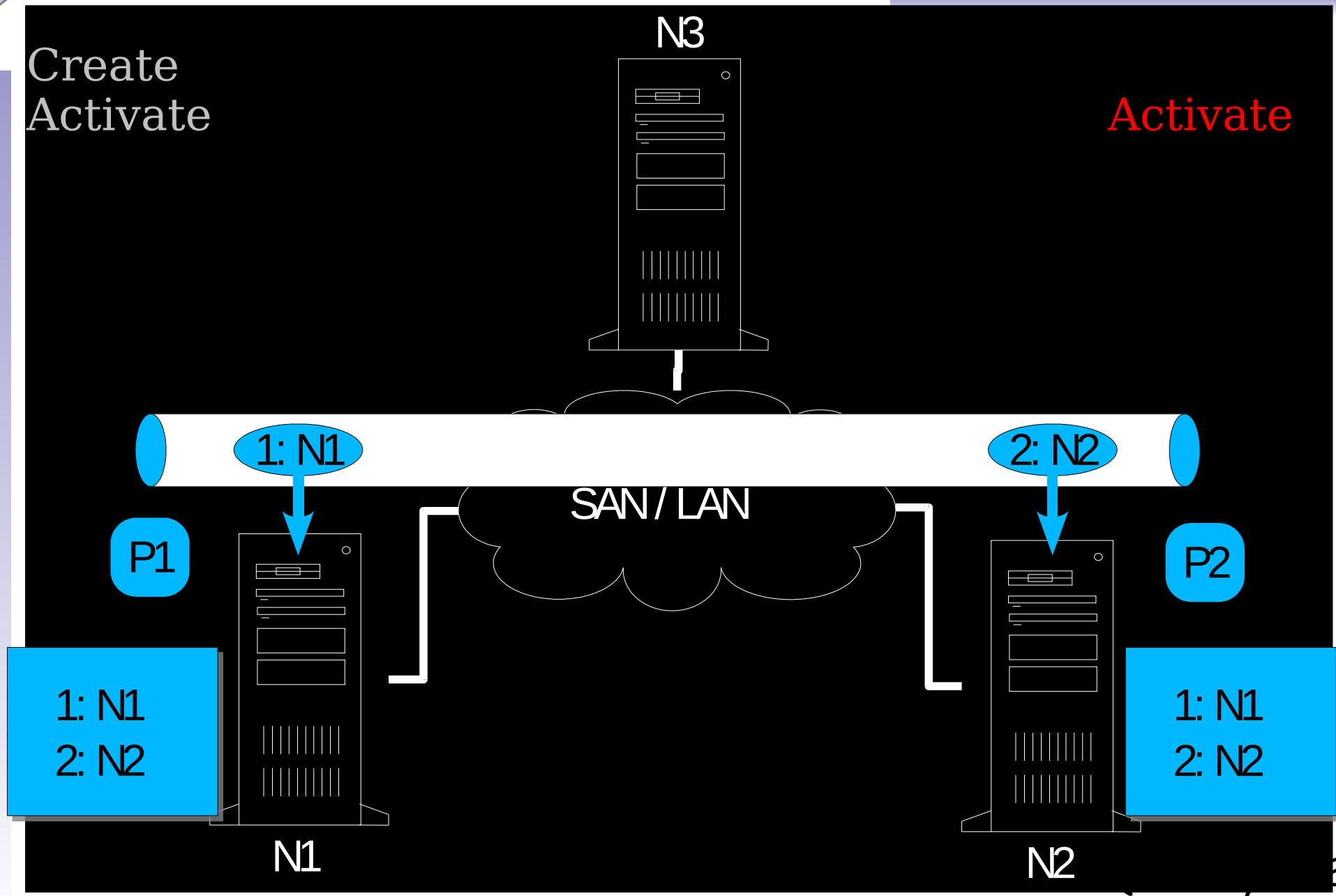

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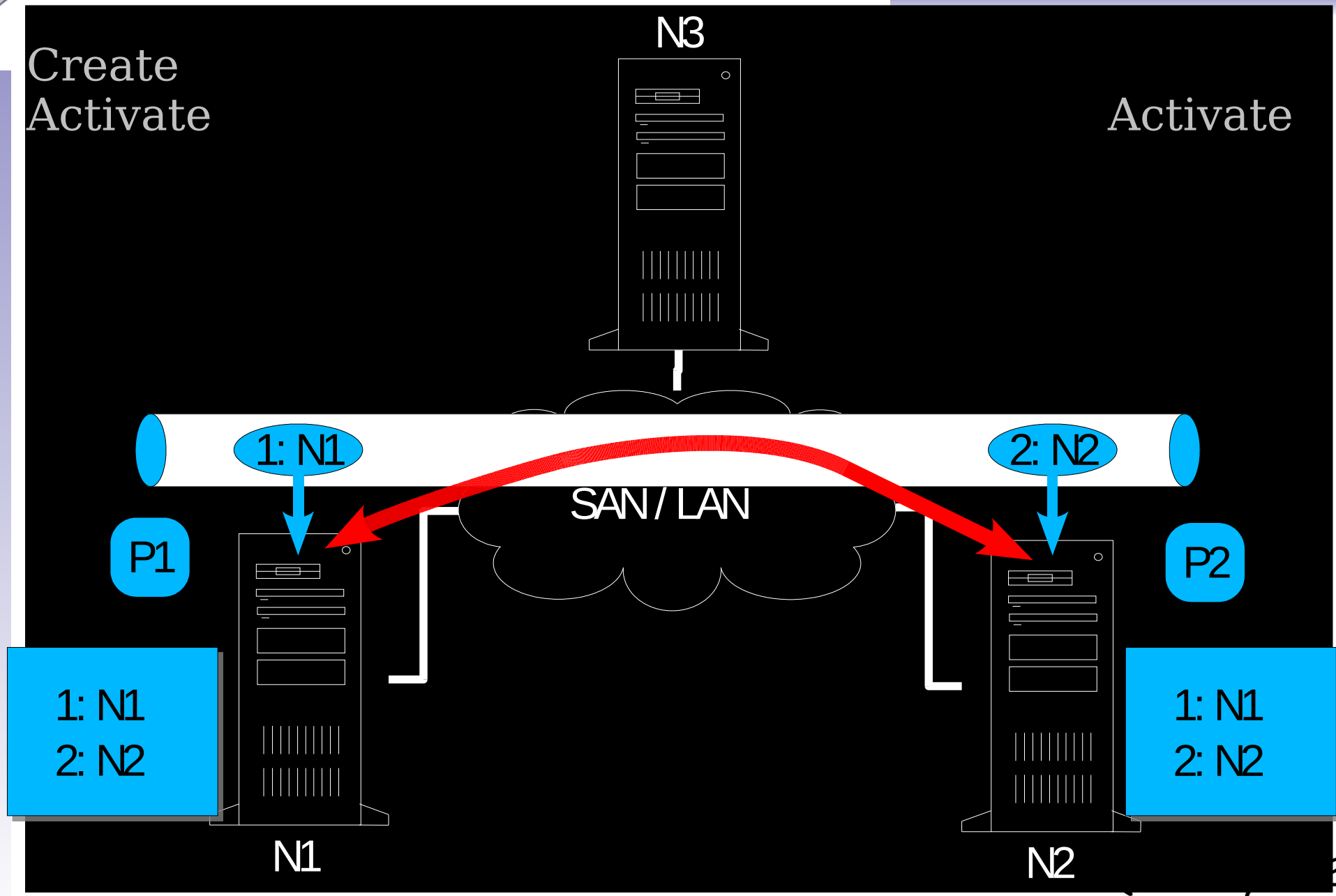

