OS for HPC in Exascale Era

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Content

- OS for HPC
- Lightweight kernel
- Full-weight kernel
- Multi-kernel
- Our attempt

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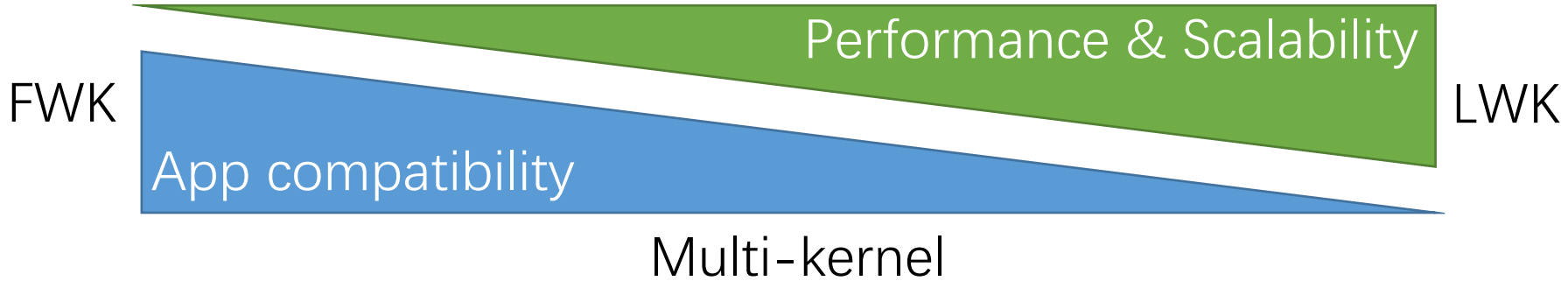
OS for HPC

- Two goals:
  - Performance
  - Application compatibility
- Performance
  - Deliver the maximum capability of the hardware
  - Requires thin OS or lightweight OS
- Application compatibility
  - To provide Linux environment most application assume
  - Requires full-weight OS

OS for HPC

- Trends:
  - LWK -> FWK, add Linux environment or API to LWK
  - FWK -> LWK, strip Linux to be lightweight
  - LWK & FWK, multi-kernel on the same node, aiming to achieve the two contradictory goals



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LWK's origin

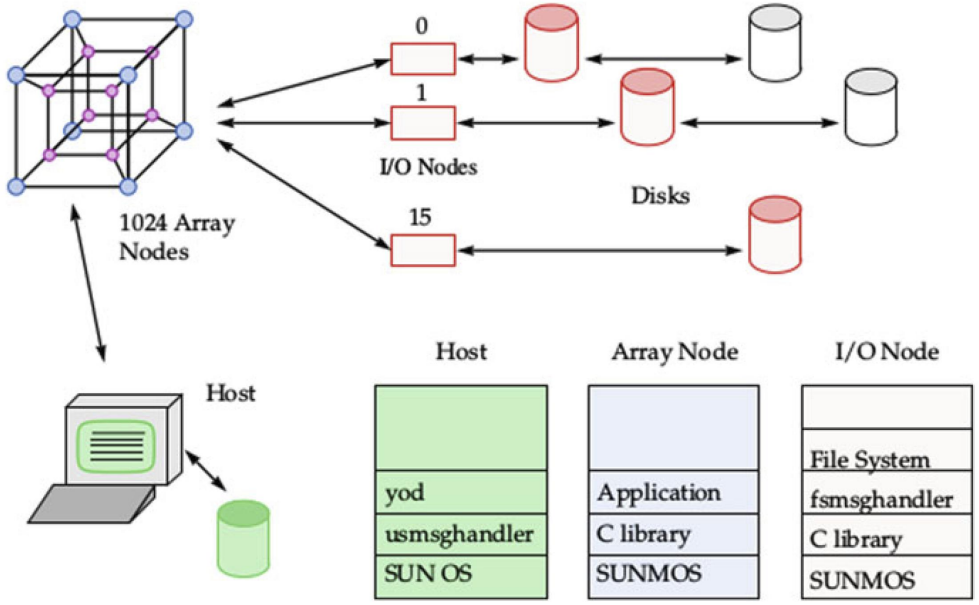
- Early days
  - Vector machine, MPP
    - Highly specialized chips and architecture, rare commodity hardware
  - Apps are highly coupled with hardware system
    - Highly involved in hardware management
  - Narrow range of app
    - Scientific computing
  - Small memory on compute node

