Kerrighed : An Overview

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What is Kerrighed ?

- An **operating system** for cluster
  - Build as an **extension** to Linux
- Key idea : offering the view of a virtual SMP
  - Single System Image (SSI)
- Key features
  - Vision of an unique machine
  - High performance
  - Highly configurable
  - Transparency to users and applications

Vision of a unique machine

- One virtual CPU
  - Unique process space (pid)
  - Cluster wide scheduling
- One virtual memory
  - Support memory sharing between threads
  - Support System V memory segments
- One global file system (alpha version)
  - Unique file name space
  - Cluster wide disk mount

High Performance

- Target scientific applications
  - Sequential applications
  - Parallel applications
- High performance stream migration mechanism
  - Pipe, sockets, …
- Efficient software shared memory
- Target high performance networks
  - Gigabit Ethernet, Myrinet, Infiniband, Quadrix
- Cooperative file cache

Highly Configurable

- Customizable scheduling policy
  - New policies can be hot loaded in the kernel
- SSI features can be enable/disable on a per process basis
- Customizable data storage on disk
  - Redundant, non redundant
  - RAID 0, 1, ...

Outline

- Kerrighed Overview
  - What is Kerrighed ?
  - What about other system ?
  - Performance Evaluation
- Kerrighed Internal
  - Introduction
  - Ghosts
  - Containers
  - KerMM
- Conclusion

What about other projects ?

- Several projects exist
  - openMosix
  - OpenSSI
  - Kerrighed
  - B-Proc
  - DragonFly BSD
  - Genesis
  - Plurix
  - ...
- Who Kerrighed compares to others ?

OpenMosix

- Based on Mosix
  - Started in 1981 at University of Jerusalem
  - Port to Linux in 1999
  - OpenMosix “fork” in 2002
- Main features
  - Global process scheduling

OpenMosix Internals

- Process migration through deputy
  - A deputy remains on the process “home node”
  - Most system calls are redirected to the deputy
- Mosix FS (MFS)
  - Allow access to distant disks
- Direct File System Access (DFSA)
  - Enhance file system accesses through local accesses

OpenSSI

- Project started in 2001 at HP Labs
- Mainly aggregates existing softwares
  - NonStop Cluster for UnixWare
  - Cluster File System (CFS)
  - Cluster Infrastructure (CI Linux)
  - Distributed Lock Manager (DLM)
- Main features
  - Global process scheduling (load leveling)
  - Unique file system tree

OpenSSI Internals

- Process migration through daemon servers
  - A pool of daemons run on each nodes
  - Many system calls are redirected to deamons
- Cluster File System (CFS)
  - Unique file system tree
- Cluster Infrastructure (CI Linux)
  - Node addition and removal

Kerrighed

- Project started in 1999 (Gobelins) at IRISA (INRIA)
  - Written from scratch within Linux
- Project renamed Kerrighed in 2002
- Main features
  - Customizable global process scheduler
  - Shared memory support
  - Efficient stream migration
  - Unique file system tree

Kerrighed Internal

- Ghost Process
  - Process migration, checkpointing, remote creation
- Scheduling policy writing framework
  - Ease creation of new policies, hot-pluggable
- Container
  - Shared memory, cooperative file cache, ...
- Dynamic global stream
  - Efficient migration of sockets, pipes, ...

View of a Unique Machine

	Kerrighed	OpenMosix	OpenSSI
Unique PID space	✔	✔ / ✘	✔
Global PS	✔	✔ / ✘	✔
Global Top	✔	✔ / ✘	✘
Global /dev	✘	✘	✔
Unique FS tree	✔ / ✘	✔ / ✘	✔

Global Process Management

	Kerrighed	OpenMosix	OpenSSI
Process migration	✔	✔	✔
Individual thread migration	✔	✘	✘
Threaded application migration	✔	✘	✔
Global process scheduler	✔	✔	✔
Customizable process scheduler	✔	✘	✘

IPC Migration Support

	Kerrighed	OpenMosix	OpenSSI
System V memory segment	✔	✘	✔ / ✘
System V semaphores	✘	✔	✔
Pipe	✔	✔	✔
Unix Socket	✔	✔	✔
INET Socket	✔	✔	✔

Fault Tolerance and Checkpointing

	Kerrighed	OpenMosix	OpenSSI
Hot node addition	✘	✔	✔
Hot node removal	✘	✔	✔
Tolerance to node failure	✘	✔ / ✘	✔ / ✘
Process Checkpoint	✔	✔	✘
Threaded application checkpoint	✘	✘	✘
Message passing application checkpoint	✘	✘	✘

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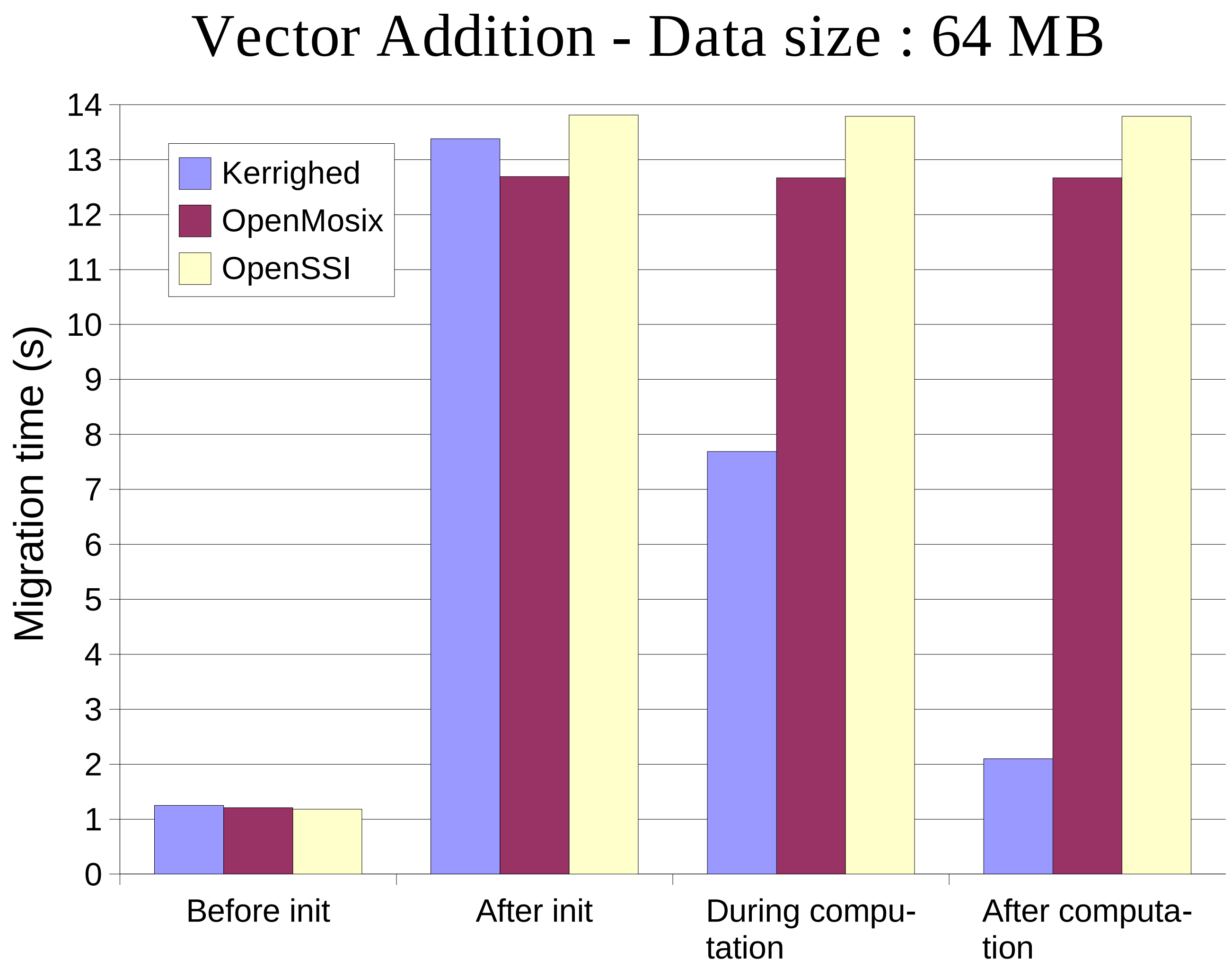
Performance evaluation

- Experimental platform
  - 4 nodes cluster
  - Intel Pentium III 1Ghz
  - 512 MB main memory
  - Fast Ethernet
- Tested systems
  - Kerrighed 1.0-rc9 (kernel 2.4.24)
  - OpenMosix 2.4.22-3 (kernel 2.4.22)
  - OpenSSI 1.0.0-rc5 (kernel 2.4.20)

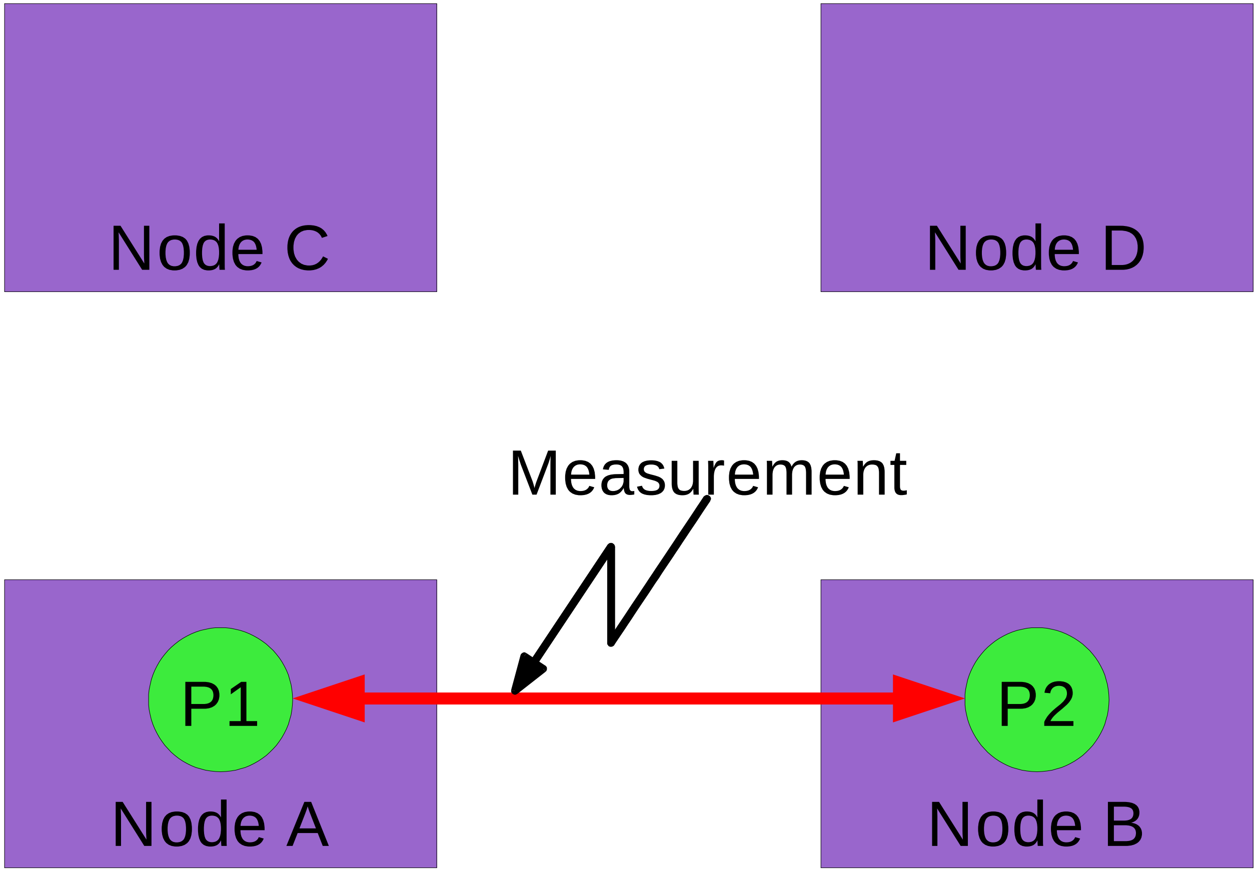
Process Migration

- Vector addition
- Data size
  - 64 MB / vector
- Migrate at different execution time
  - Before vector initialization
  - Before computation
  - During computation
  - End of computation
- Compute the overhead

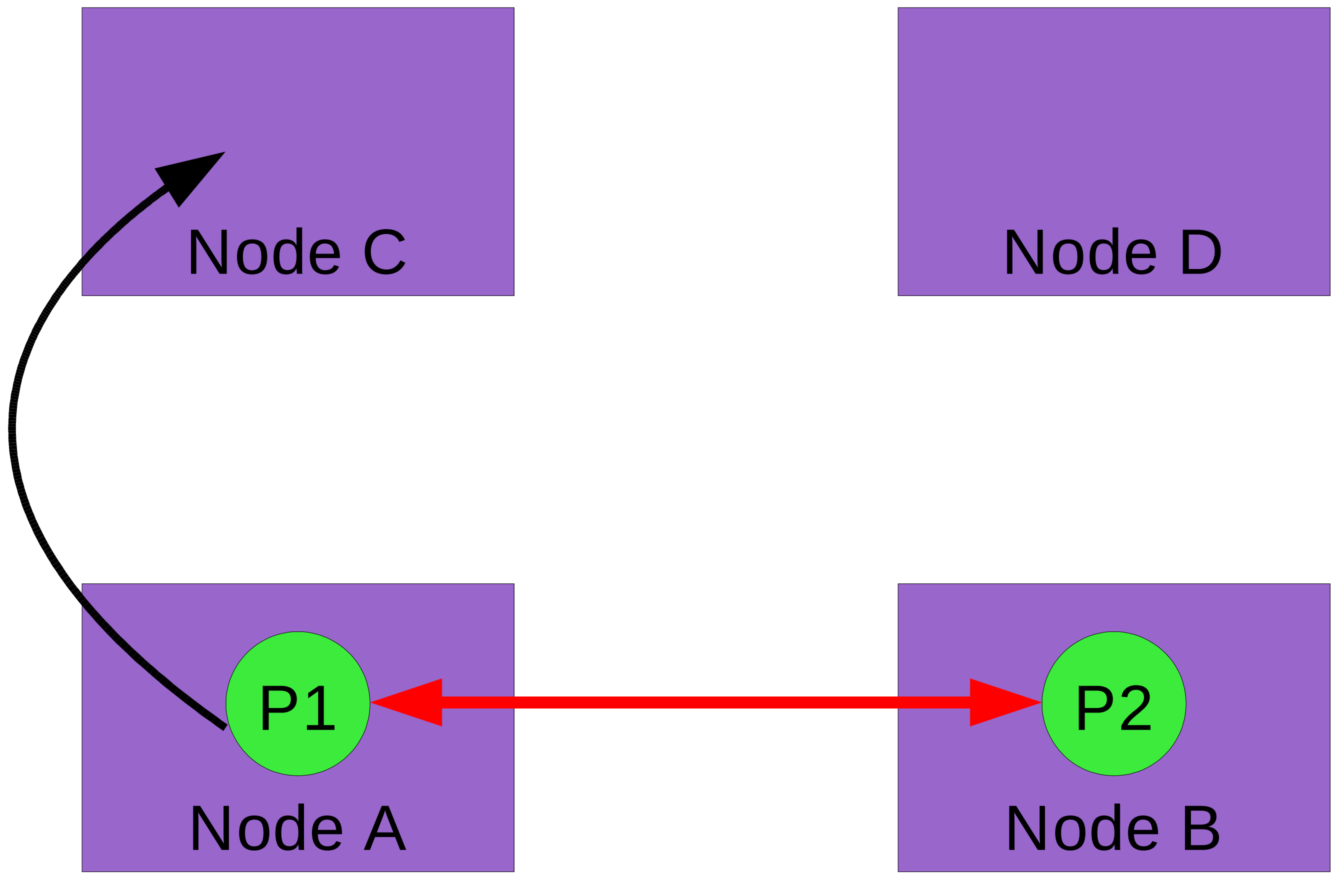
Process Migration Overhead



Socket Migration (Case 1)



Socket Migration (Case 2)



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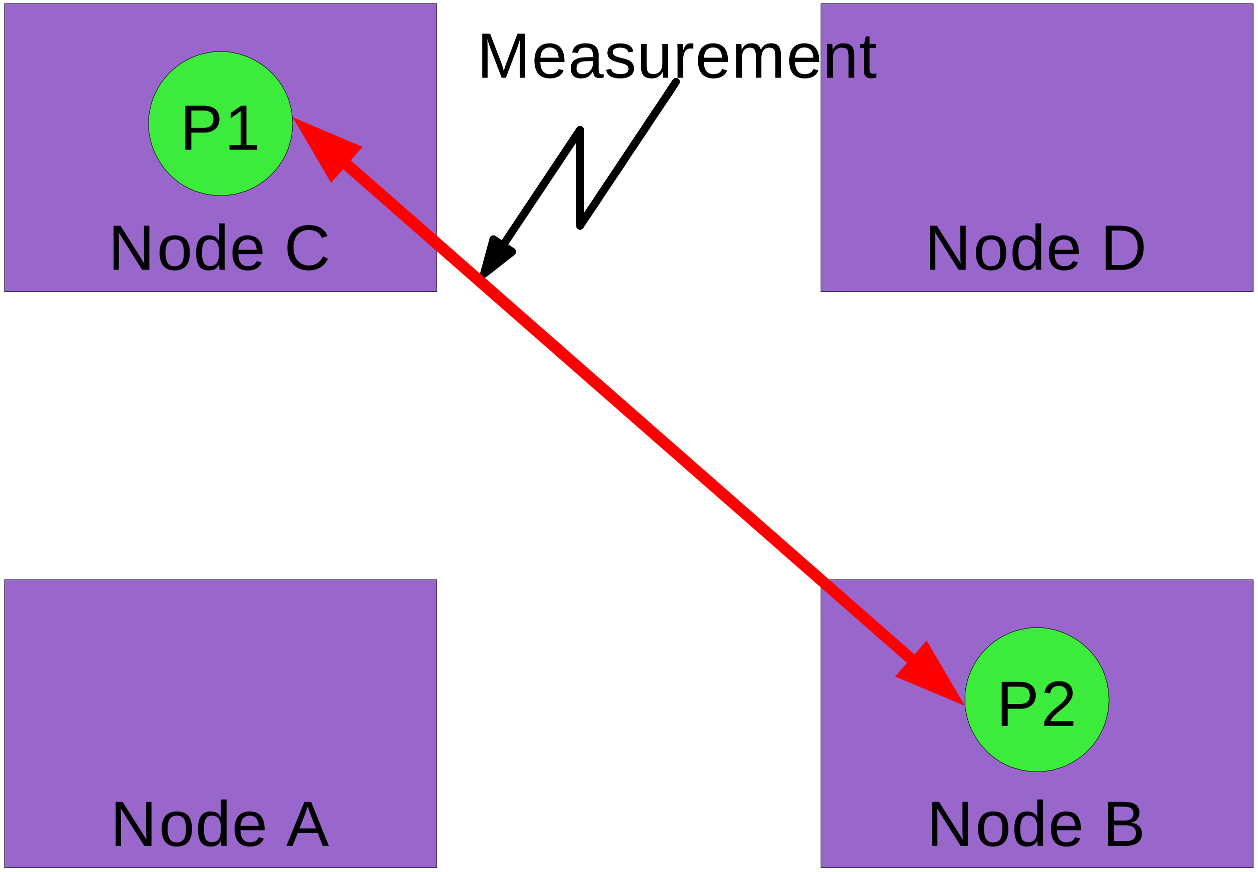