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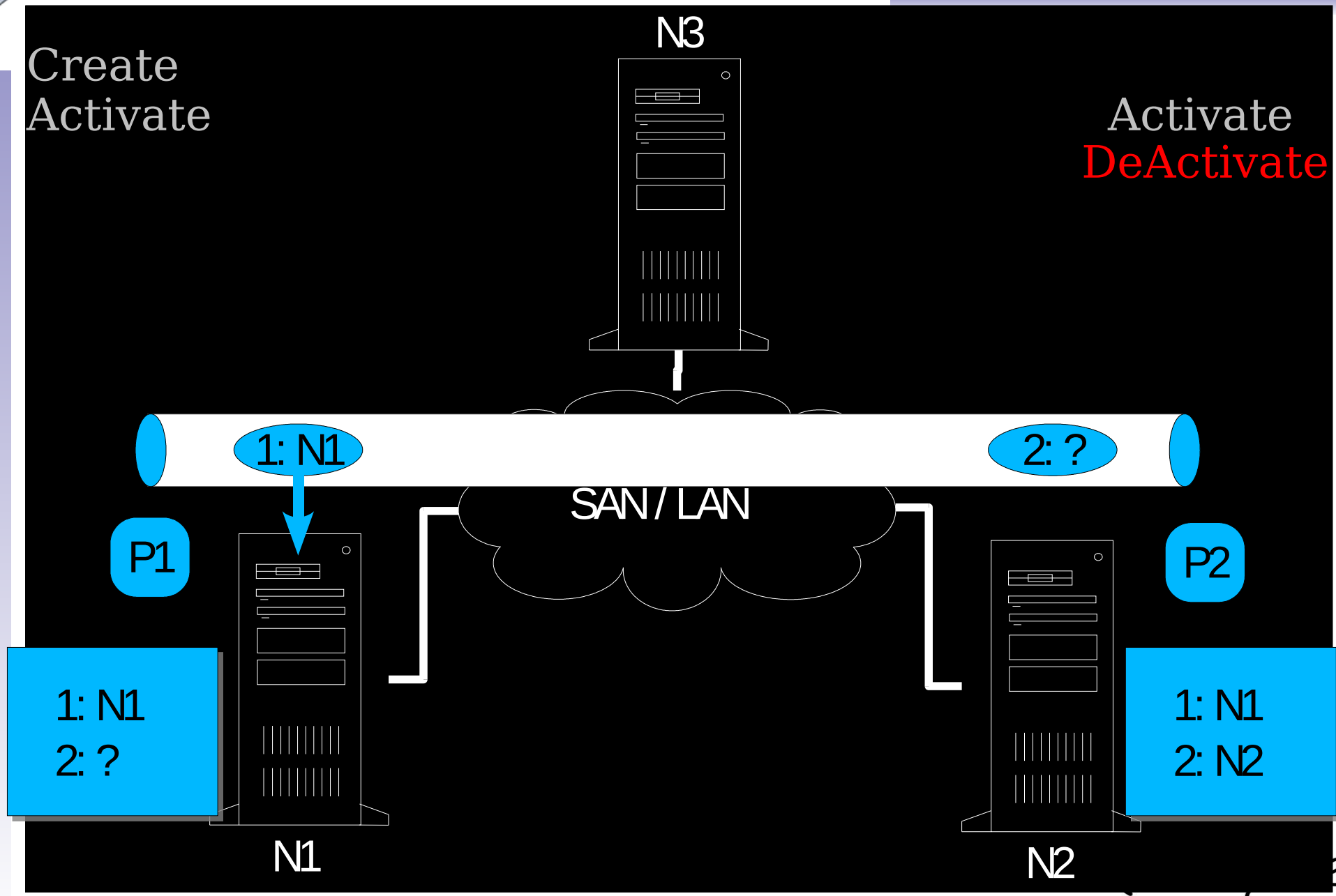