LWK's philosophy

- Highly customized OS
  - Minimal features
    - Low OS noise, highly scalable
    - Emphasize efficiency over functionality
  - Thin hardware management and abstraction layer
    - User-managed
  - Small memory footprint
  - High message-passing performance

SUNMOS (1991)

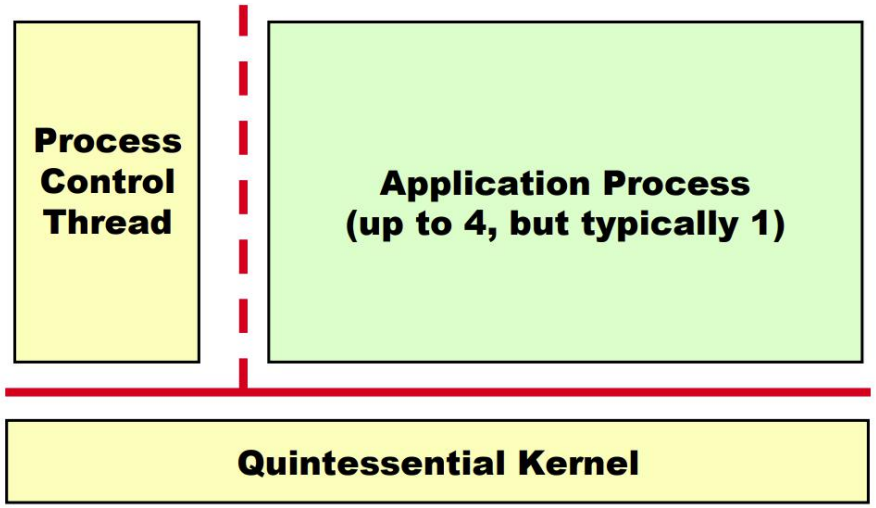
- For Intel Paragon (1993), much like an app launcher
- Single tasking
  - Application manages all the resources
- Small memory footprint
  - Only 16MB on compute node, SUNMOS occupies 250k

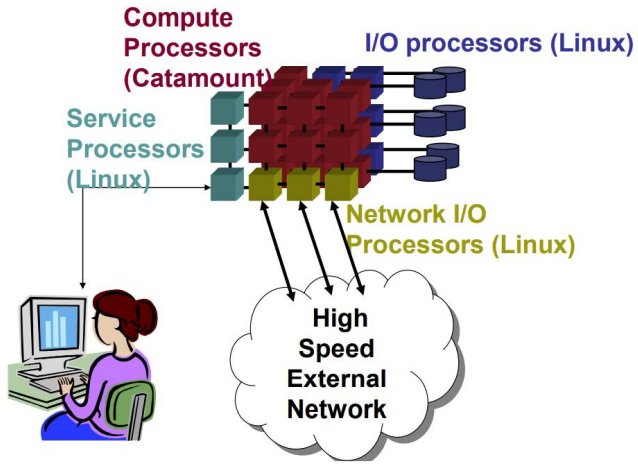


Intel Paragon

Catamount (2004)