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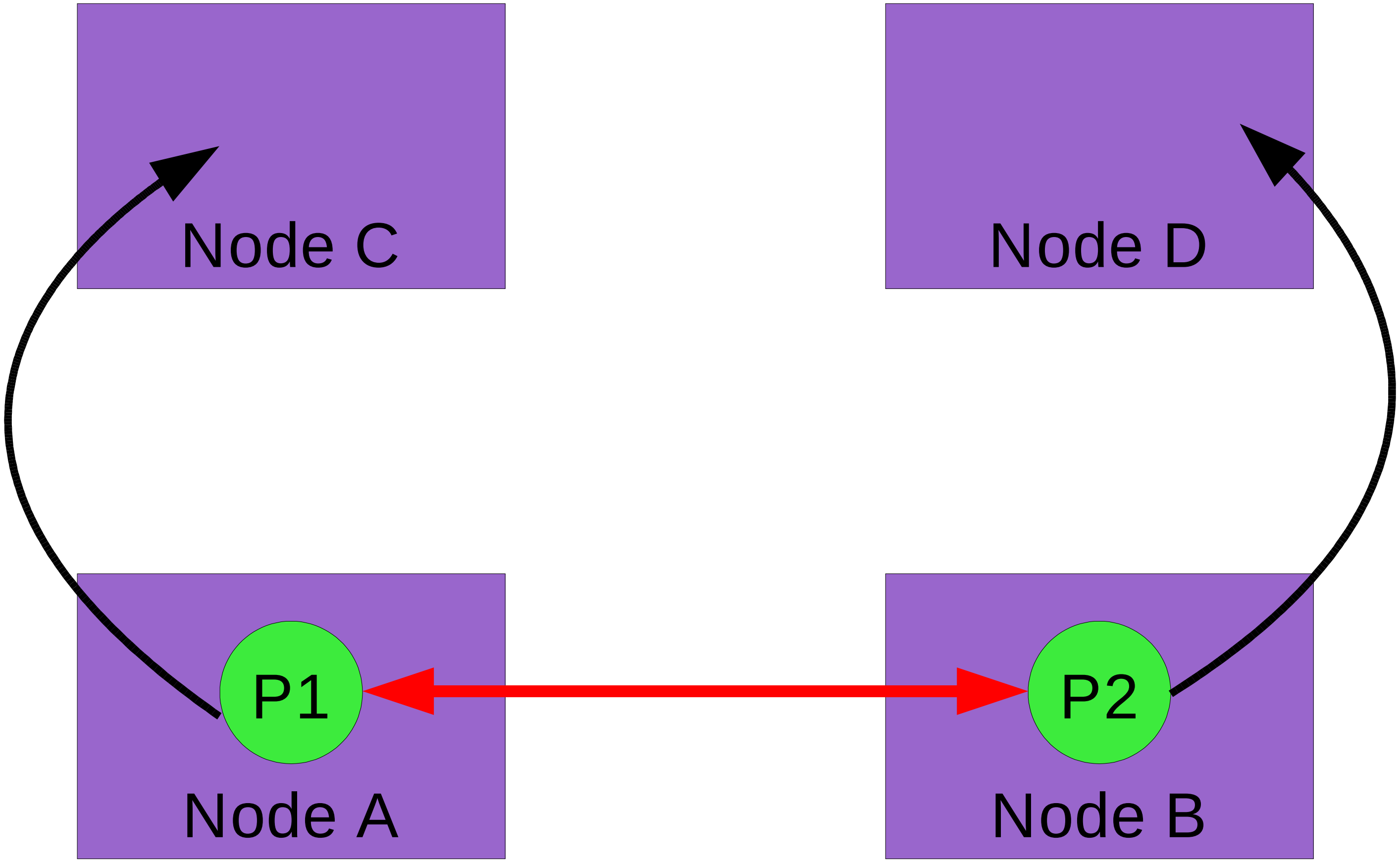

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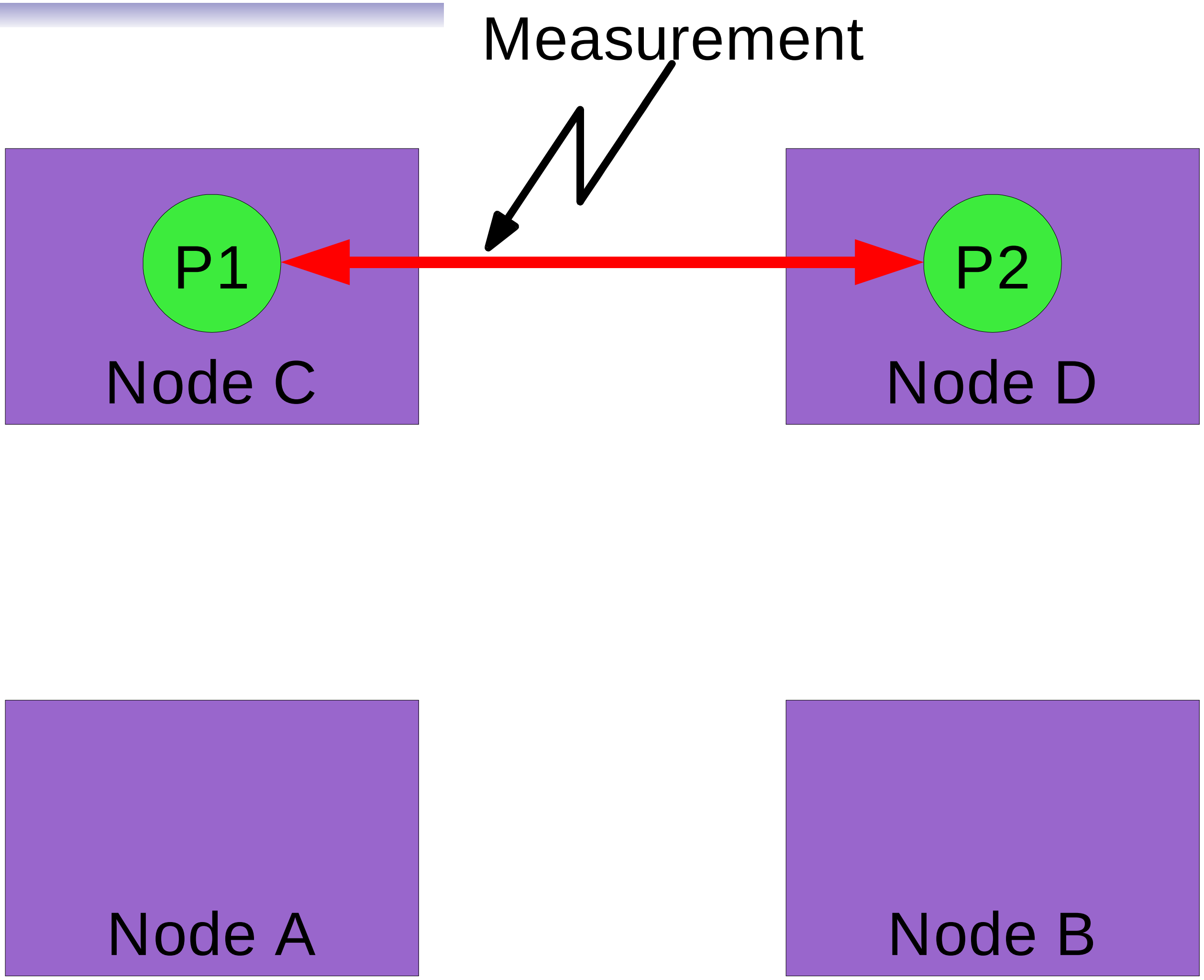
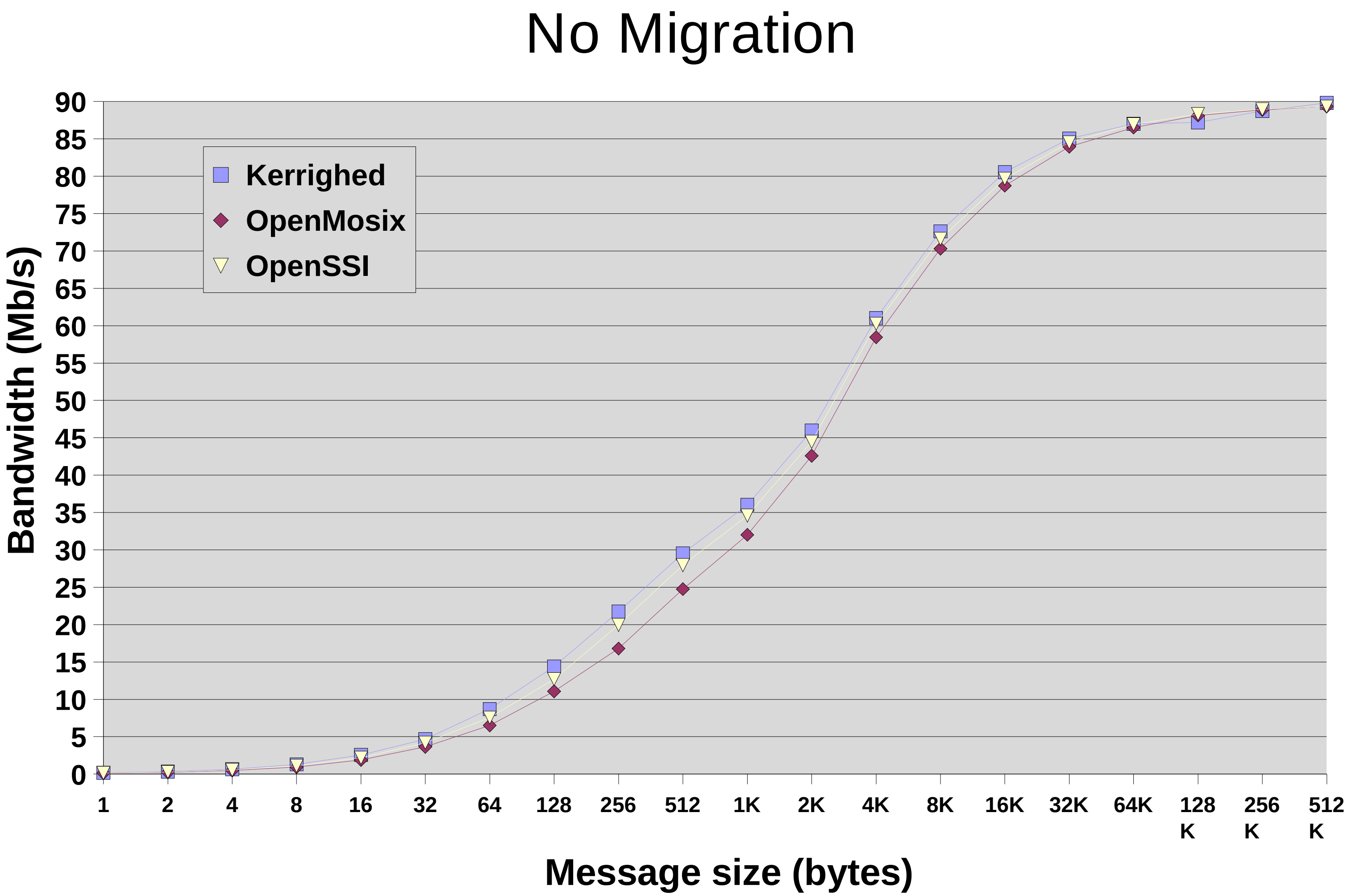
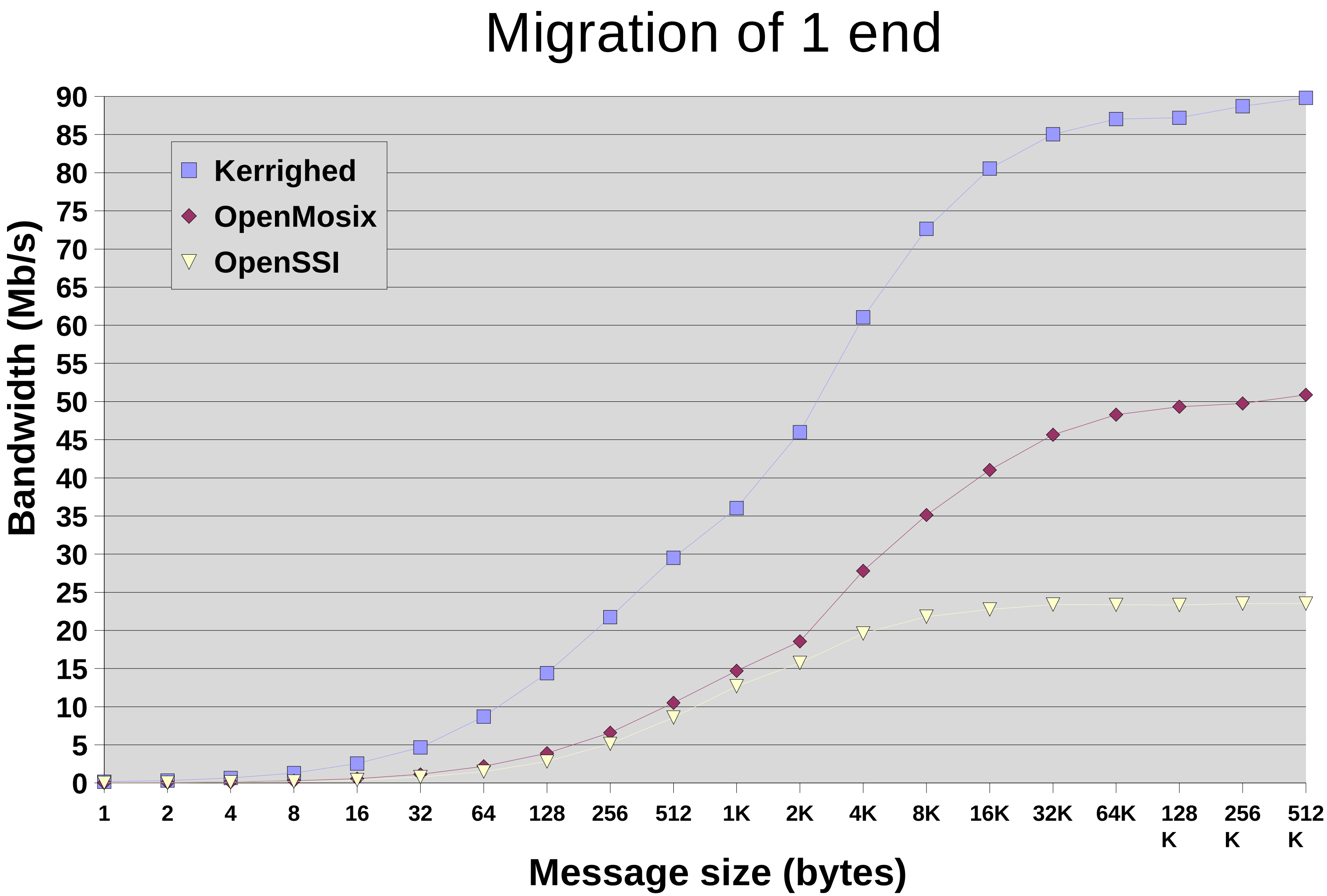


TCP Socket Bandwidth (Case 1)



TCP Socket Bandwidth (Case 2)