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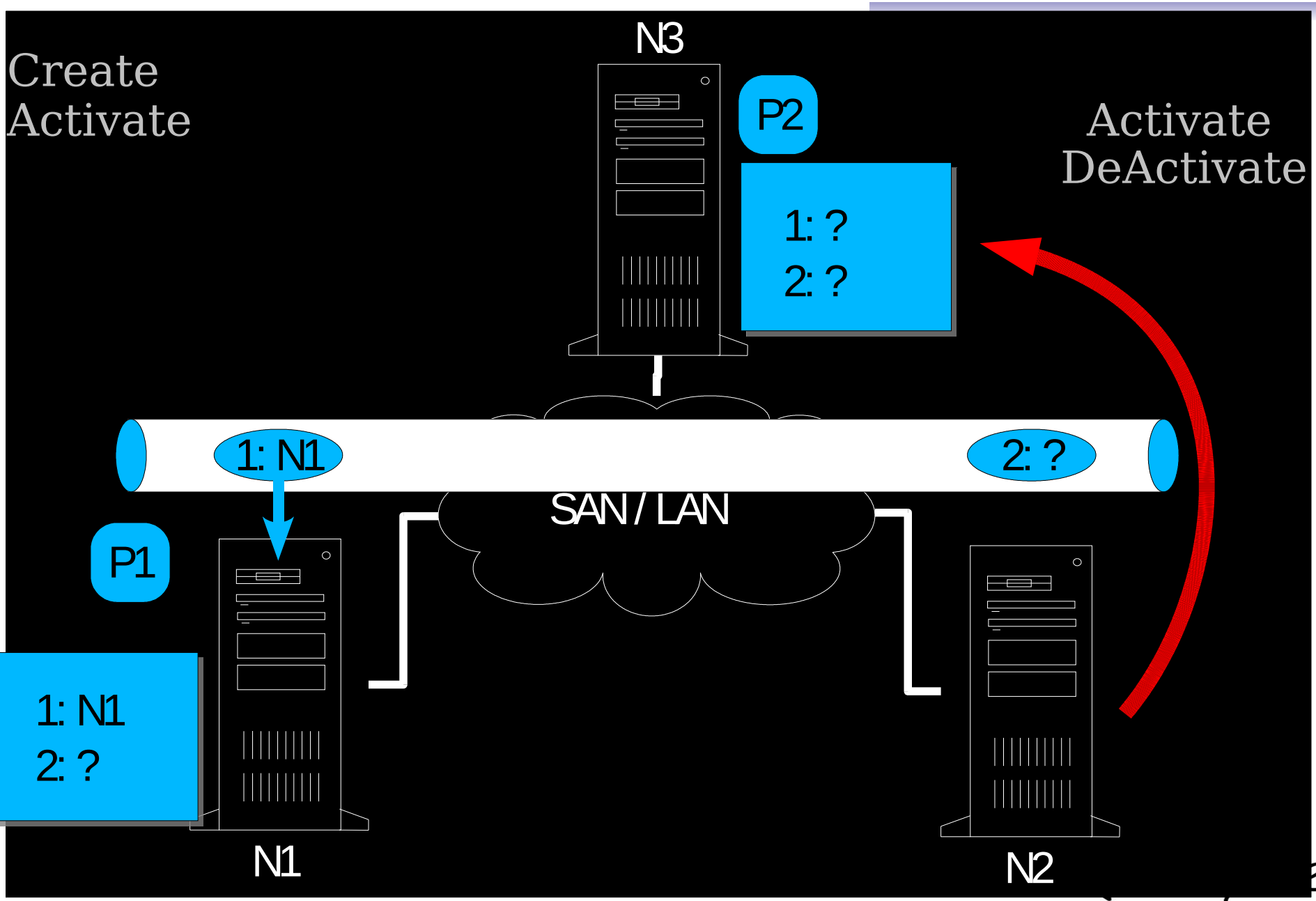