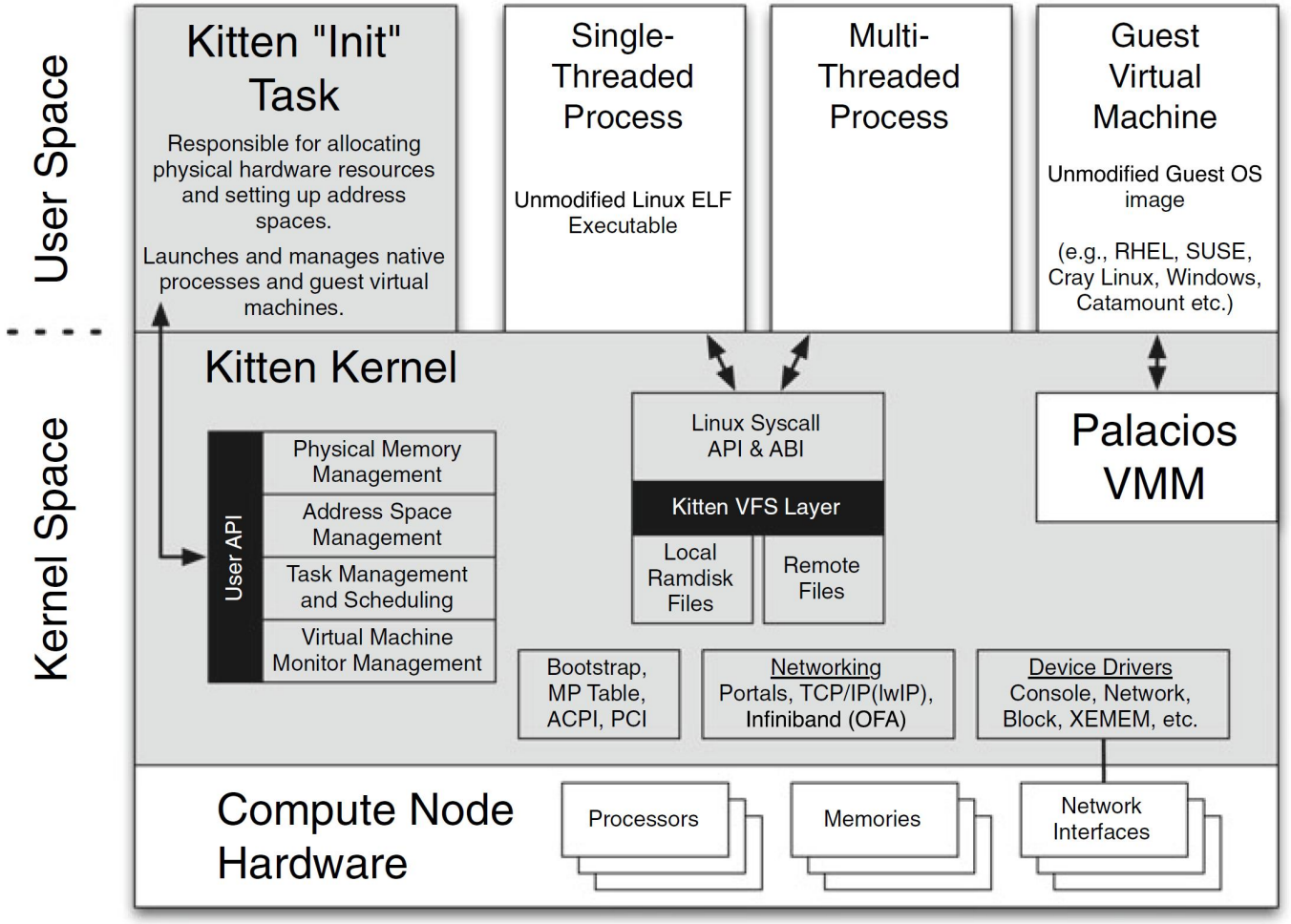
- SUNMOS for Intel's Paragon -> Puma -> Cougar for ASCI Red -> Catamount for Cray's XT3/4 (2004)
- Move as much functionalities out to user-space(PCT) as possible
  - Policy part in PCT and mechanism part in QK
    - Memory and process management
    - Job queueing
    - May have several different PCTs
- Compute nodes only focus on high performance computing
  - Relies on service nodes (running Linux) to provide wide functionalities