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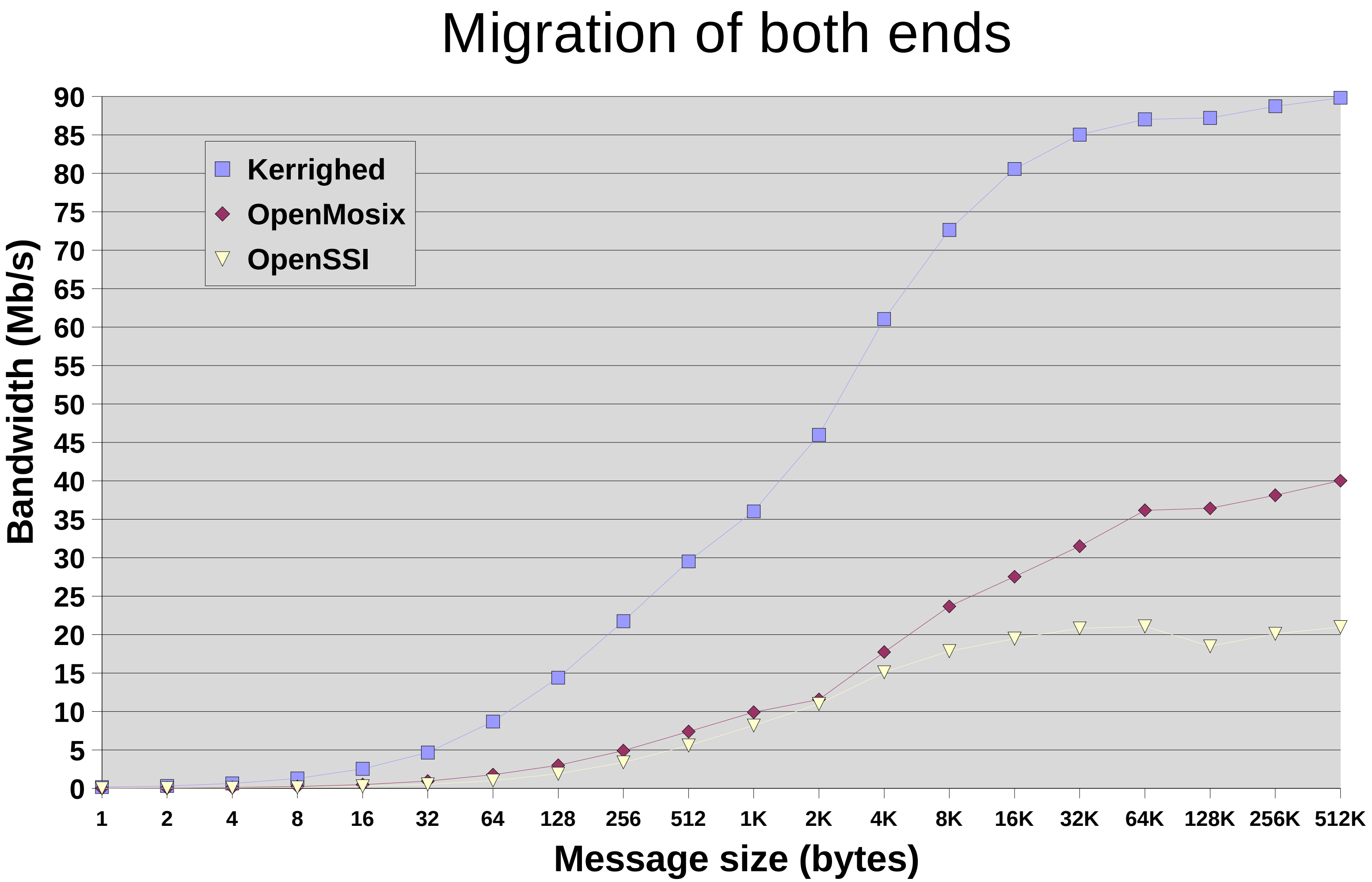
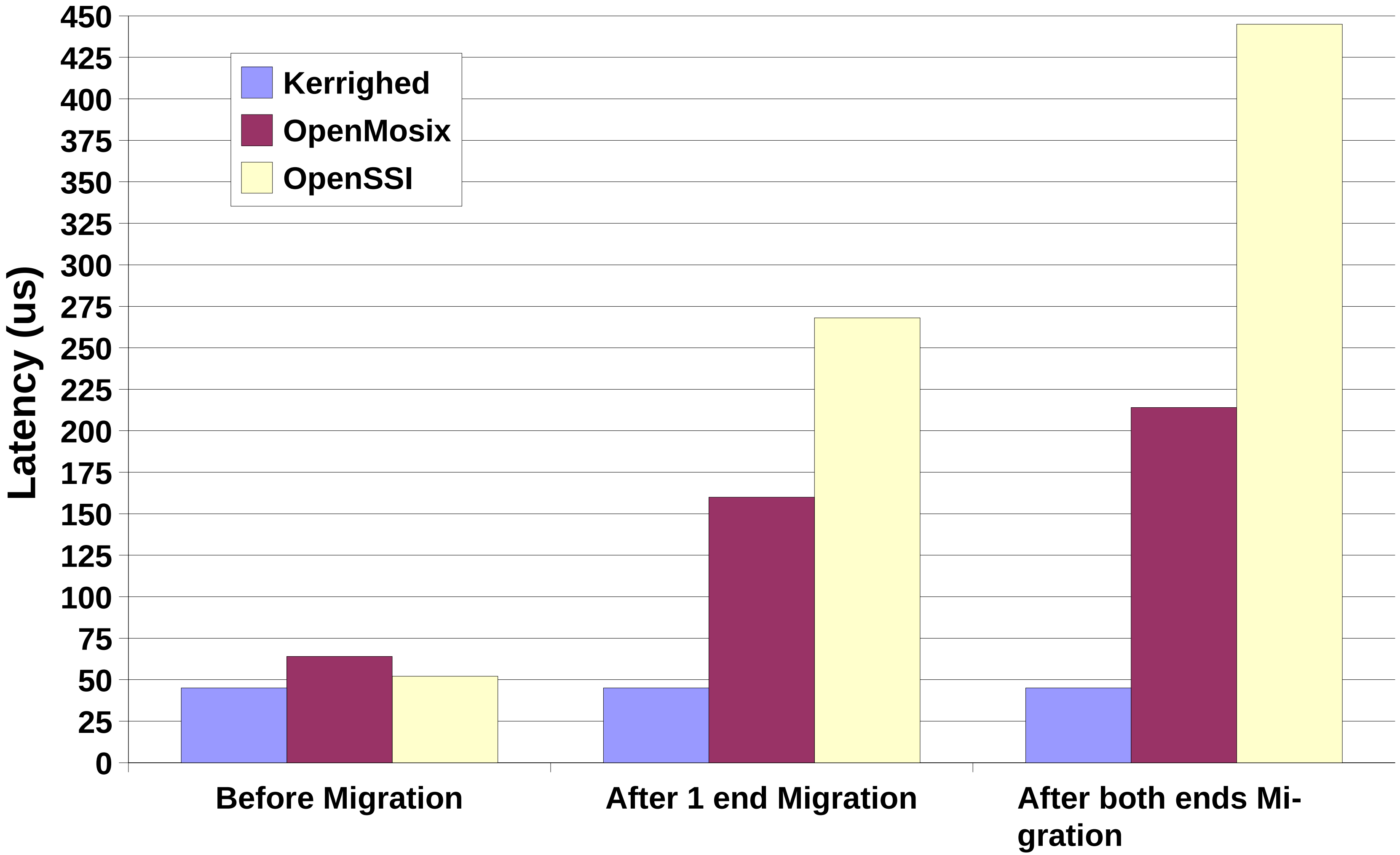
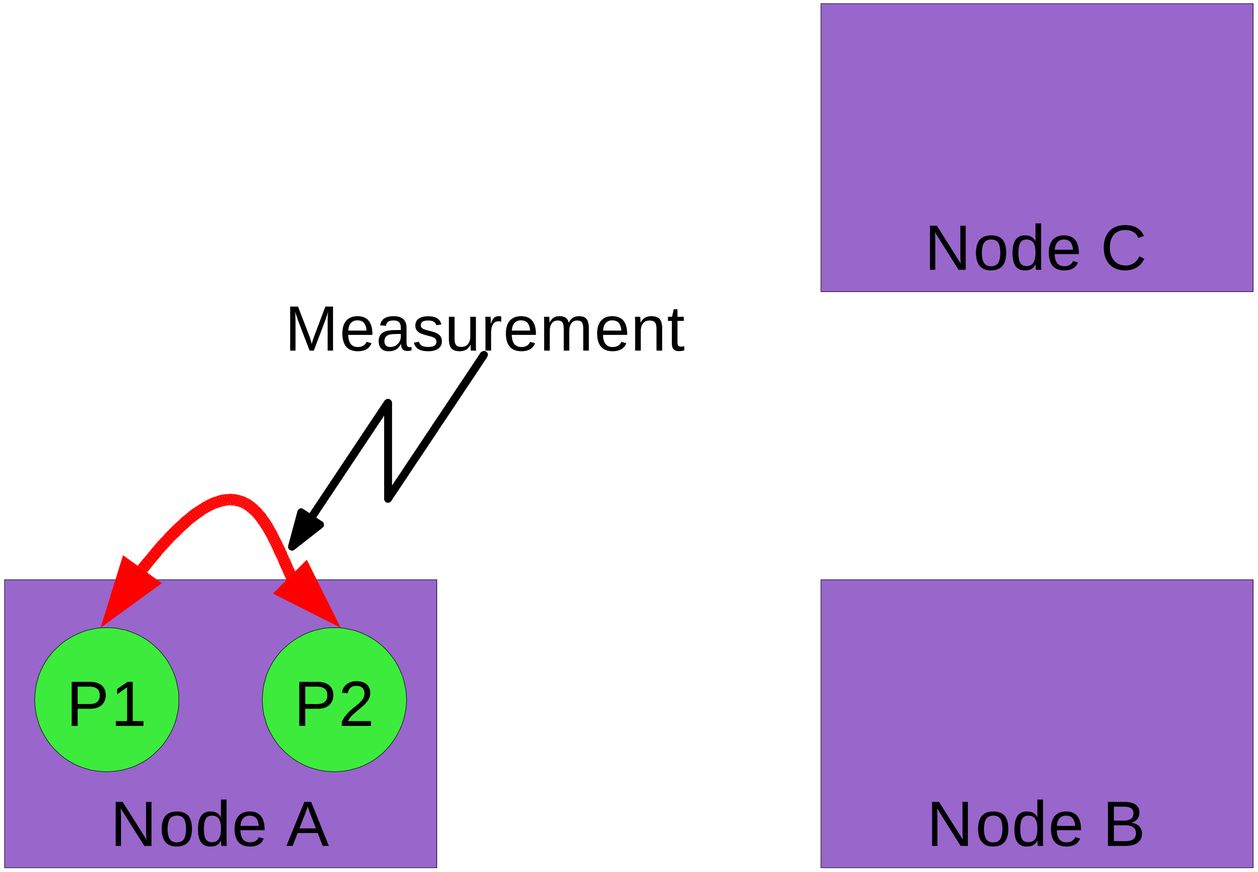


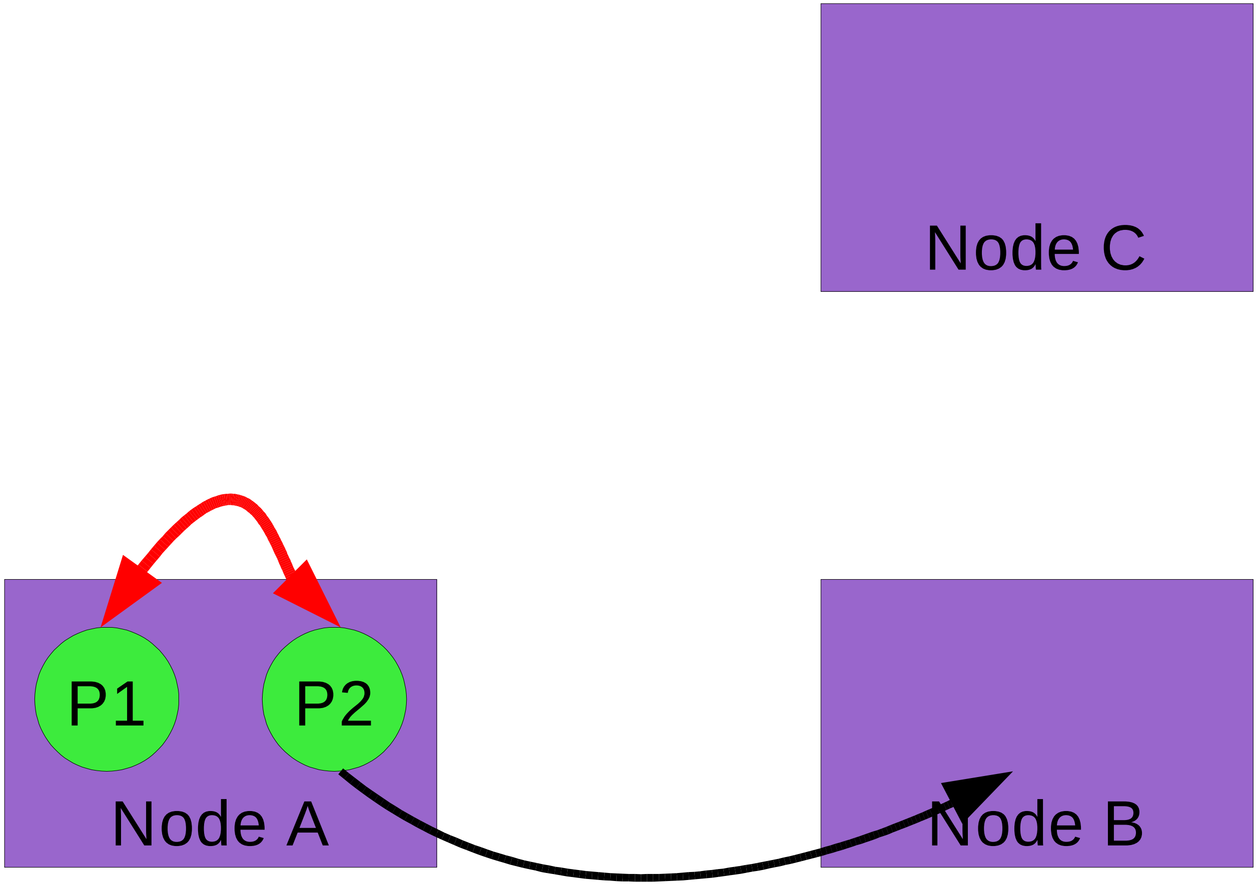
TCP Socket Latency



Pipe Migration (Case 1)



Pipe Migration (Case 2)



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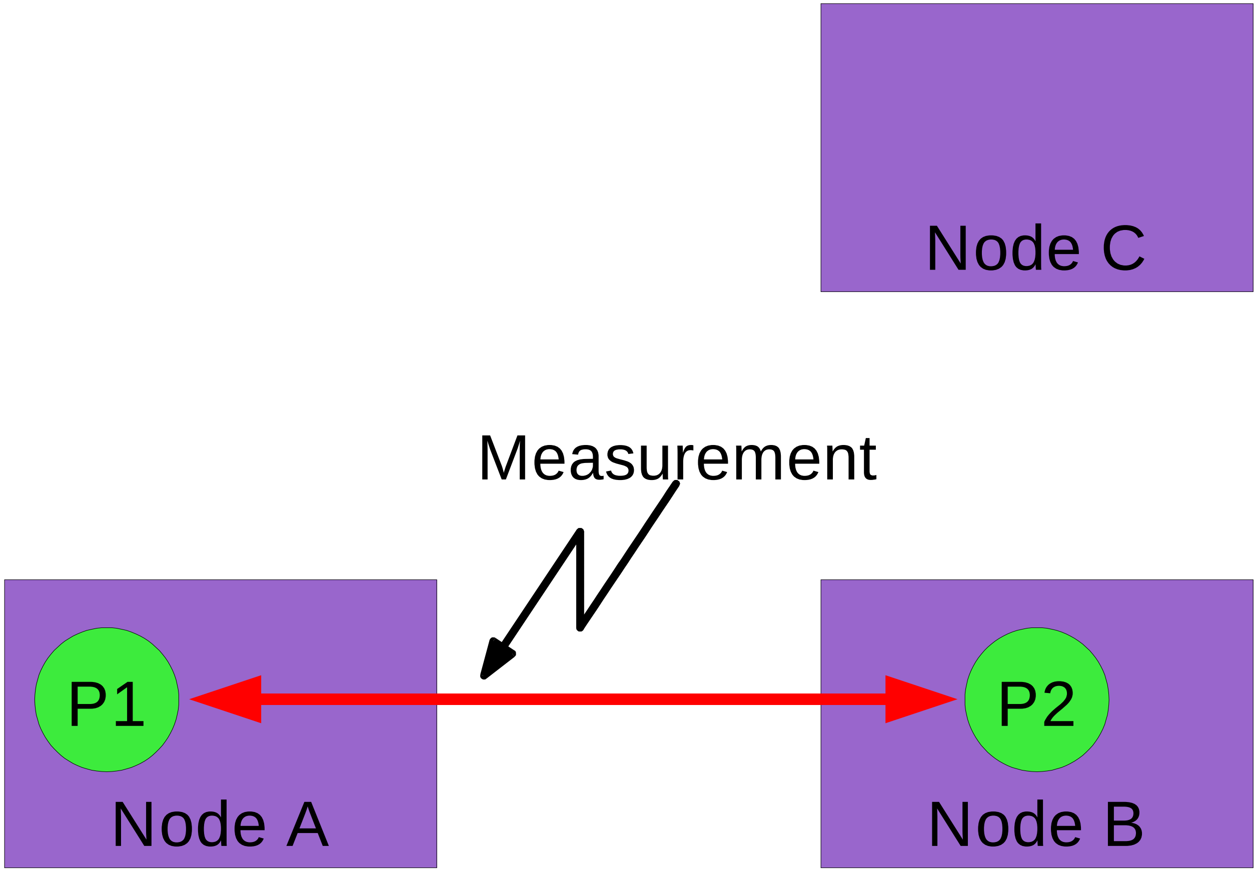

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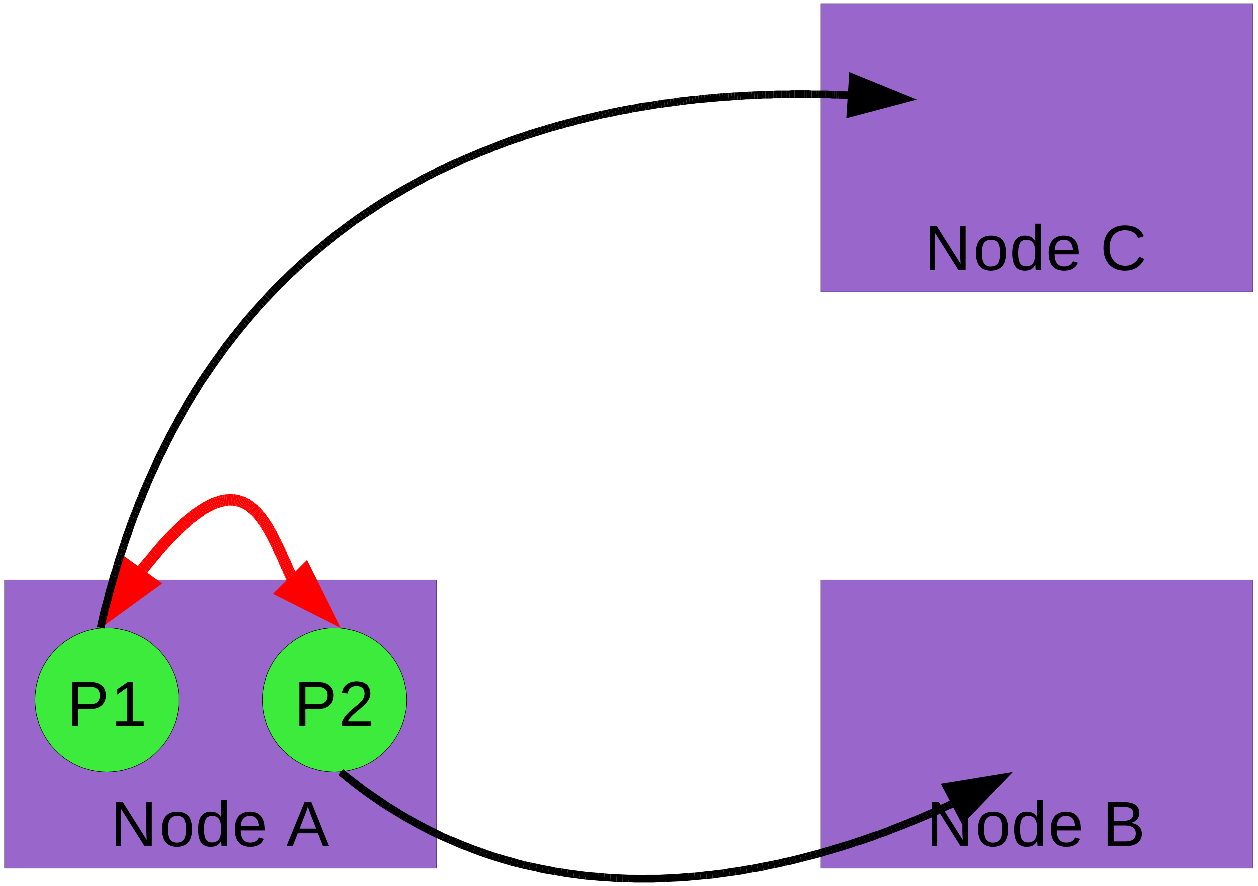

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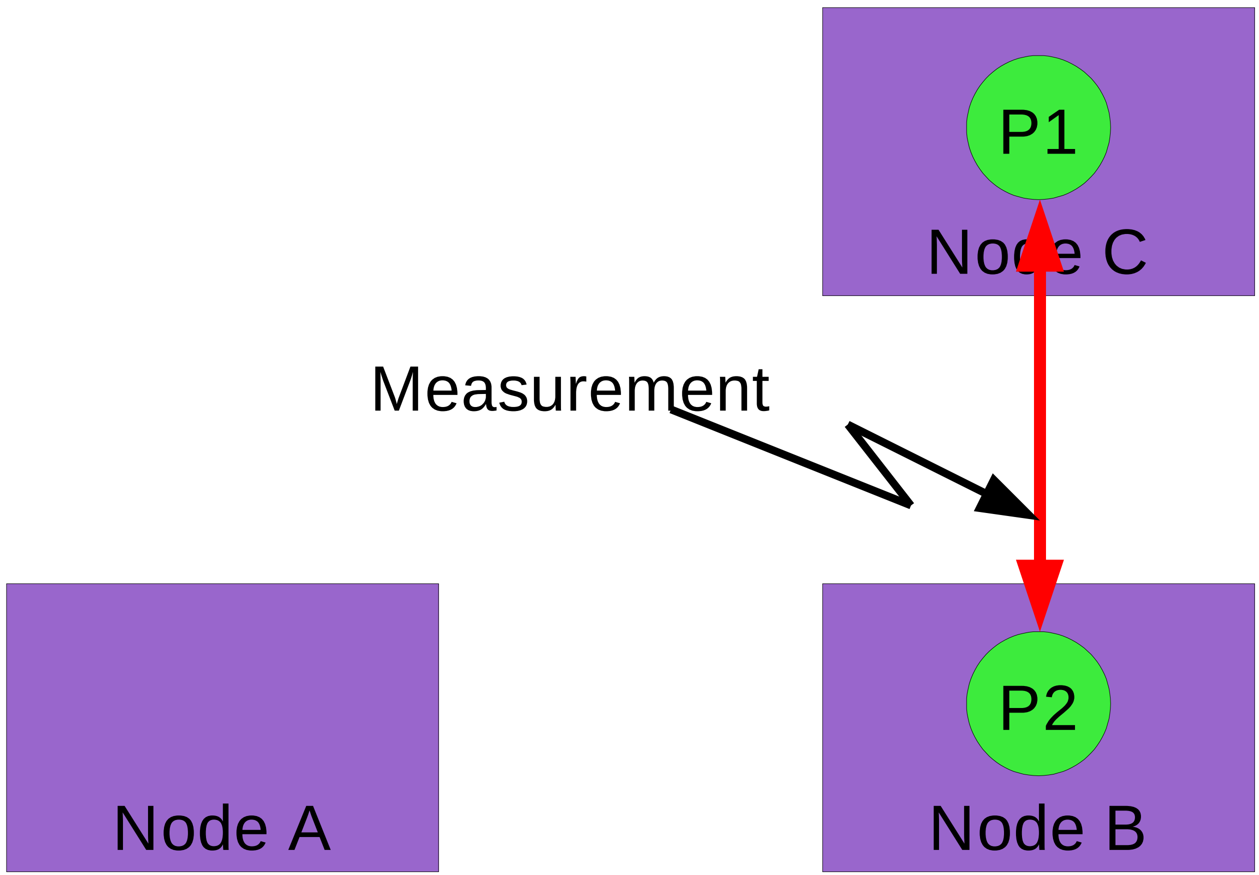
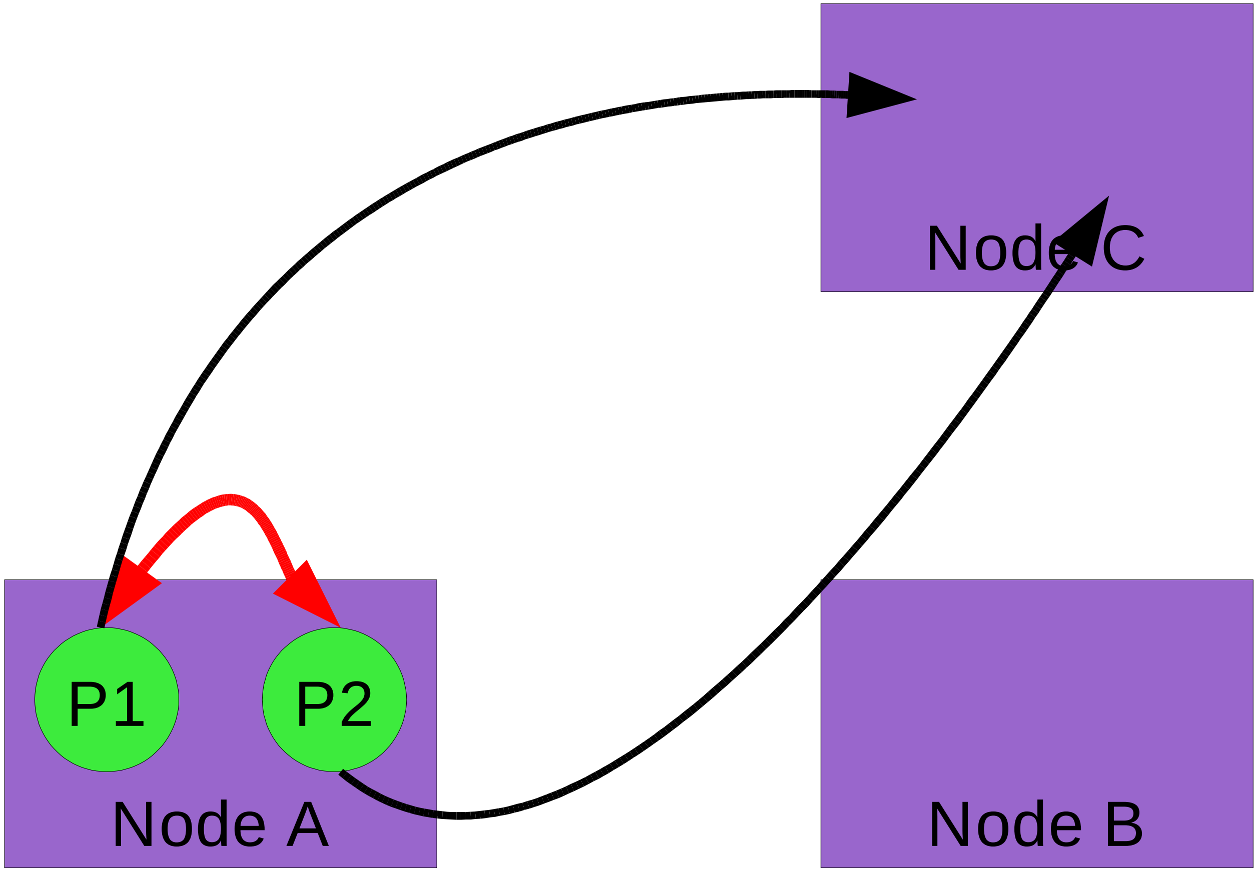