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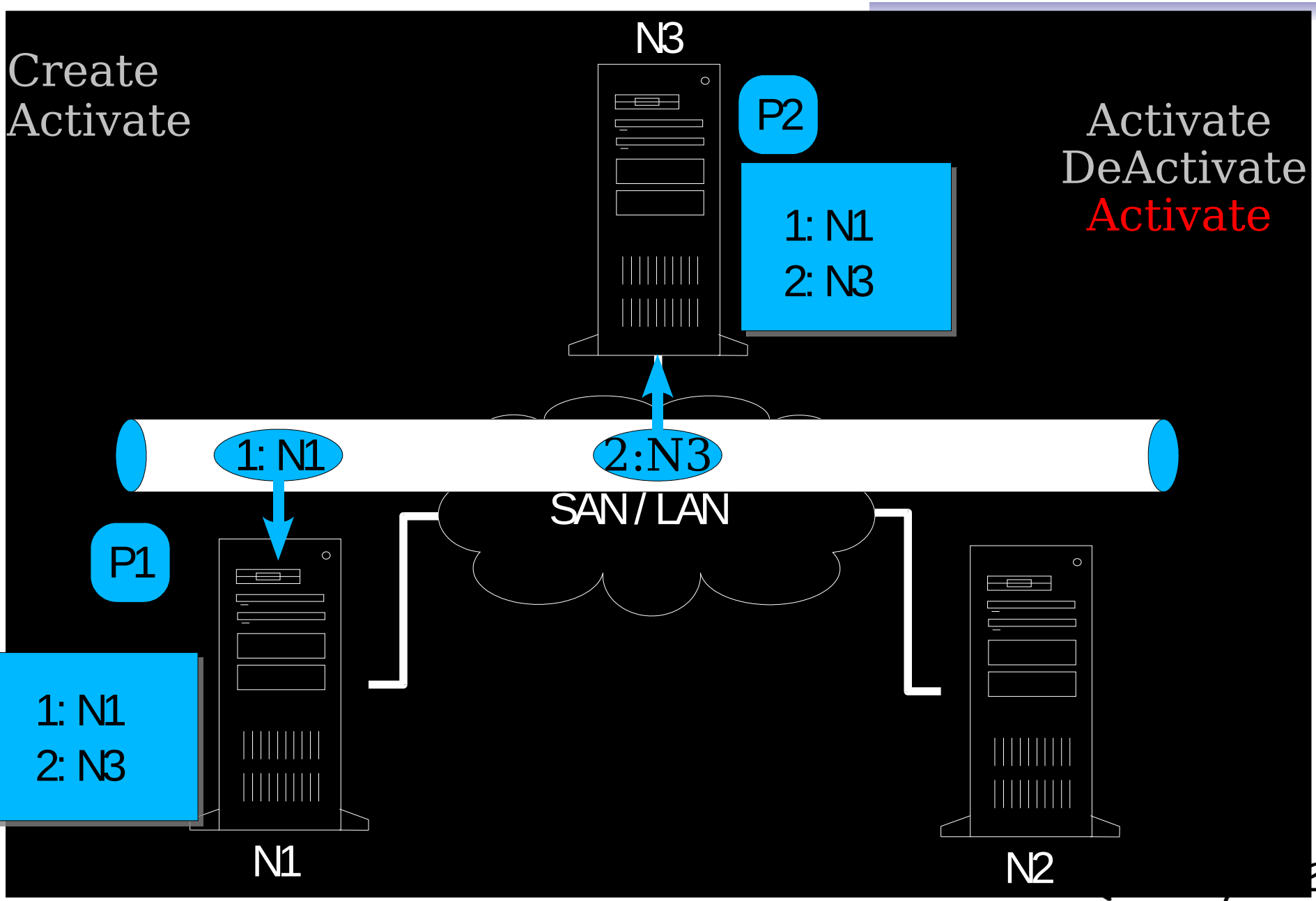