Pipe Migration (Case 4)



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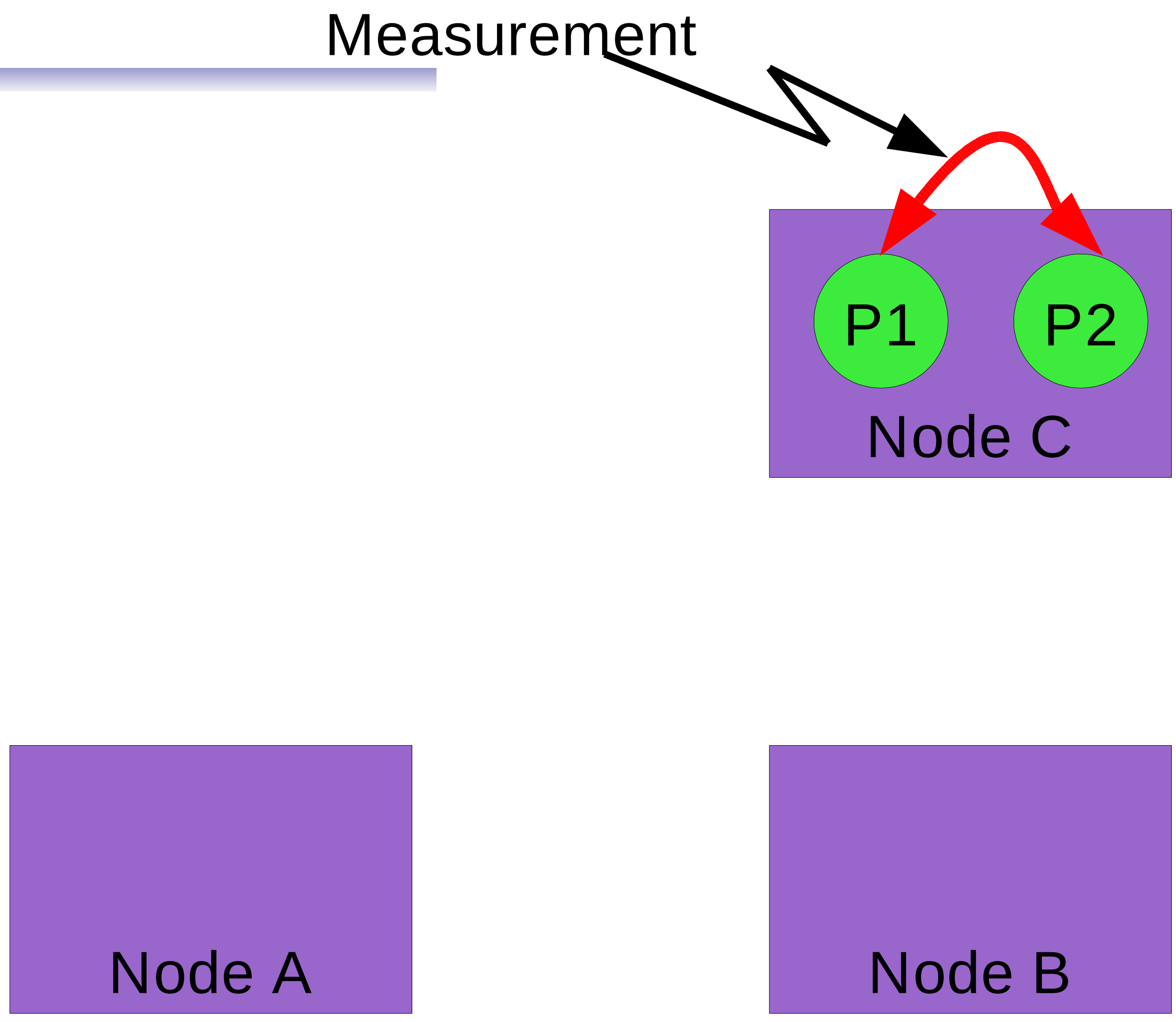

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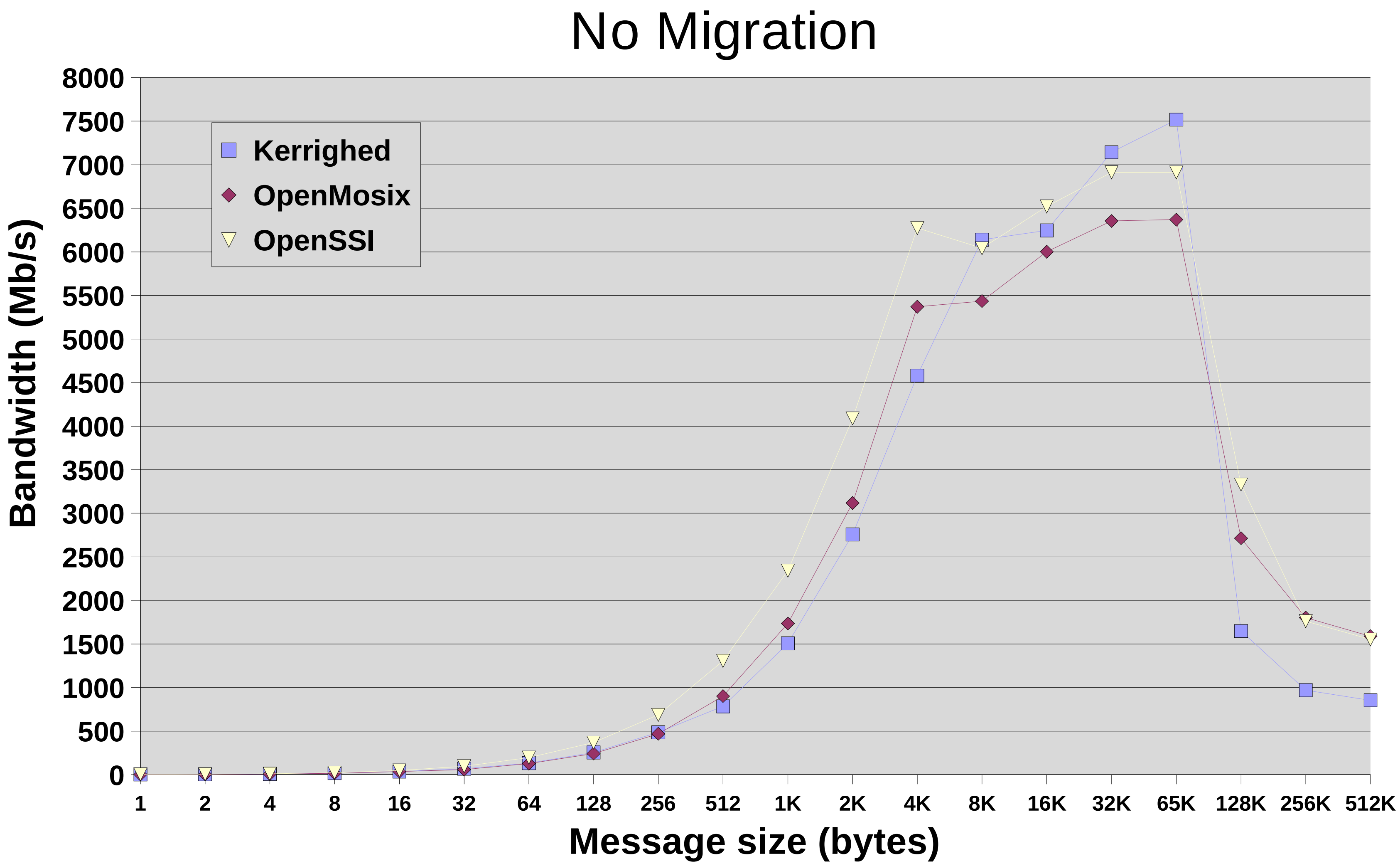
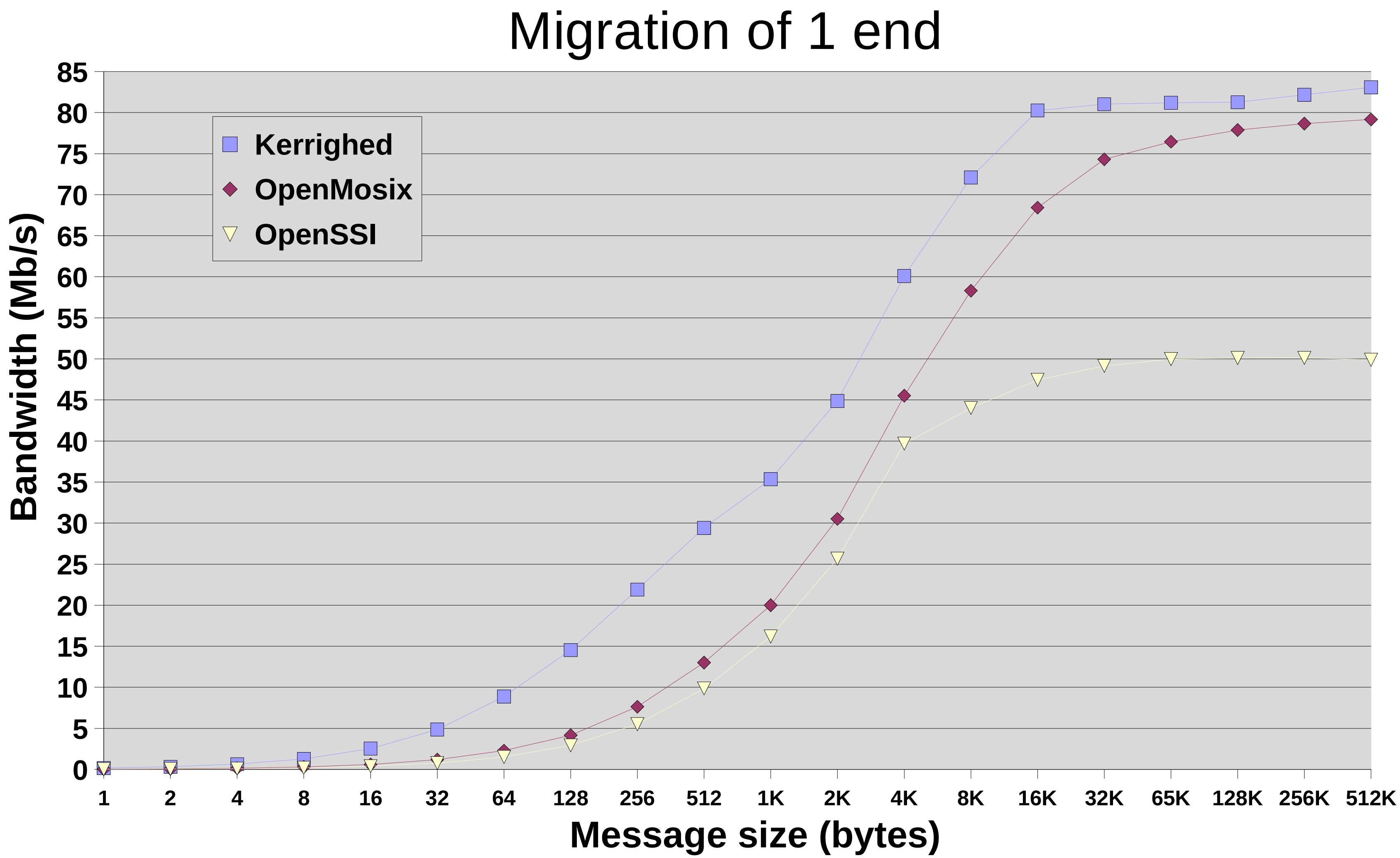


Pipe Bandwidth (Case 2)



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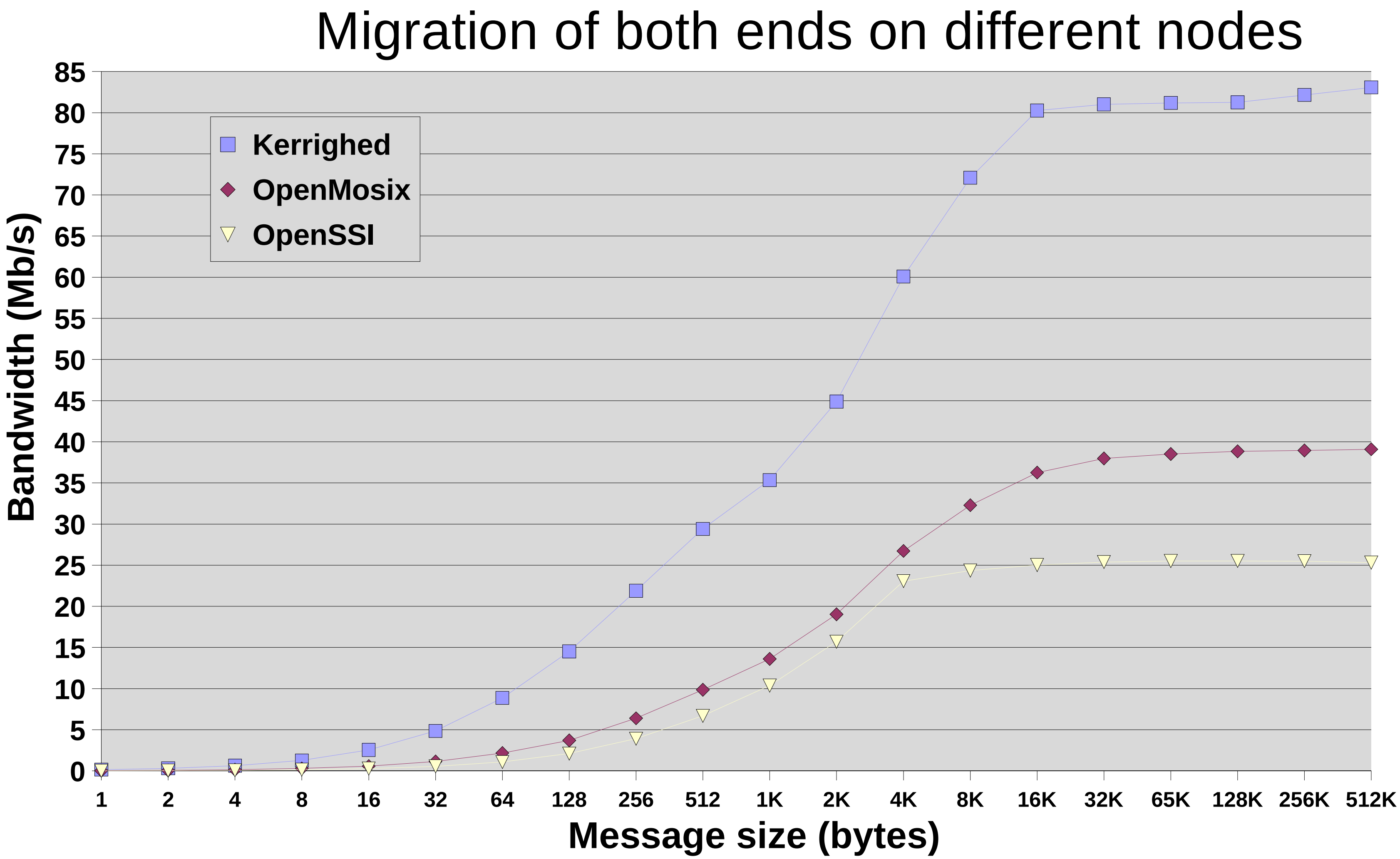