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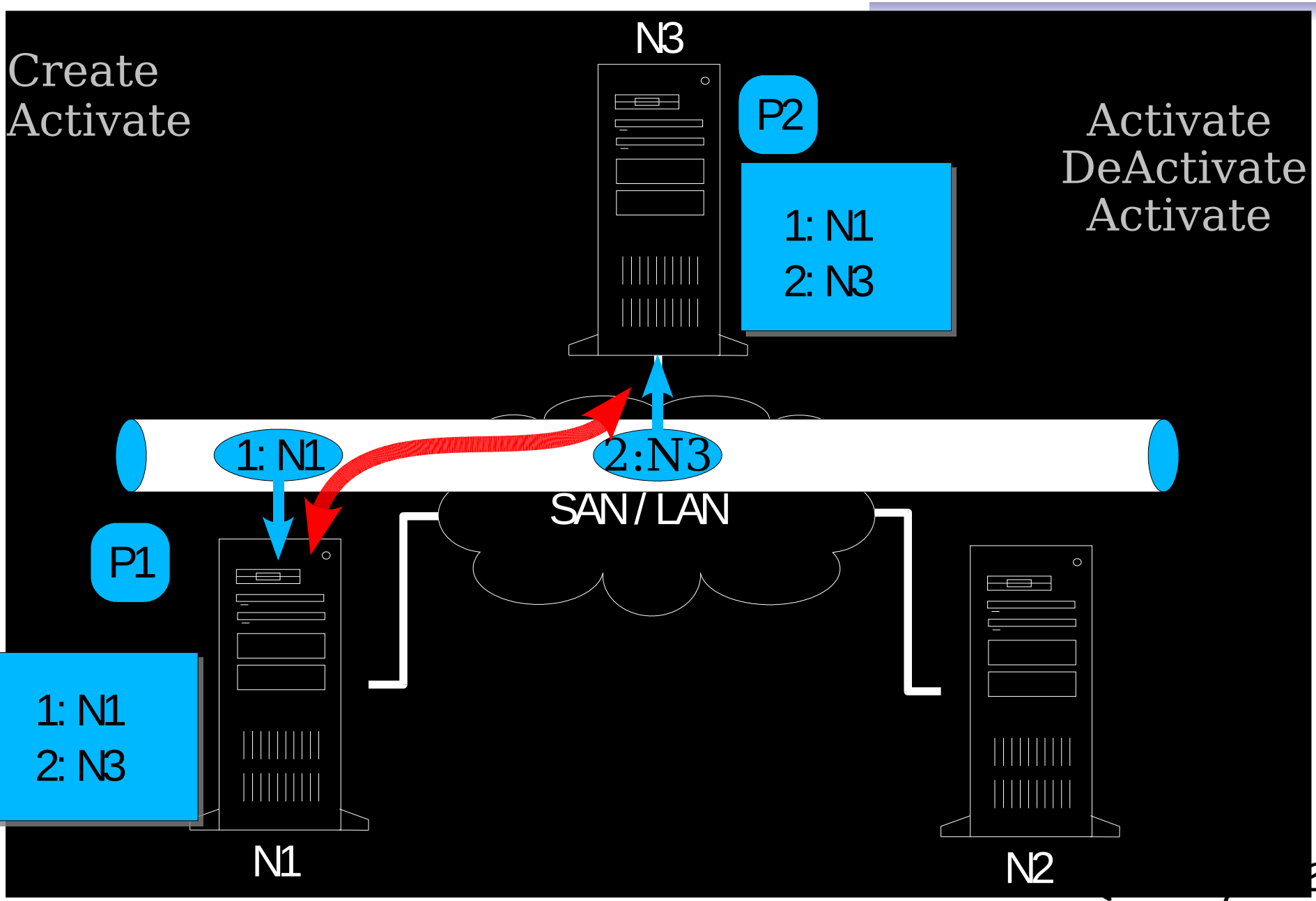

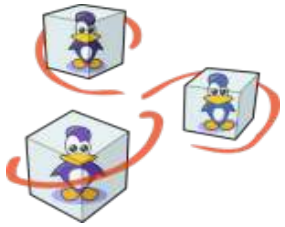

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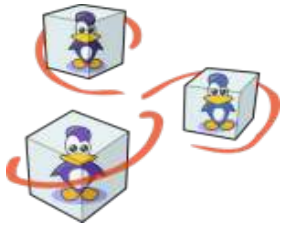
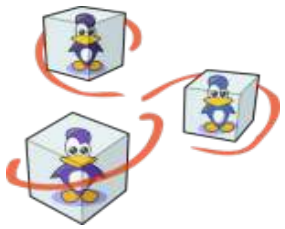


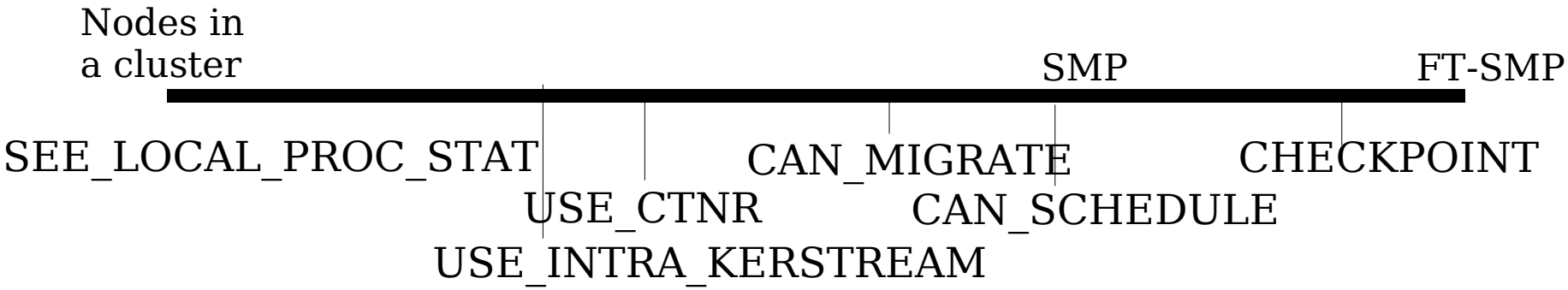
Capabilities: SSI fit your needs

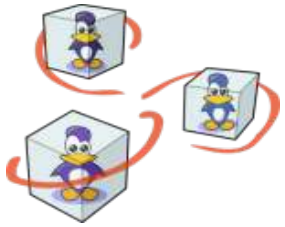
- Kerrighed provides lot of features:
  - global process ID
  - remote process creation
  - process migration
  - global scheduling
  - checkpoint/restart of process
  - cluster-wide stream layer
  - ...
- Not all of them are useful at one time



Capabilities: SSI fit your needs

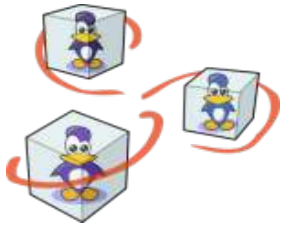
- Kerrighed provides lot of features
- Not all of them are useful at one time
- Kerrighed capabilities: enable SSI features on a per-process way.