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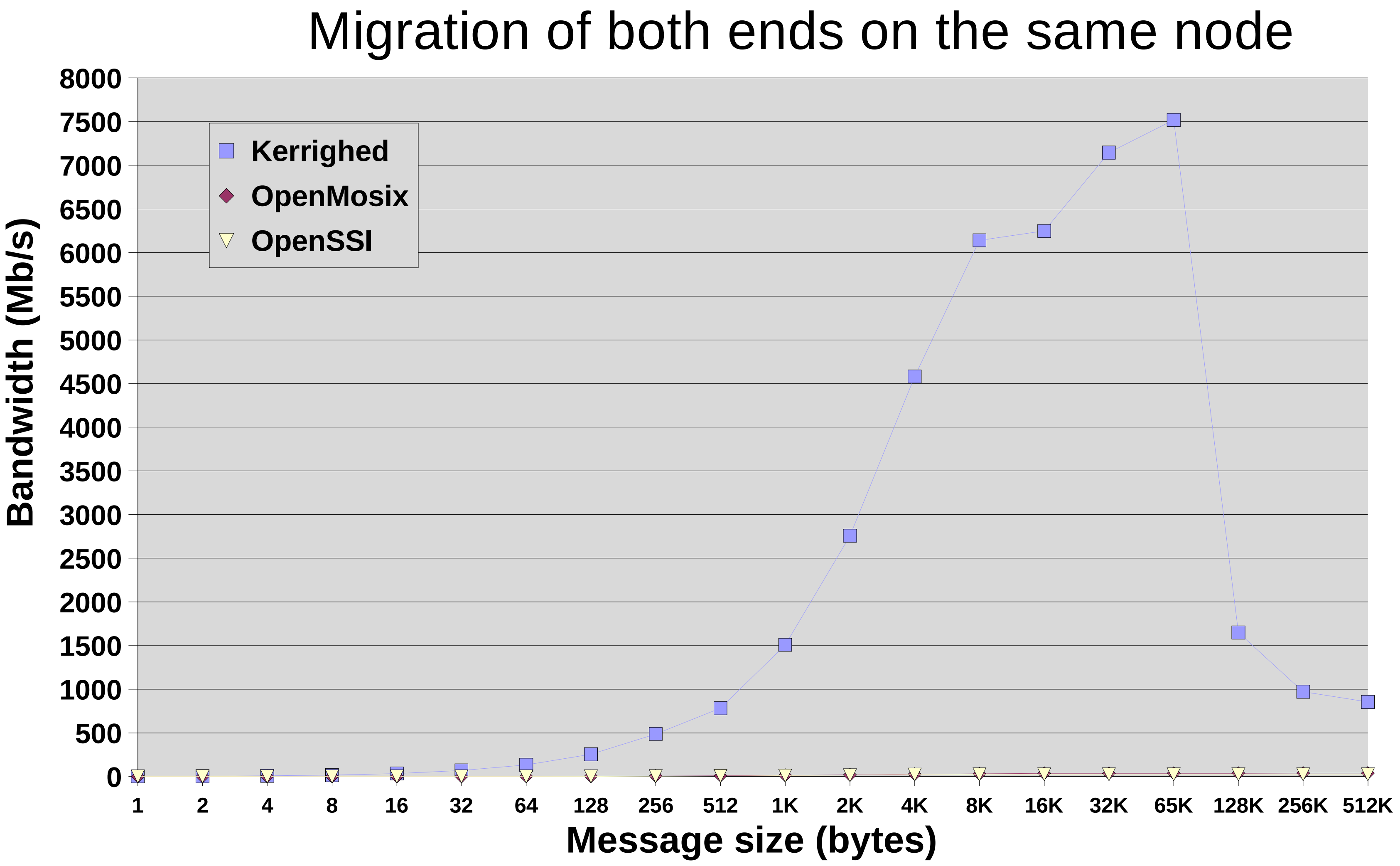
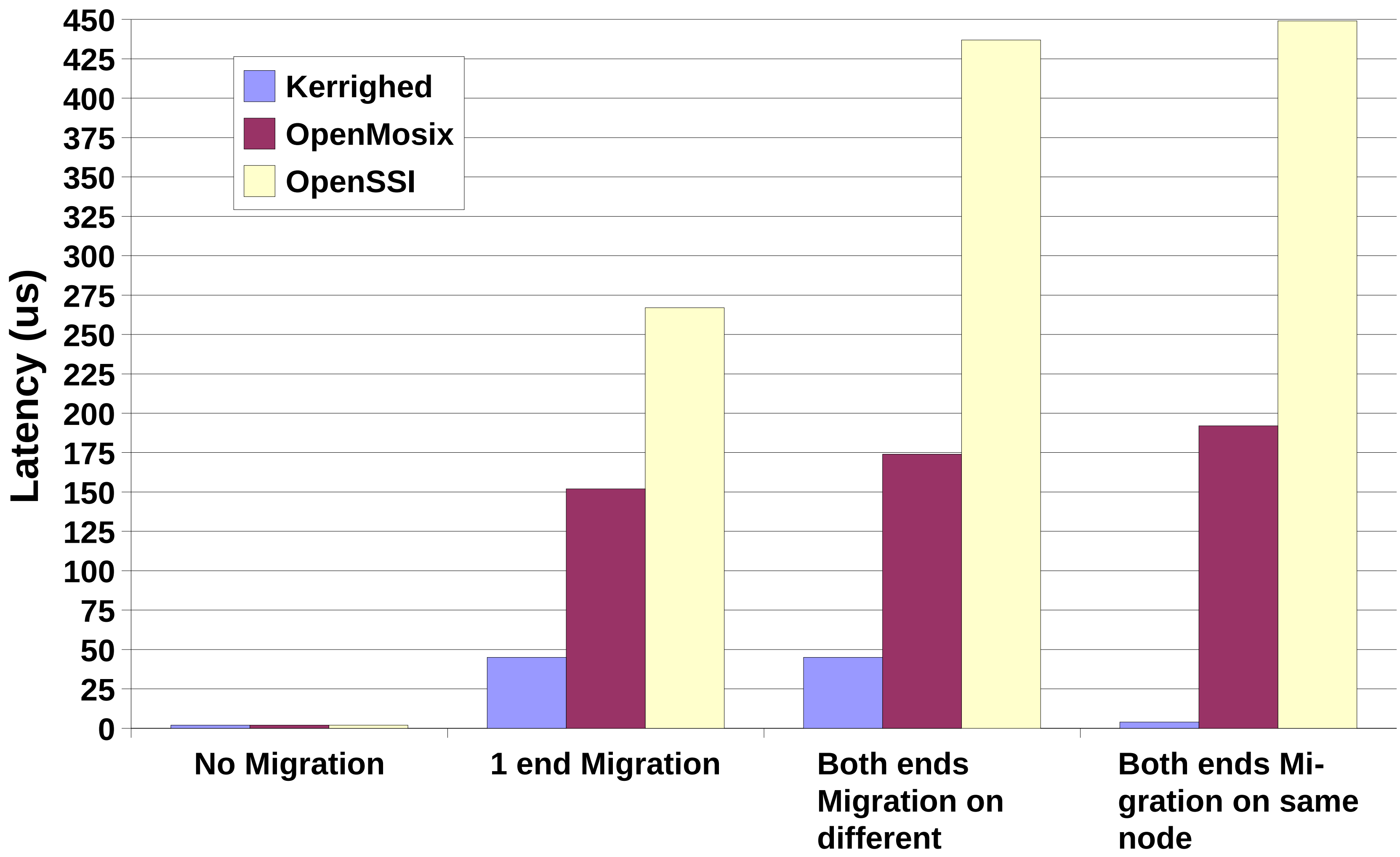


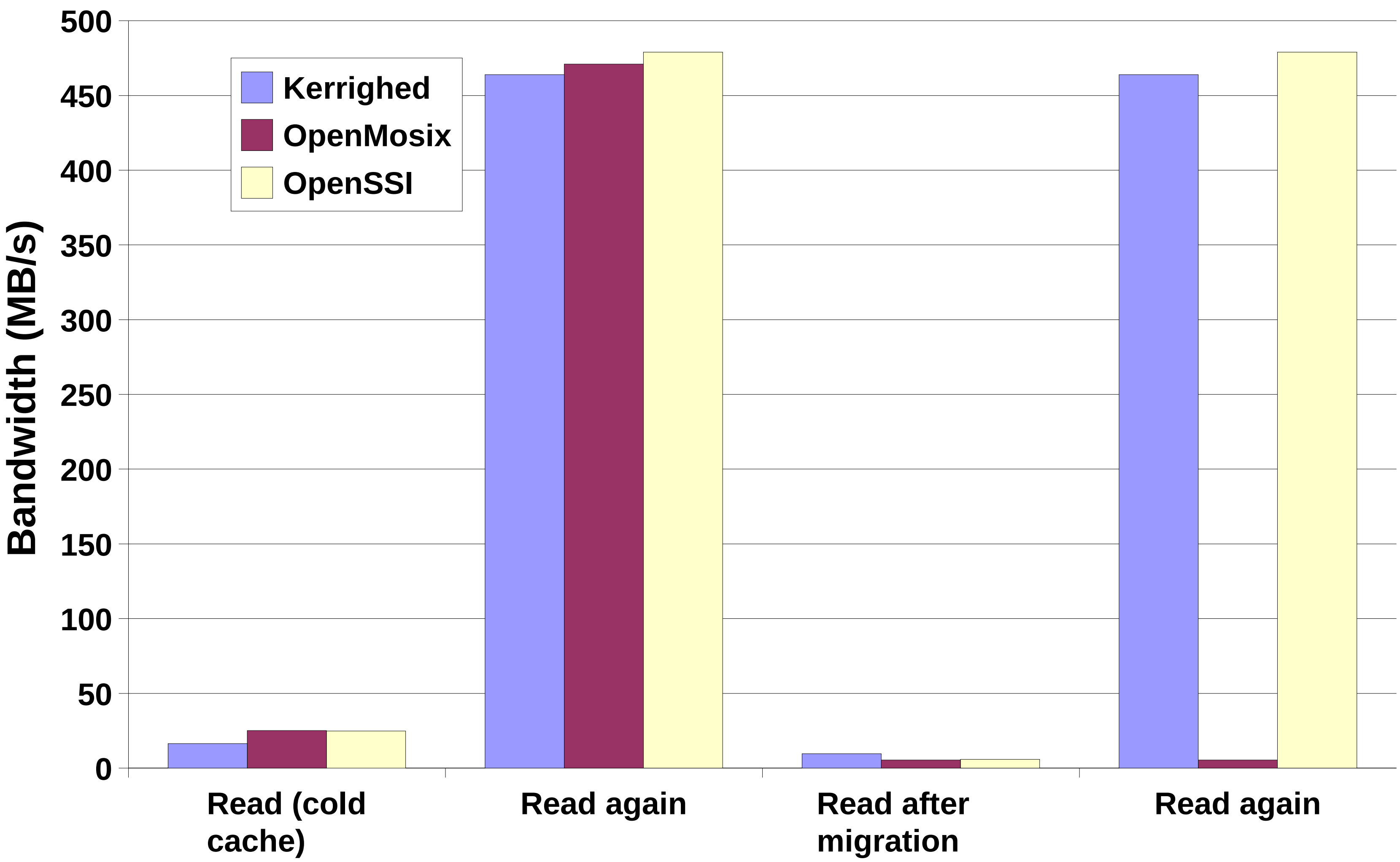
Pipe Latency



File Read

- 10 MB file
- Sequential read
- On node A
  - Read the file (cold cache)
  - Read again the file
- Migration to node B
- On node B
  - Read the file (cold cache)
  - Read again the file

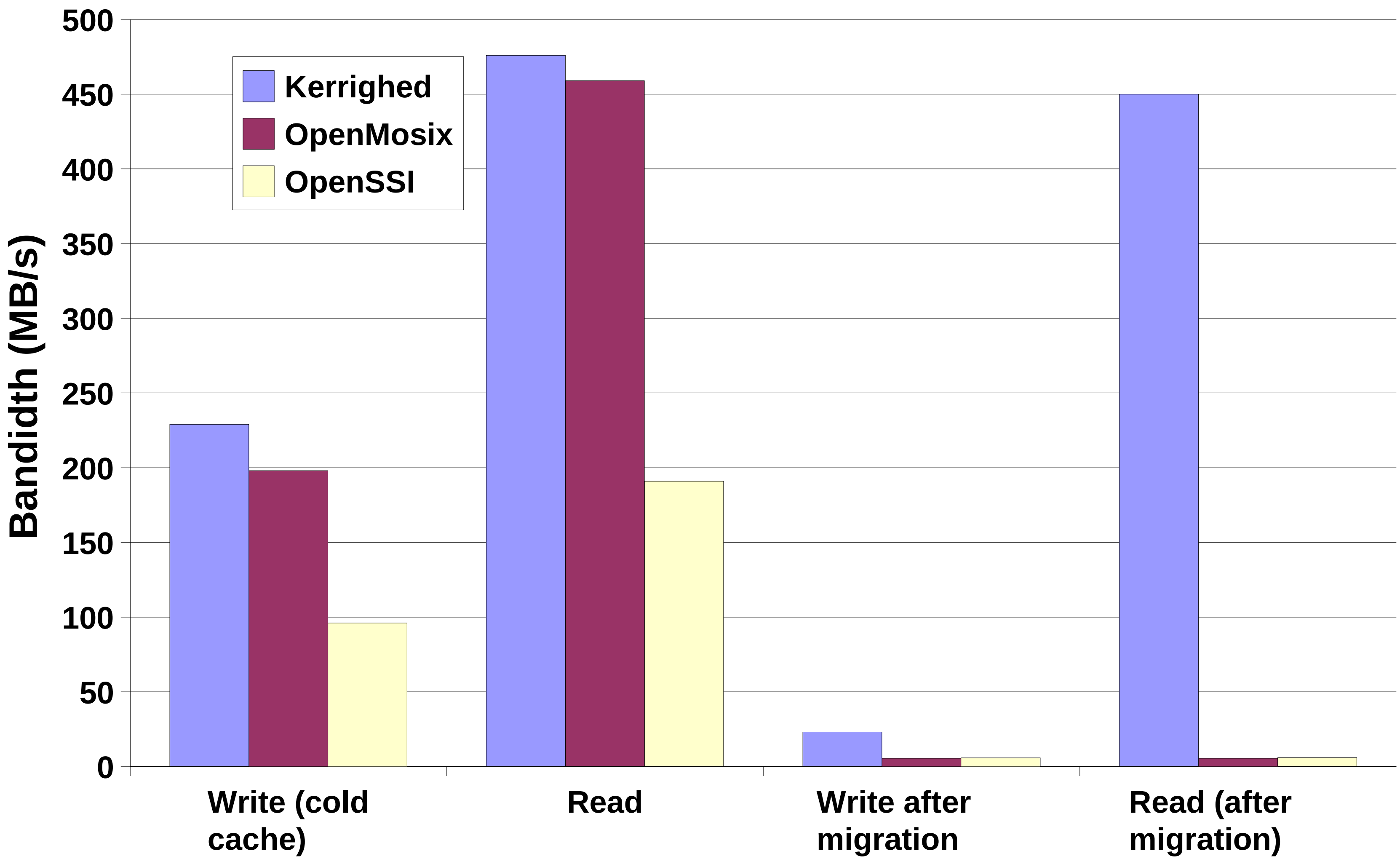
File Read: Results



File Write

- 10 MB file
- Sequential write : read
- On node A
  - Write to the file (cold cache)
  - Read the written data
- Migration to node B
- On node B
  - Over-write to the file (cold cache)
  - Read the written data

File Write : Results



Summary

- Kerrighed
  - ✔ Performance
  - ✔ Real view of a unique SMP machine
  - ✔ Highly customizable
  - ✔ Good internal software architecture
  - ✗ Stability
  - ✗ No support for node addition/removal/failure
  - ✗ No support for SMP / 64 bits architectures
  - ✗ Very small community

Summary (2)

- OpenSSI
  - ✔ Real view of a unique SMP machine
  - ✔ Support from HP
  - ✔ Robustness
  - ✗ Performance
  - ✗ Poor internal software architecture
  - ✗ Small community

Summary (3)

- OpenMosix
  - ✔ Very good global process scheduler
  - ✔ Large user community
  - ✔ Relative robustness
  - ✔ Scale very well
  - ✗ Performance
  - ✗ Incomplete view of an SMP machine

Kerrighed Future Works

- Node addition/removal (april 2005)
- SMP / 64 bits (july 2005)
- Distributed/Parallel file system (july 2005)
- 2.6 port (july 2005)
- Parallel checkpoint (? 2005)
- High availability (2006)
- Grid extensions (?)

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Previous works

- Many works have already been carried out
  - Global process management
    - Condor, Sprite, Mosix, Bproc, ...
  - Global memory management
    - IVY, TreadMarks, GMS, ...
  - Global disk management
    - XFS, PFVS, Lustre, GFS, ...
  - Communications
    - RPC, Active messages, Madelaine, ...

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

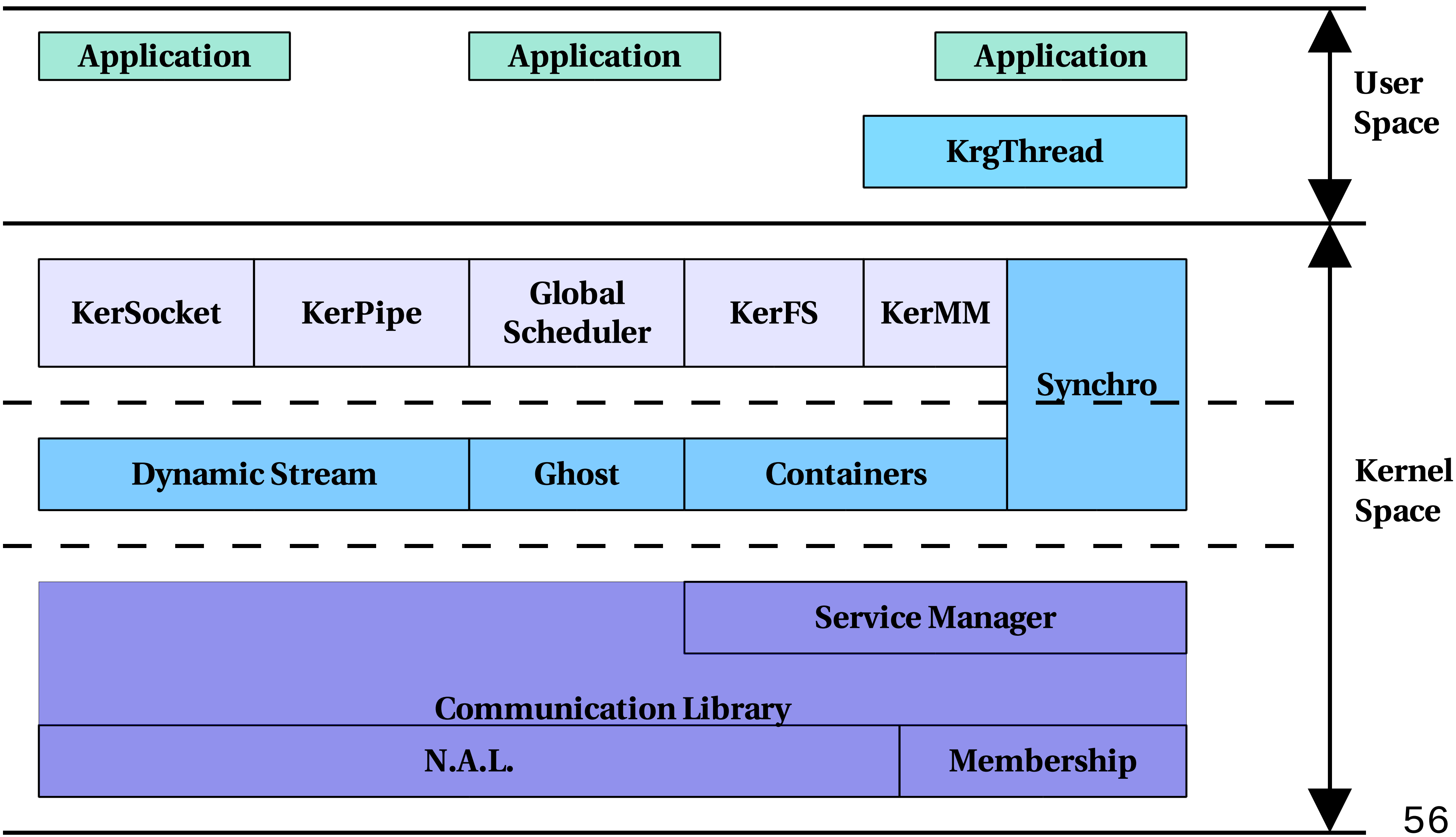
Factorization examples (1)

- 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



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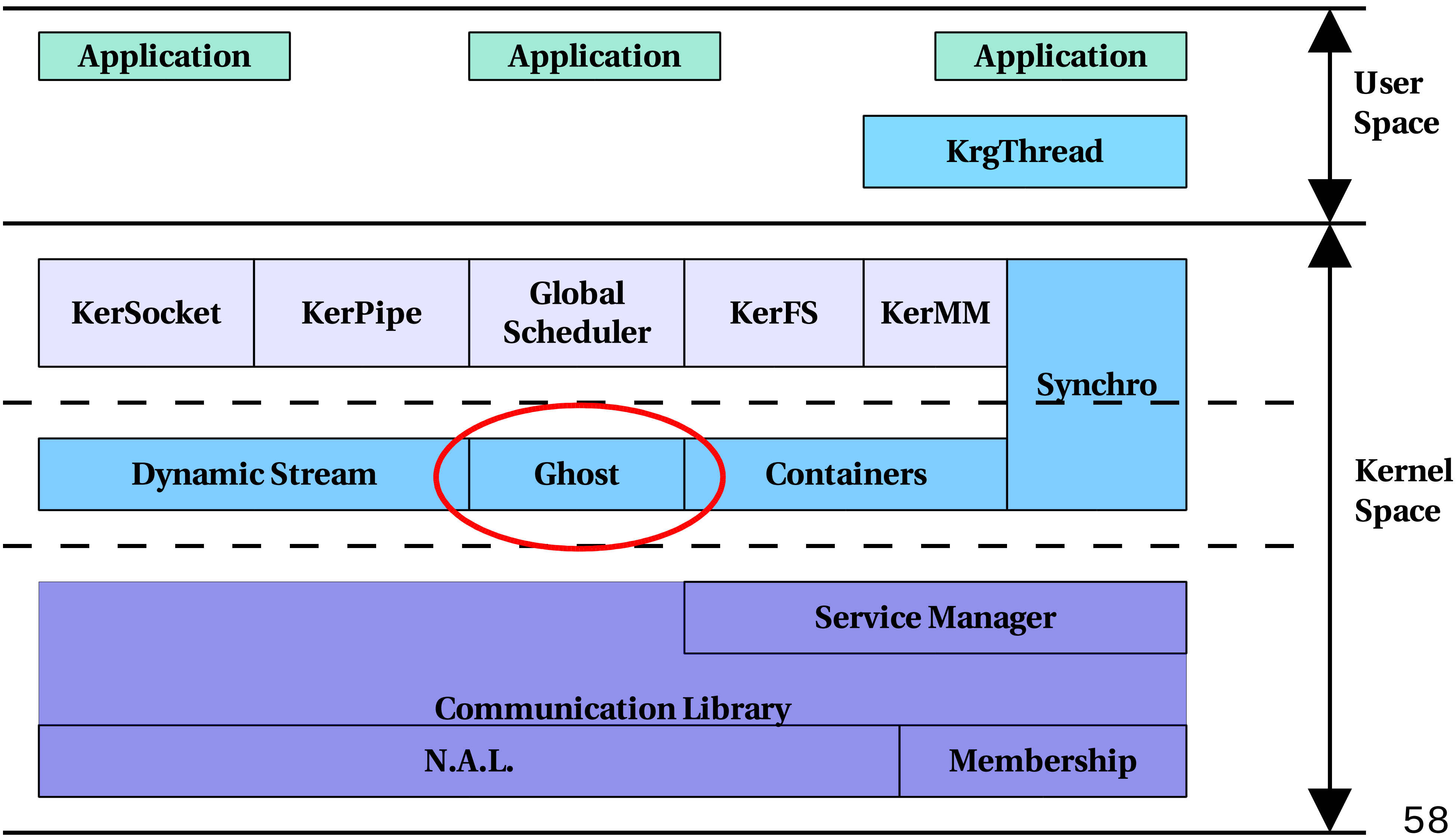


Process Migration in Kerrighed

- 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

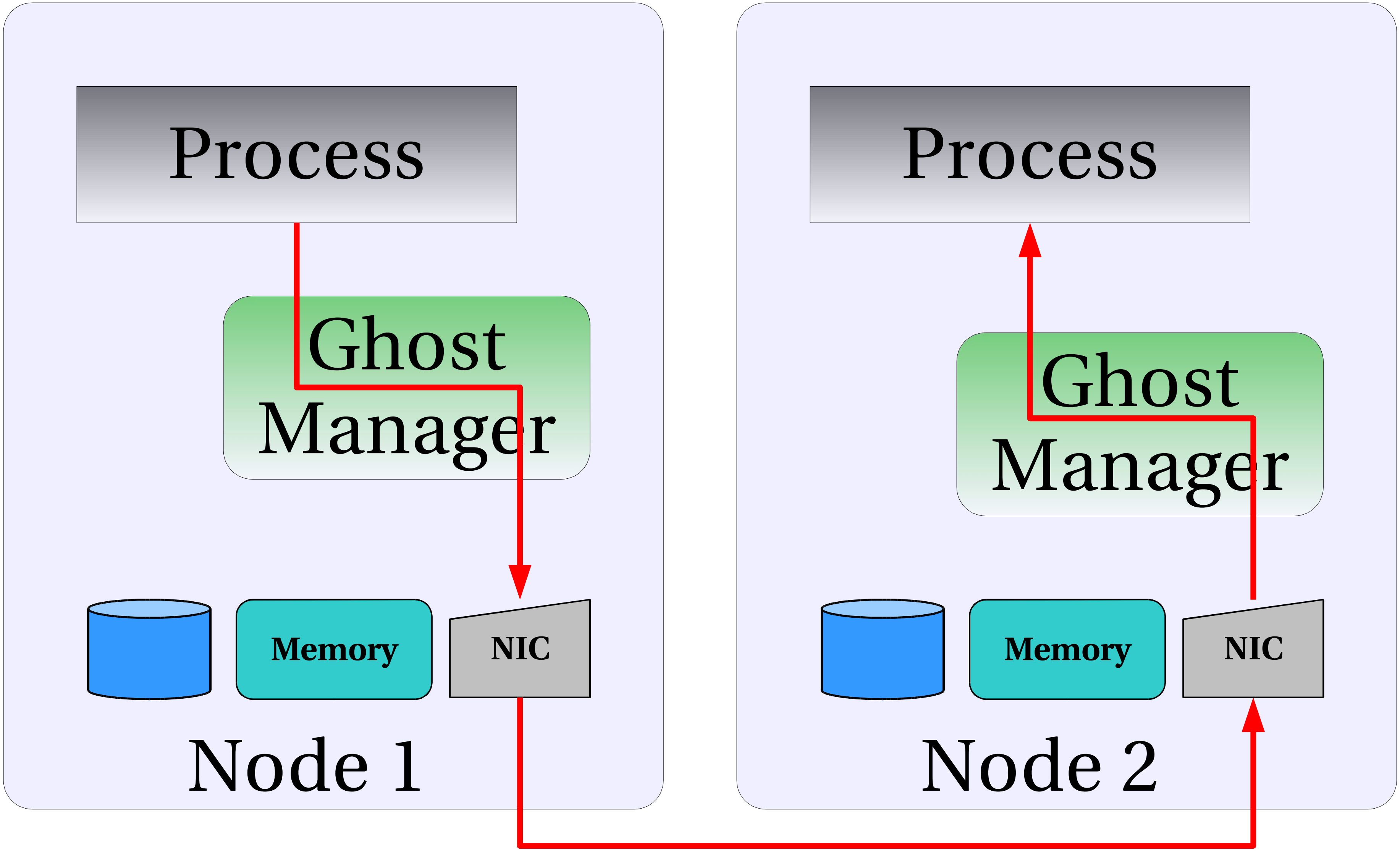
Process Migration in Kerrighed (2)

- 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

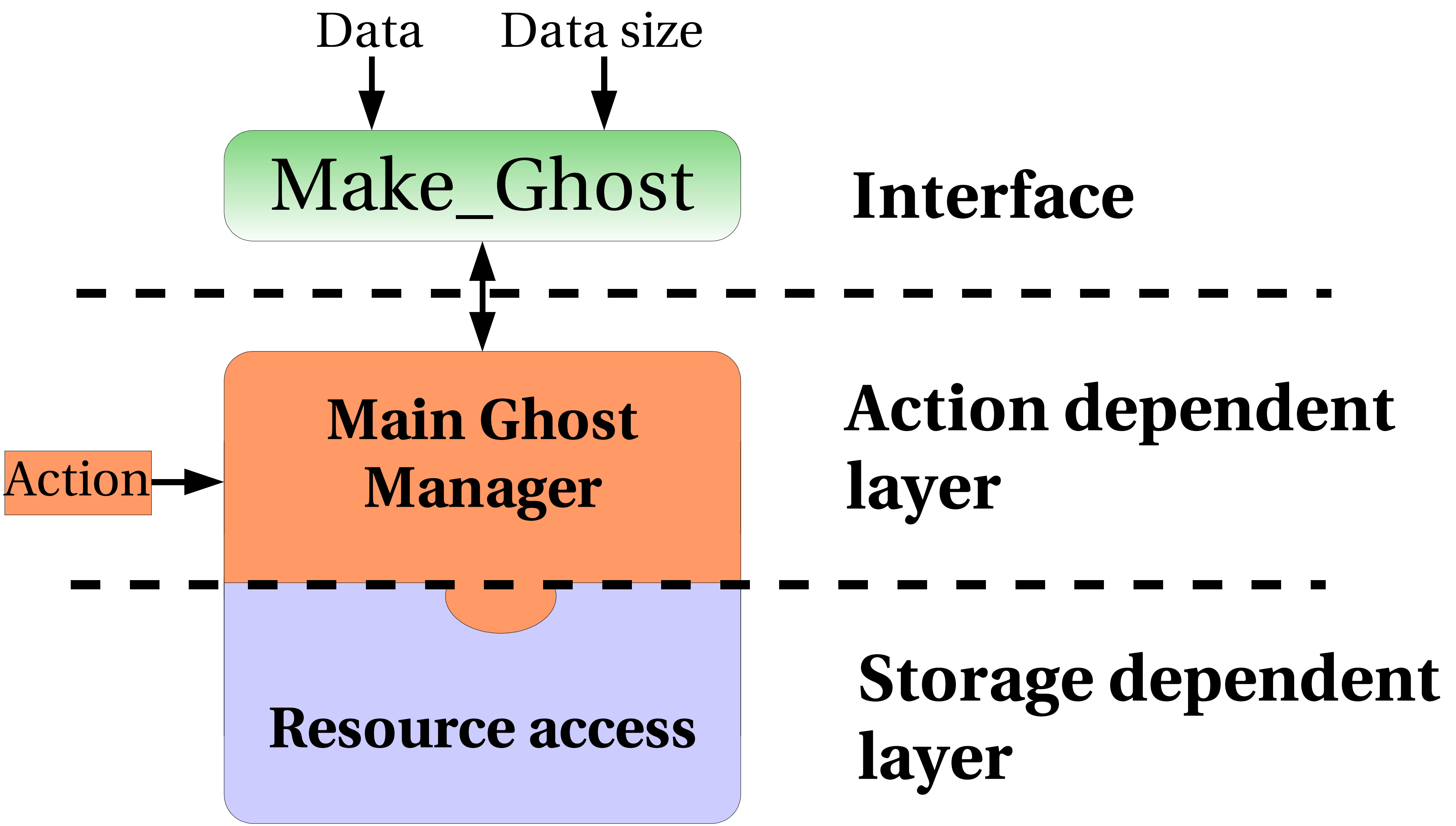
Migration / Duplication



Ghost Architecture

- A ghost is defined by
  - A cluster wide ghost identifier
  - An associated device
    - Network
    - Memory
    - Disk
- A ghost is controlled by an action
    - Load data
    - Store data
- One unique interface
  - Same code for load/restore data

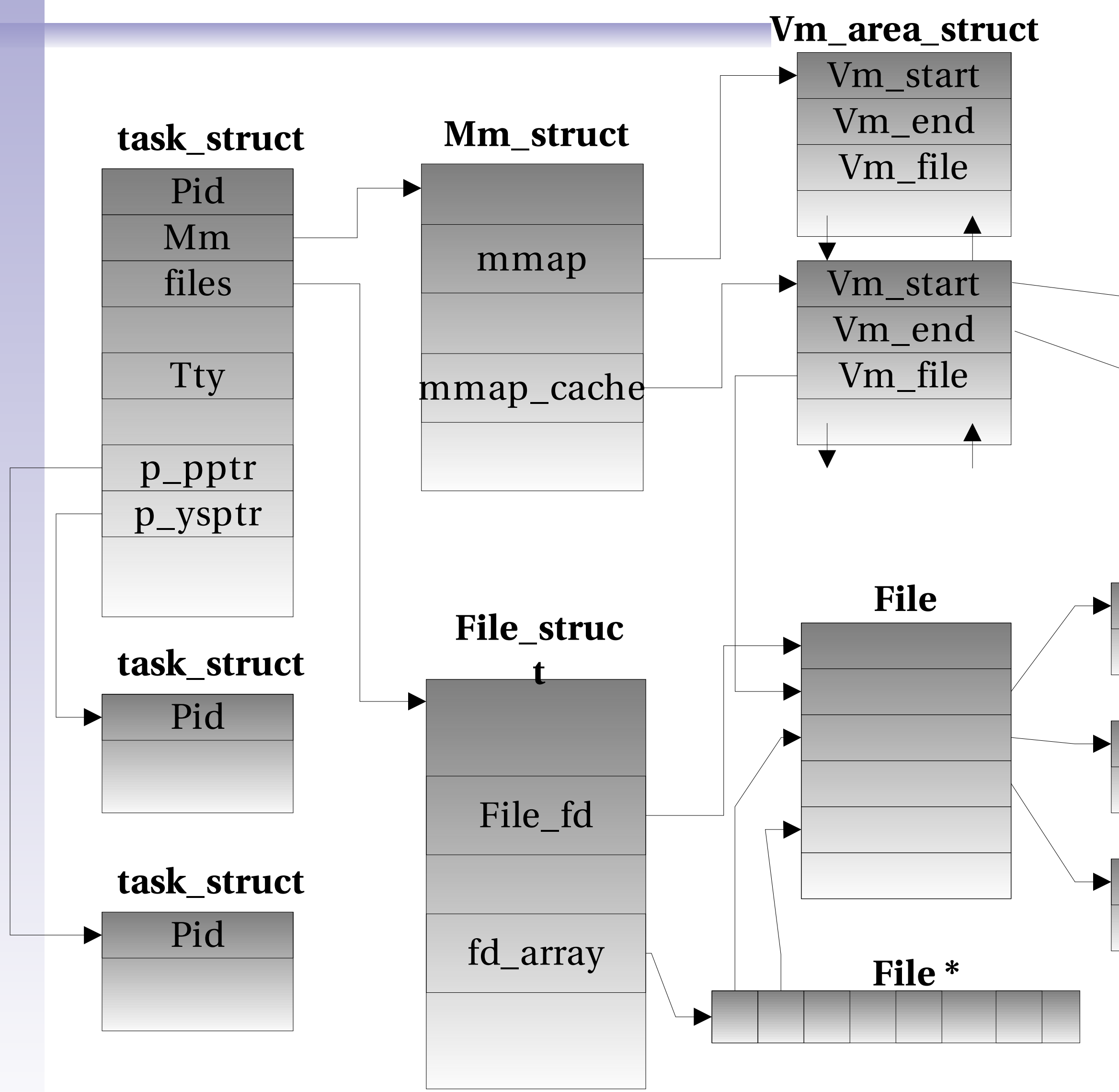
Ghost Architecture (2)



Ghost Use

- Ghost are used by functions parsing kernel data structures
  - Structure data pre-processing
  - Make ghost
  - Structure data post-processing
  - Call sub functions for sub data-structures

“Ghosting” a task structure

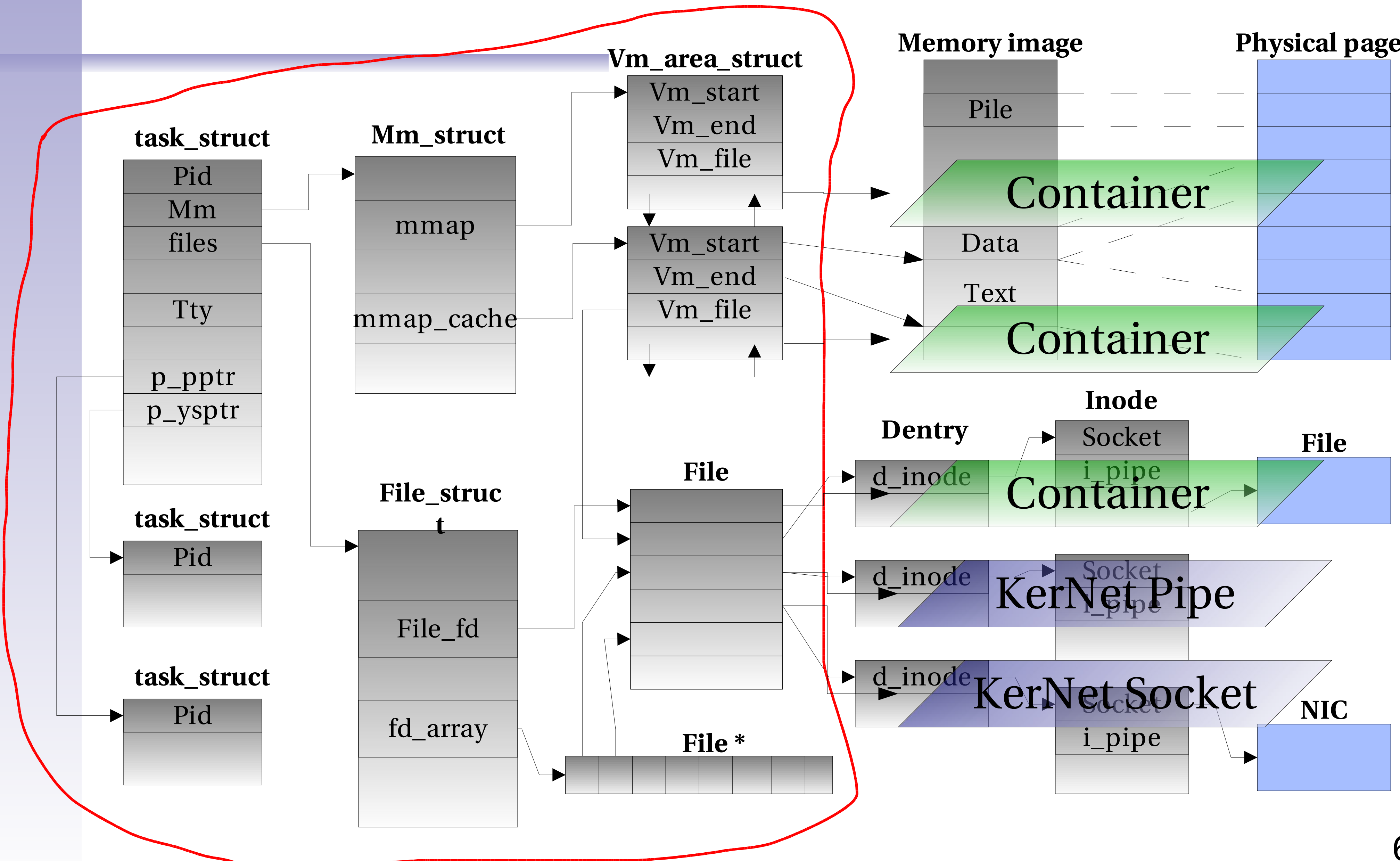



```
make_ghost_of_task_struct(
    ghost_t *ghost,
    struct task_struct *tsk)
{
 make_ghost (ghost, tsk,
      sizeof(task_struct));

 make_ghost_of_mm(ghost,
      tsk->mm);

 make_ghost_of_files (ghost,
      tsk->mm);

  ...
}
```

Migrating a task

- Ghost mechanism side effect :
  - We can migrate a pure computational sequential task !
    - Ghost device target = network
  - We can checkpoint a pure computational sequential task
    - Ghost device target = disk