Capabilities design

- Per process architecture
- Each process manage several sets of capabilities:
  - own enabled capabilities
  - own authorized capabilities
  - default enabled capabilities for its sons
  - default authorized capabilities for its sons



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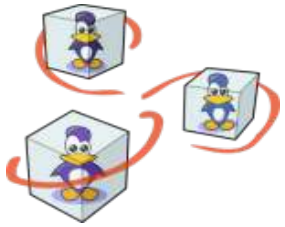
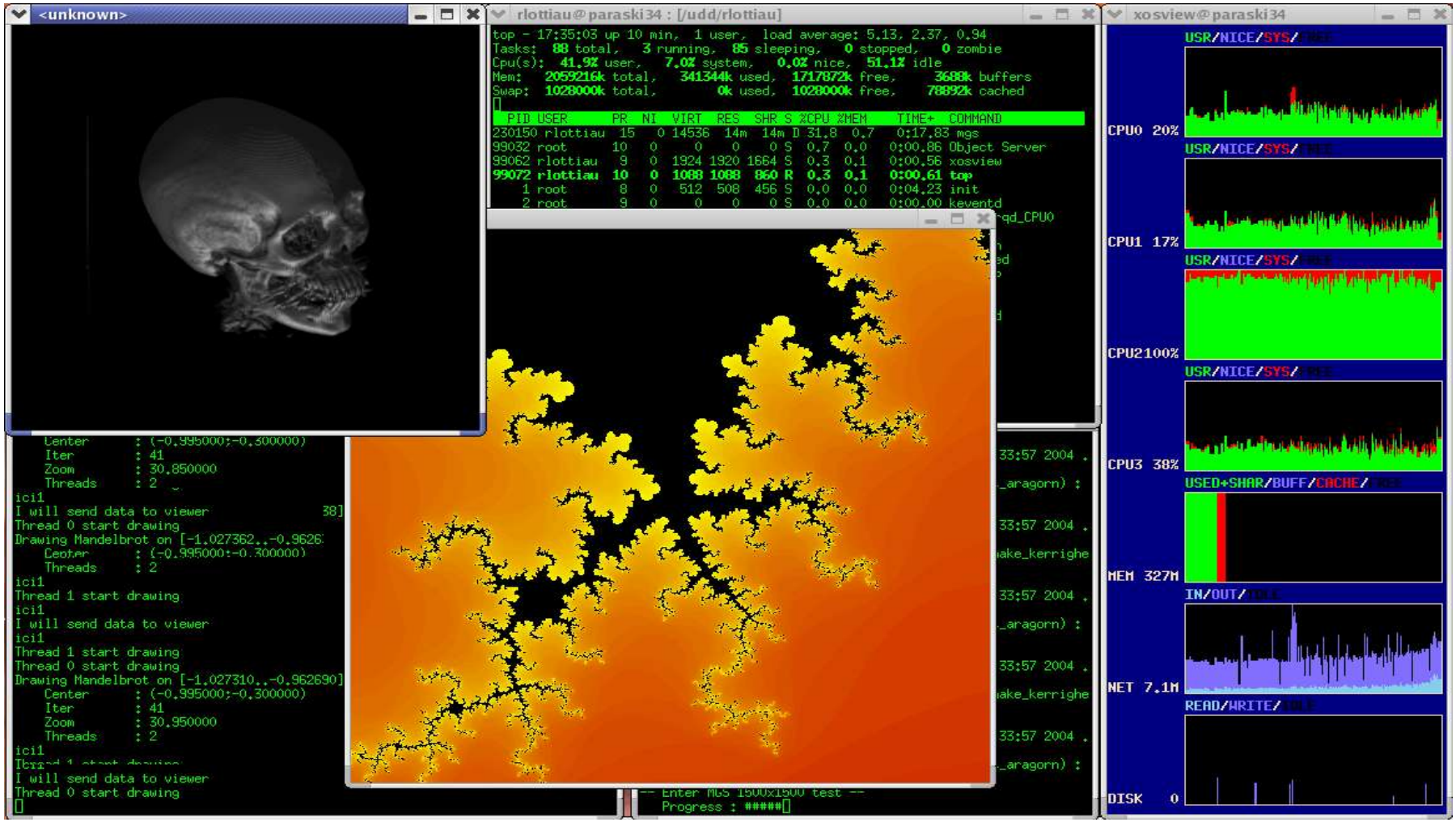


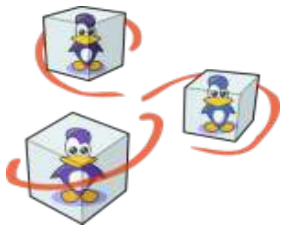
What is Kerrighed Good for ?

- Balancing CPU load
  - Large number of jobs to run
  - Parallel compilation
- Message passing parallel applications
  - Transparent use of Kerrighed high speed comms
  - Configure MPICH just like an SMP machine
- Shared memory parallel applications
  - Spread threads over cluster nodes
- Ease your life !
  - One big SMP machine

Kerrighed in Action !