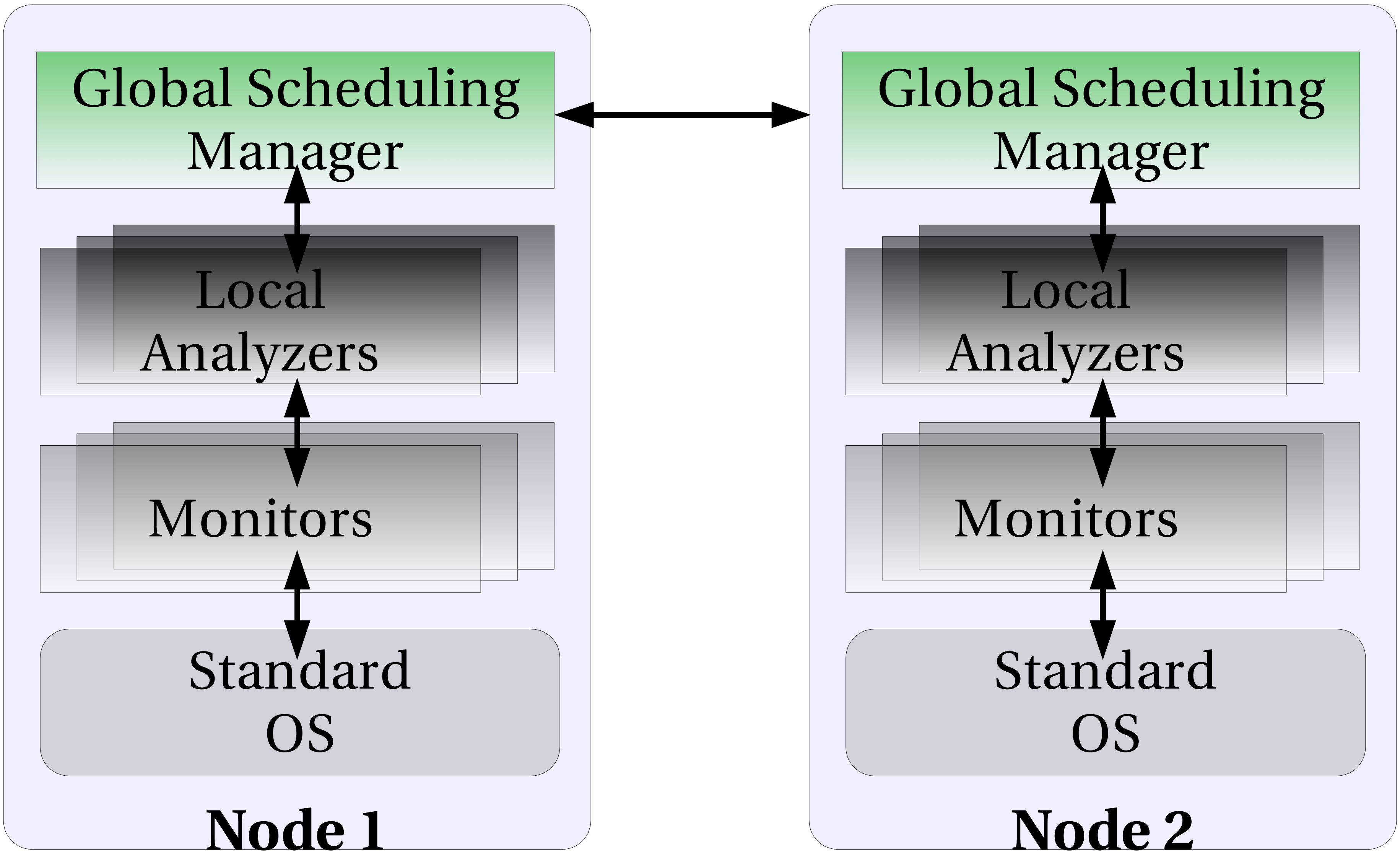
The Ghost Frontier



Configurable Global Scheduler : Design Goals

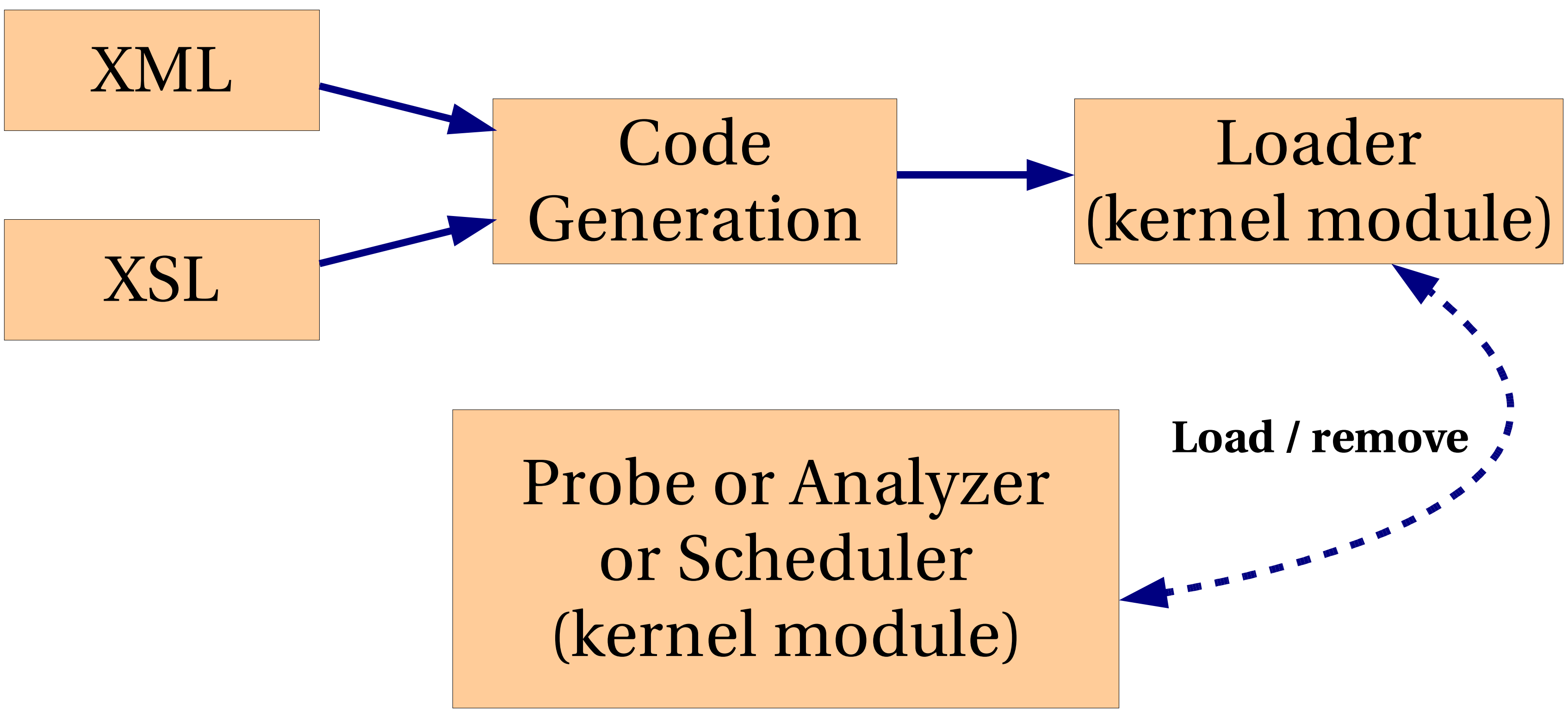
- It should be possible to implement any traditional placement or load balancing policy
  - Development and integration of global policies should be easy
    - Development environment
    - Modular architecture
  - Dynamic configuration of the global scheduler
  - Adaptive global scheduler
- Efficient process management mechanism
  - Minimal modification to the OS kernel
    - No modifications to the local OS scheduler

Modular Global Scheduler

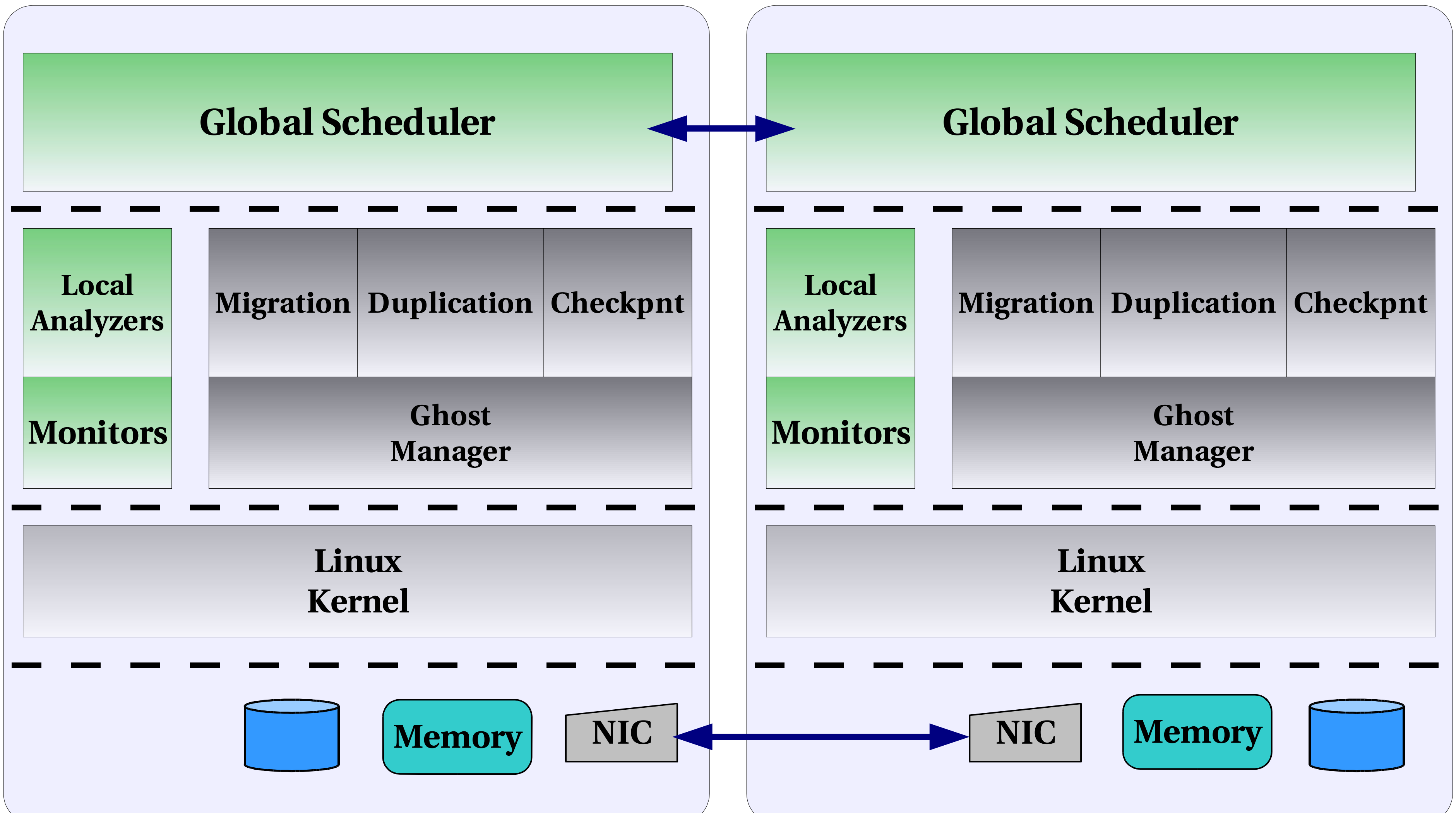


Configuration

- All components are configured with XML files
- All components can be hot-loaded and hot-removed



Process Management Big Picture



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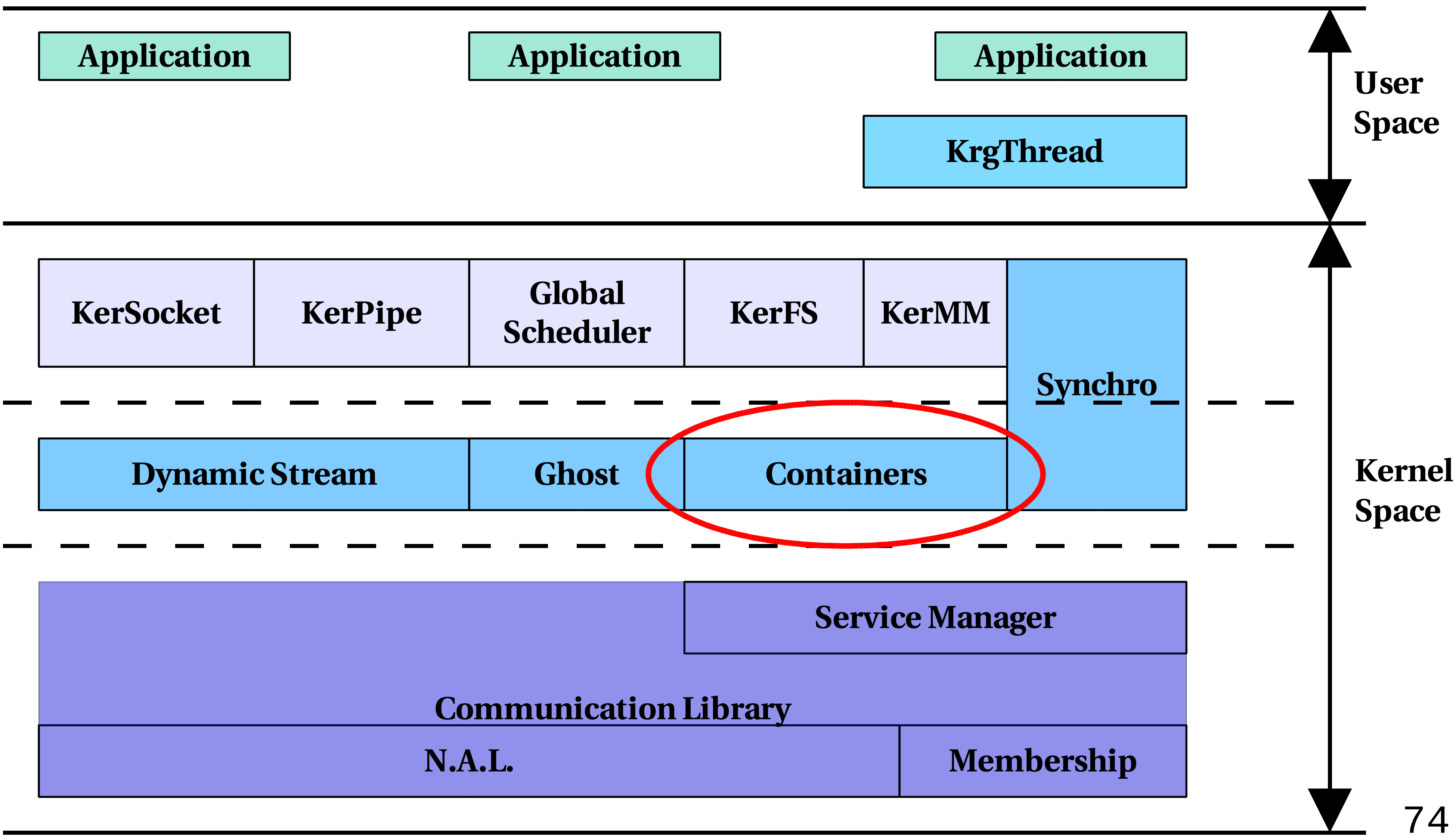


Definition of container

- 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

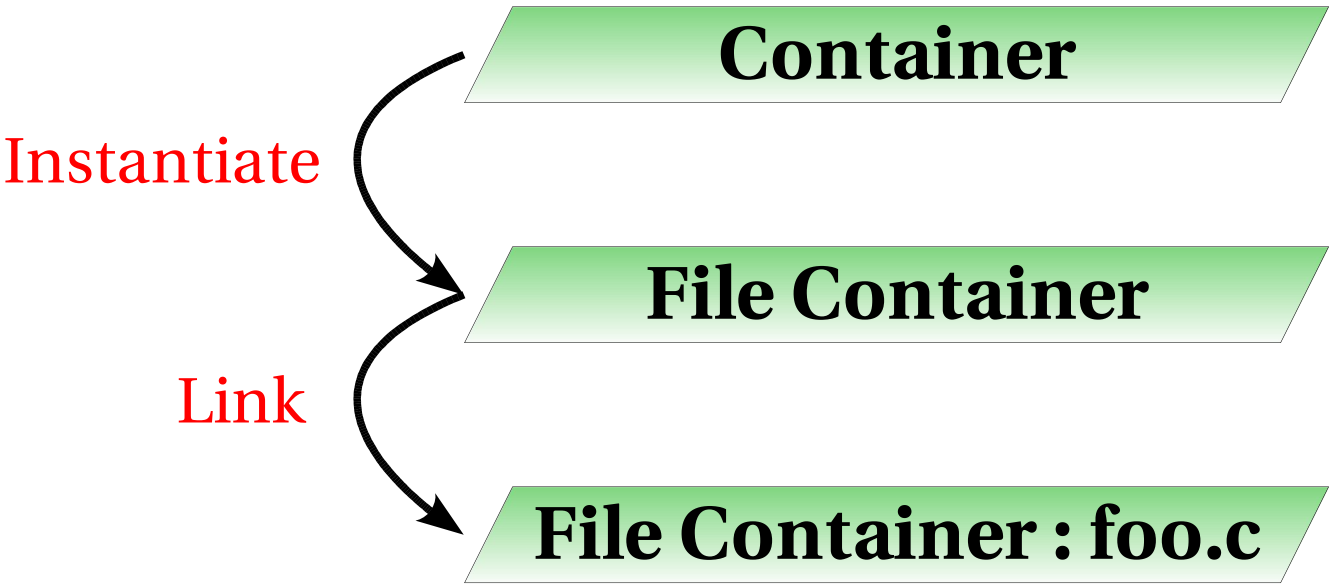
- Data hosting and sharing
  - A container hosts a set of **objects**
  - Objects : memory pages, data structure
  - Unit of sharing : 1 object
  - Node local memory = **cache** of container objects
- Object coherence management
  - **MESI**-like coherence algorithm
    - Single writer / multiple reader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

Container Instantiation : IO Linkers

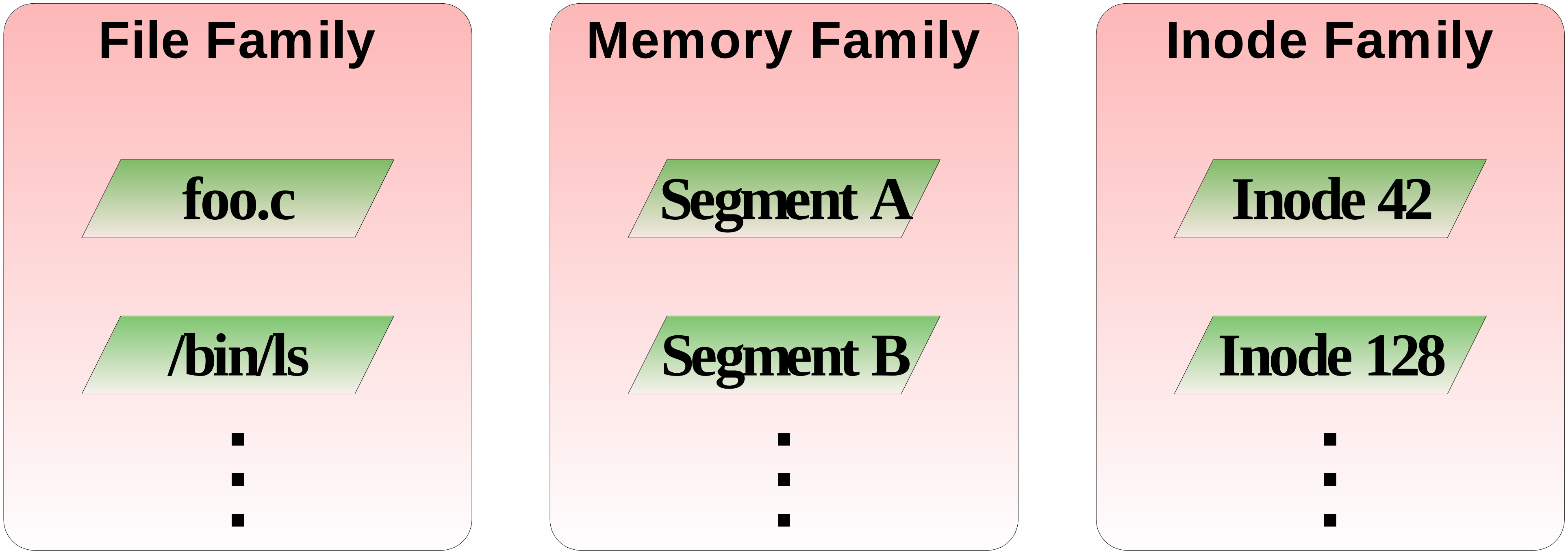
- Container : **generic** mechanism
  - Can host any kind of object
- Containers instantiated by **IO linkers**
  - Determine the nature (**family**) of hosted object
  - Define object input/output functions
  - One kind of IO linker per kind of object to share
    - Memory pages
    - File cache pages
    - Inodes
    - ...