Kerrighed
Linux clusters made easy



Capabilities: an example

```
paraski33% krg_capset -l
  Effective Capabilities: 043
    CHANGE_KERRIGHED_CAP, USE_CONTAINERS
  Effective Capabilities: 043
    CHANGE_KERRIGHED_CAP, USE_CONTAINERS

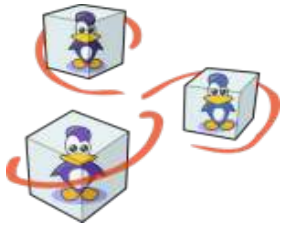
paraski33% cat /proc/cpuinfo
  processor       : 0
  vendor_id       : GenuineIntel
  cpu family      : 15
  ...
  processor       : 1
  vendor_id       : GenuineIntel
  cpu family      : 15
  ...

paraski33% cat /proc/meminfo
  MemTotal:      1032644 kB
  MemFree:        831052 kB
  ...

paraski33% cat /proc/meminfo
  MemTotal:      1032644 kB
  MemFree:        831052 kB
  ...
```

```
paraski33% krg_capset -d +SEE_LOCAL_PROC_STAT
paraski33% cat /proc/cpuinfo
  processor       : 0
  vendor_id       : GenuineIntel
  cpu family      : 15
  ...

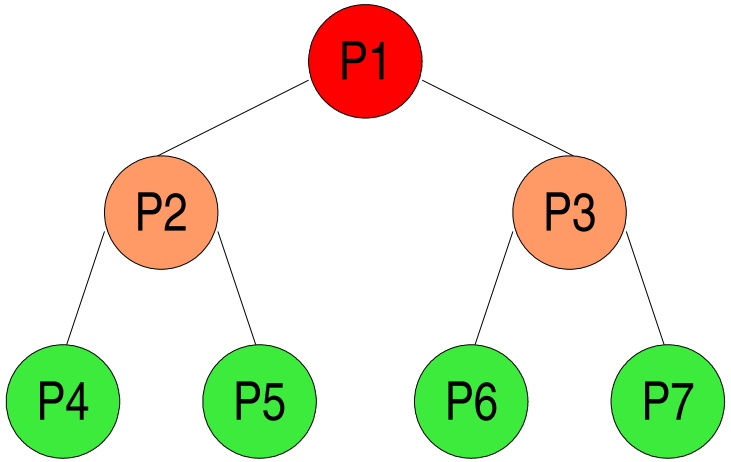
paraski33% cat /proc/meminfo
  MemTotal:       498944 kB
  MemFree:        457936 kB
  ...
```

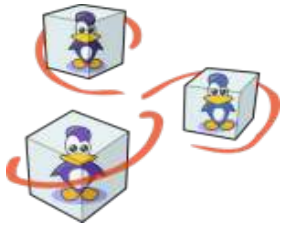


Capabilities: another example

```
void main(void)
{
    int nb_sons = 0;
    int depth = 0;

    while (nb_sons != 2 && depth < 2) {
        if (fork())
            nb_sons++;
        else {
            depth++;
            nb_sons = 0;
        }
    }
}
```





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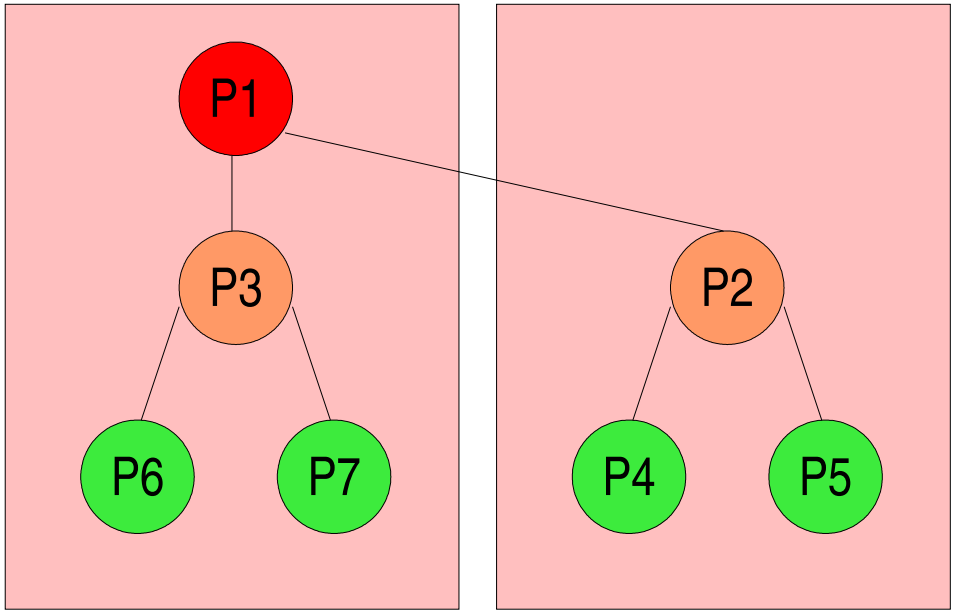
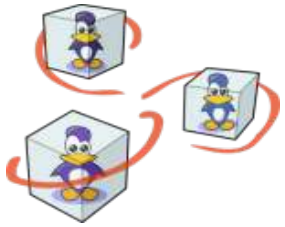
          }
     }
}
```

```
paraski33% krg_capset -e +DISTANT_FORK
paraski33% ./fork-test
```





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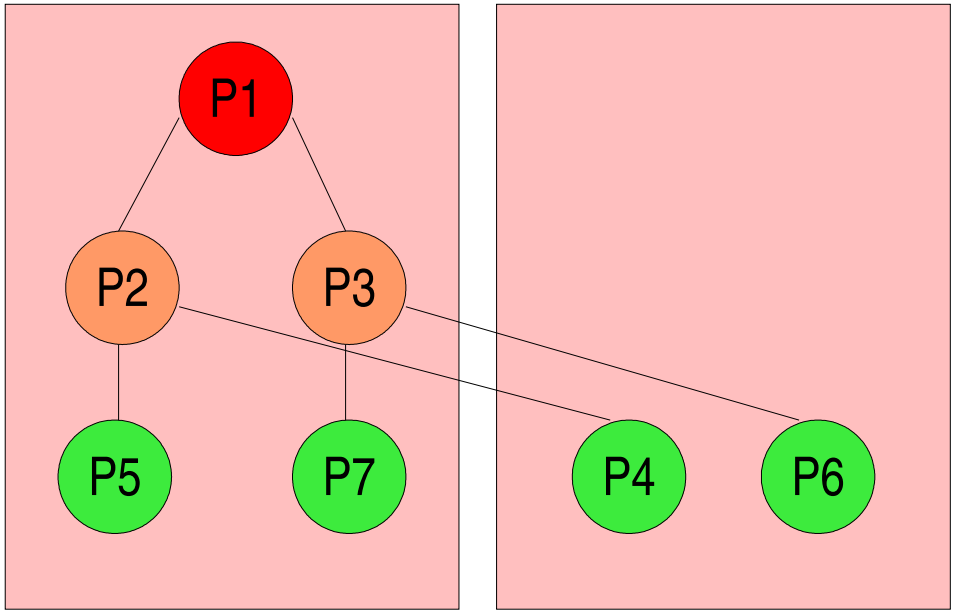

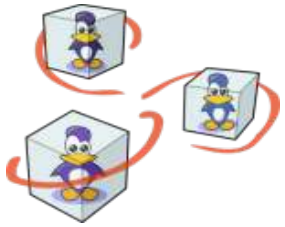

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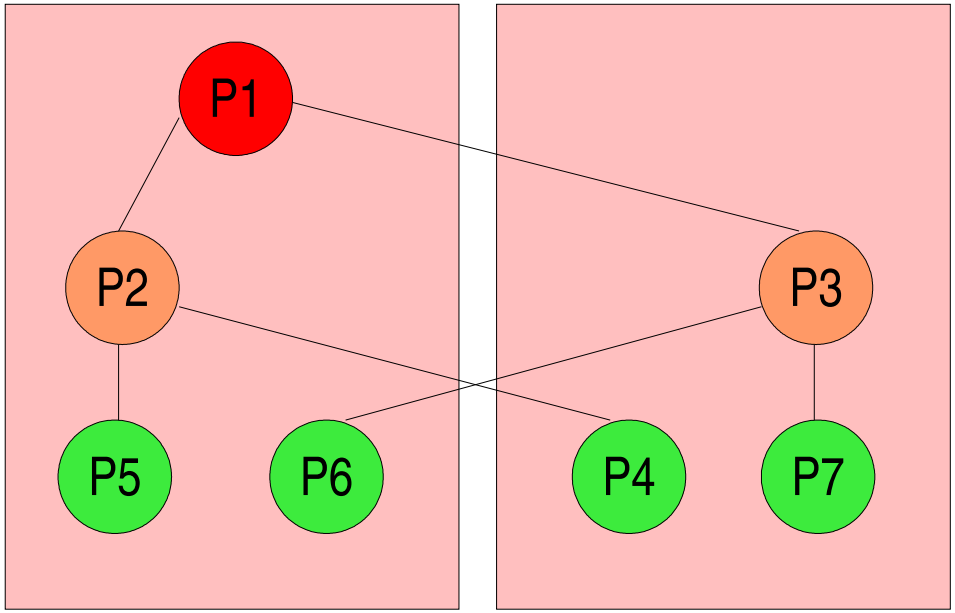
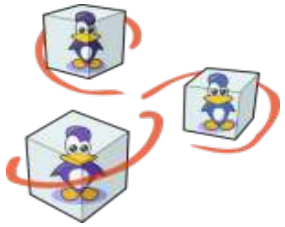
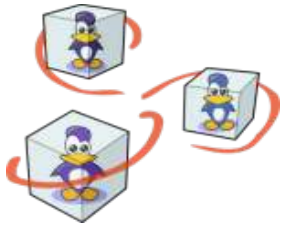




Conclusion

- Kerrighed provides an SMP-like system on top of a distributed architecture
- Main features:
  - High-performance architecture
  - Easily tunable
  - Full binary compatibility
- Software available under GPL licence
  - http://www.kerrighed.org



On going works...

- Kerrighed needs some works on:
  - Linux 2.6 port
  - SMP support
  - Checkpoint/restart of parallel applications
  - Add/Remove nodes operations