Container Linked Object

- 1 container + 1 file linker = 1 file container
- One container per object to share
  - The object to share has to be **linked** to the container



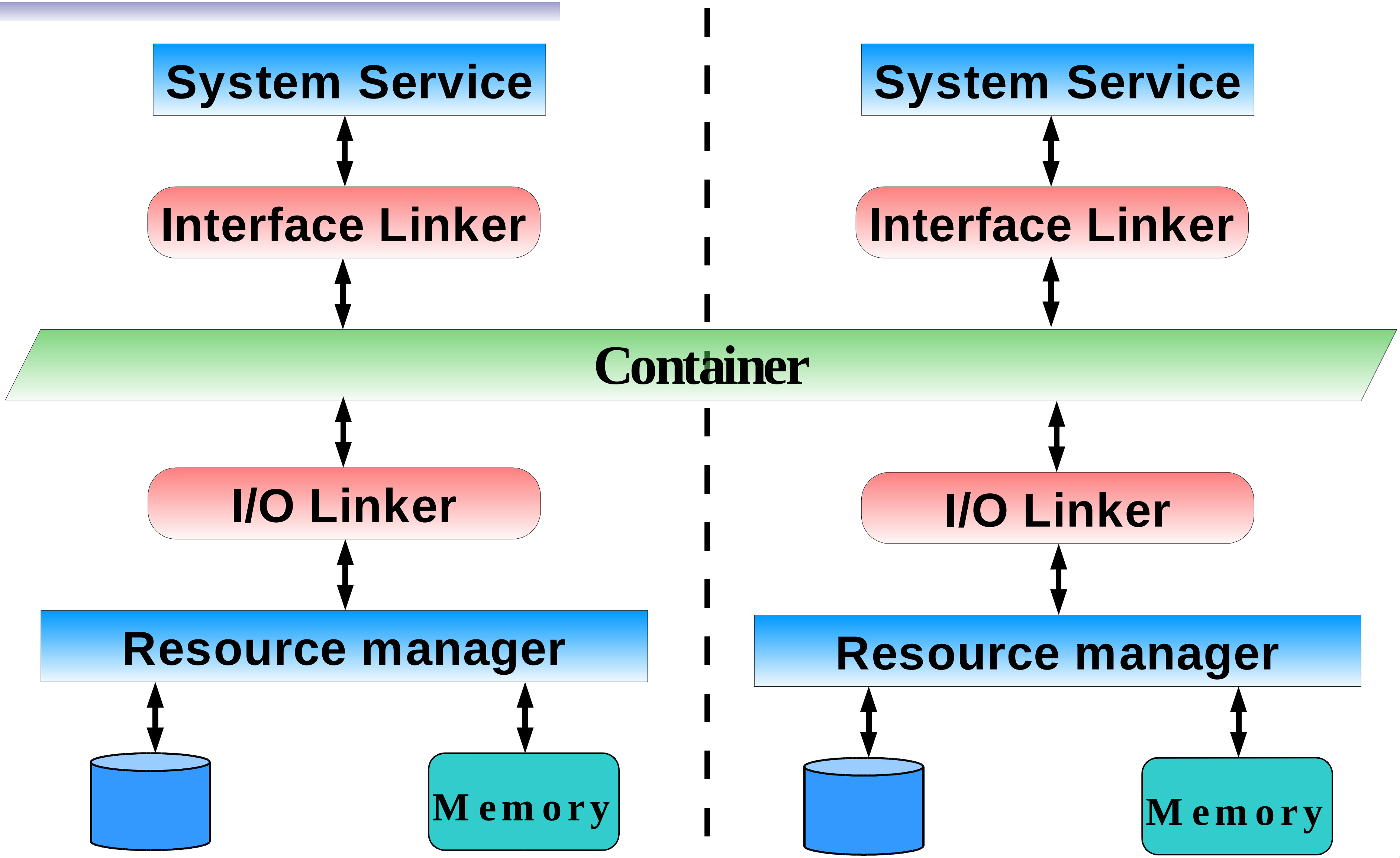
Container Families



Container Linked Node

- A container can be linked to a given device
  - Disks
- Linked containers
  - Container data are stored on device(s) located on specific node(s)
  - First access to a data is sent to the linked node(s)
- Not linked container
  - Data are not linked to a specific node
  - First access to a data can be done locally

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

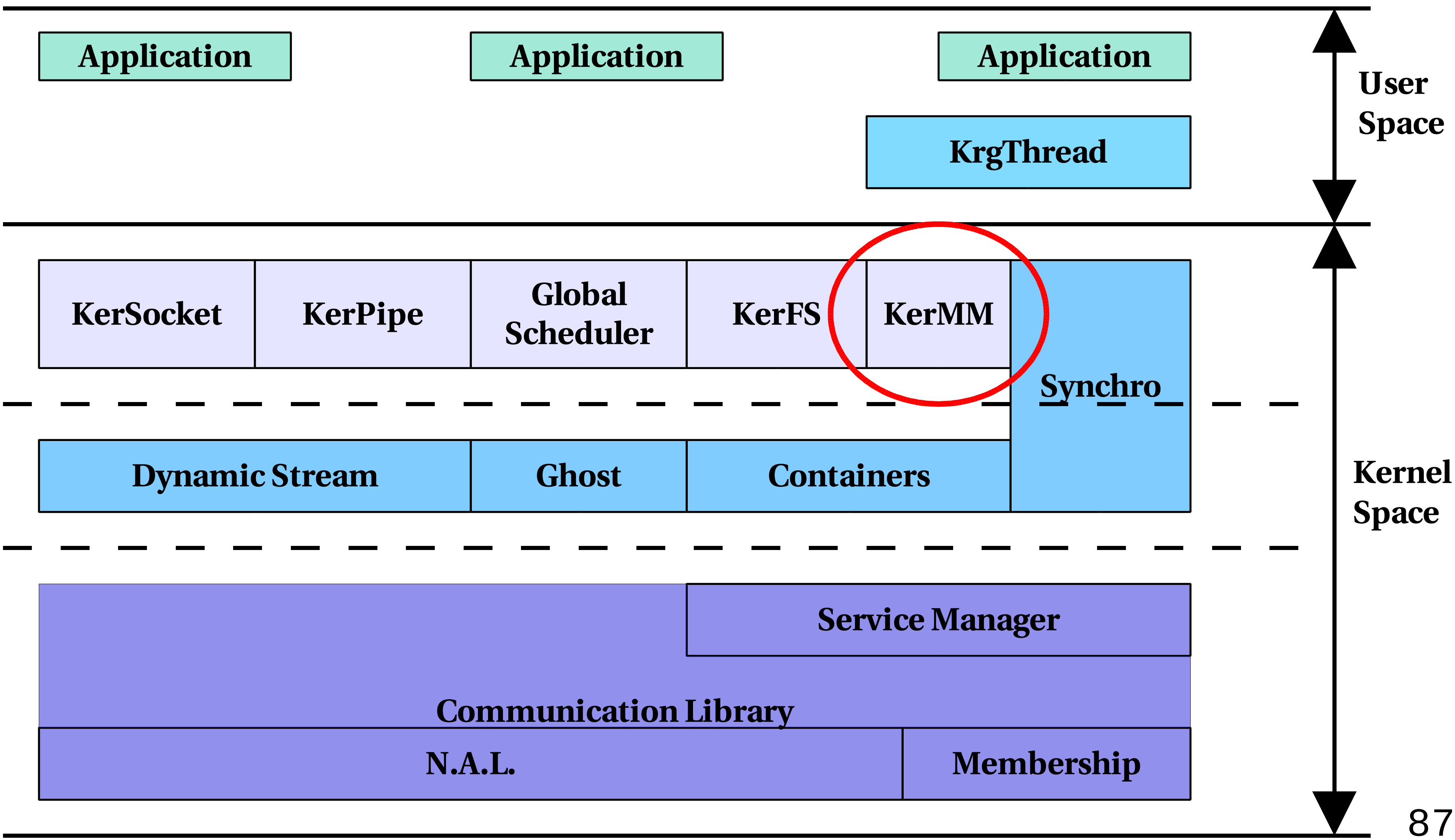
Container use in Kerrighed

- 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
  - Open files pointer sharing

Outline

- Kerrighed Overview
  - What is Kerrighed ?
  - What about other system ?
  - Performance Evaluation
- Kerrighed Internal
  - Introduction
  - Ghosts
  - Containers
  - KerMM
- Conclusion

Global View of the Kerrighed Software Architecture



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 ;
```

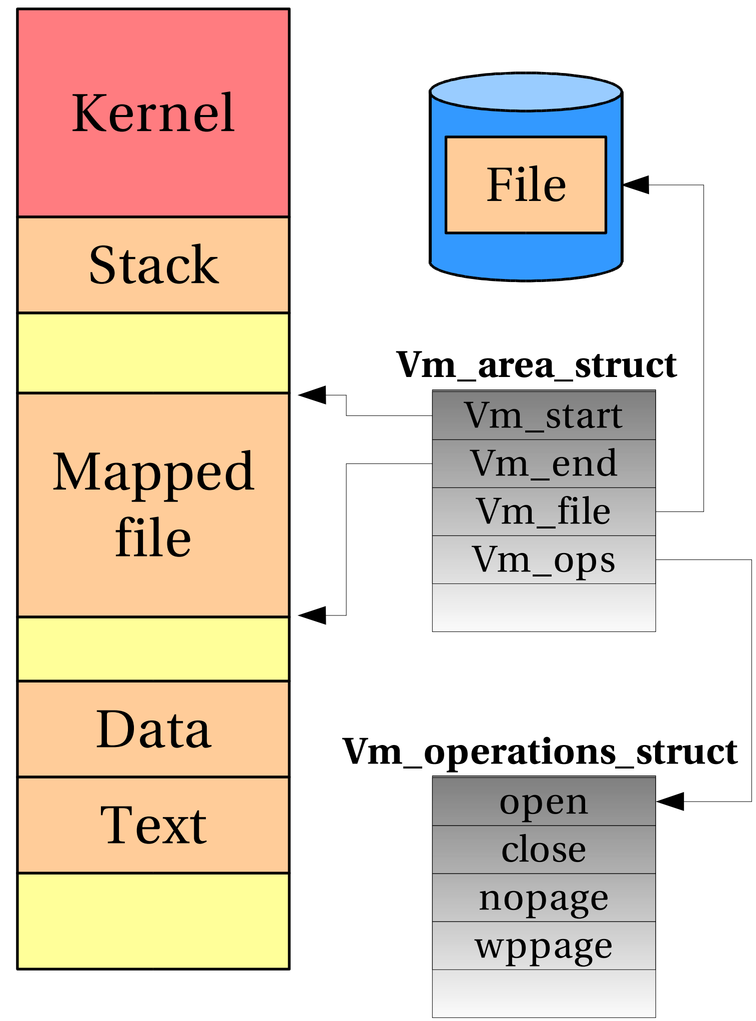
```
Flush_Page ( p )
  NOP ;
```

Memory Interface Linker

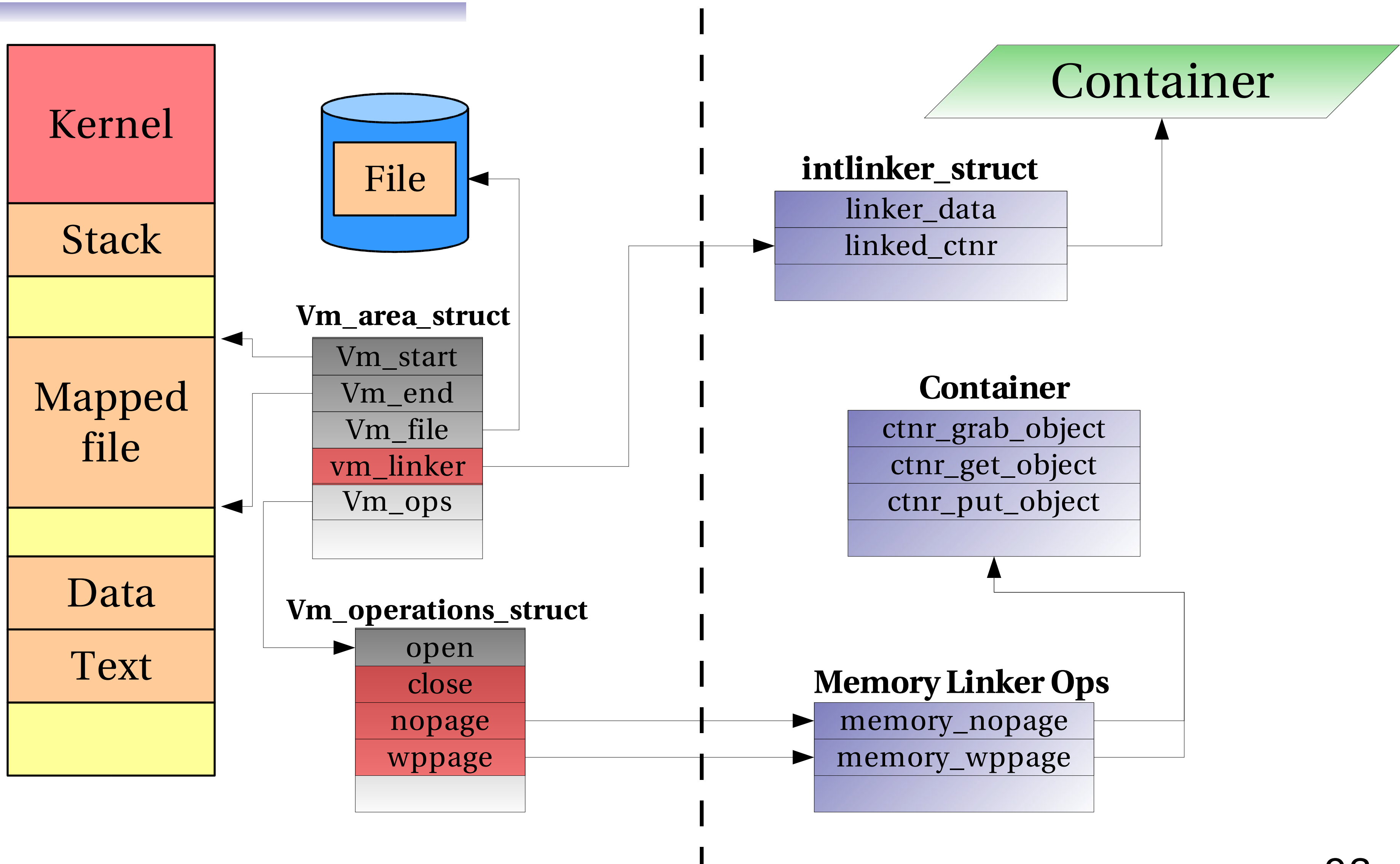
- Goals
  - Link a memory segment to a container
  - Divert page faults to the linked container
- Done at the Virtual Memory Area (VMA) level

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)

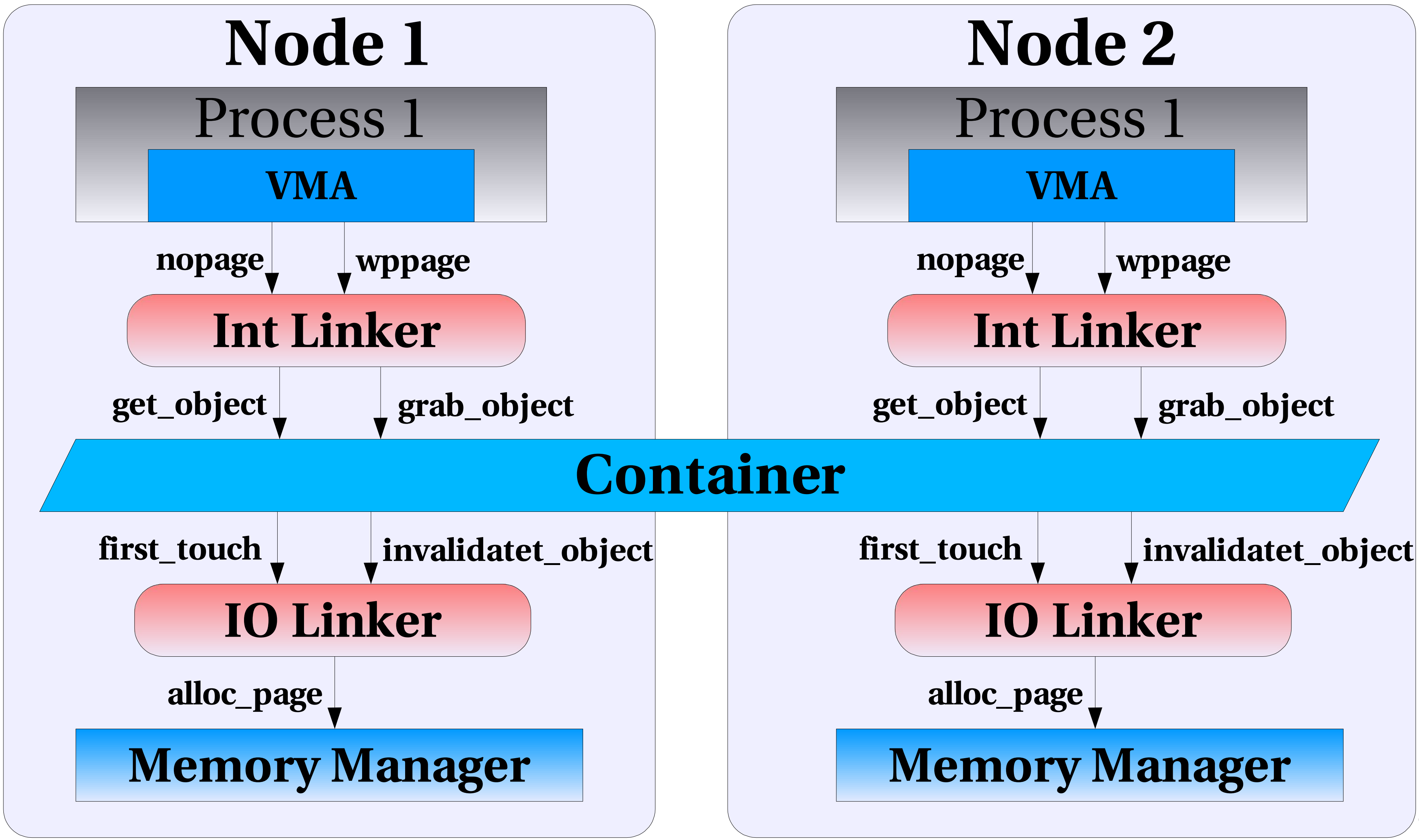


Memory Interface Linker (4)

```
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 ;
```

Memory Linkers Summary



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Kerrighed Code Size

Process Management	20 000
KerFS	9 500
KerMM	3 000
Container	10 000
Synchro	11 000
KerPipe / KerSocket	8 000
Dynamic Streams	3 500
Comm lib	9 000
N.A.L.	4 000
Service Manager / Ghost	7 000
Total	**85 000**

Kerrighed People

- **Project head**
  - Christine Morin
- **Research Engineers**
  - Pascal Gallard
  - Renaud Lottiaux
- **Post-Doc**
  - Geoffroy Vallée
- **Faculty**
  - Thierry Garcia
- **Ph.D. Students**
  - Emmanuel Jeanvoine
  - Louis Rilling
- **Interns**
  - Boris Daix
  - Matthieu Fertré

www.kerrighed.org