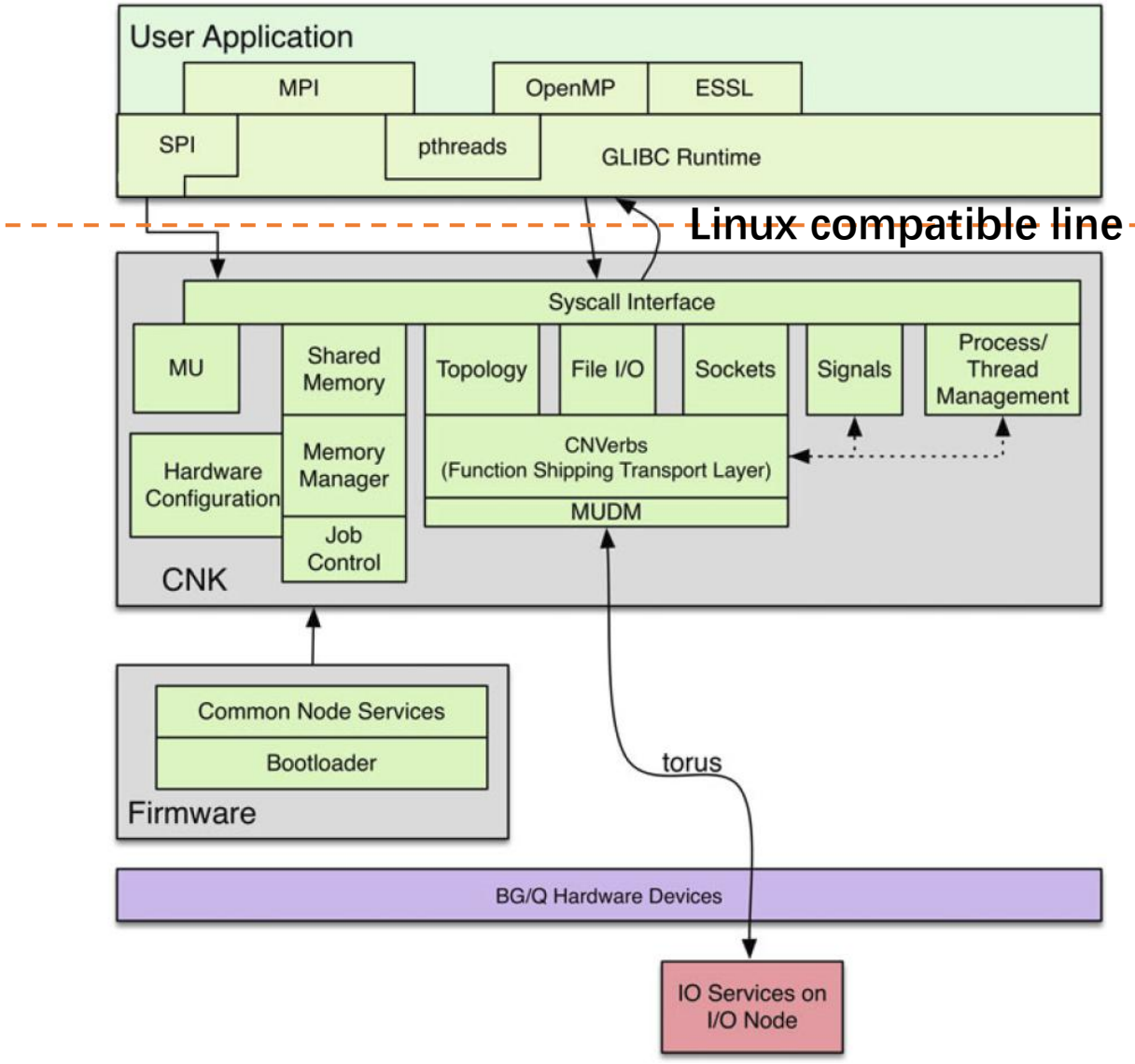
Kitten (1999)

- LWK + VMM hypervisor
- Linux env is provided by guest OS over hypervisor
- Kernel/init are like QT/PCT in Catamount
- Based on Linux code
  - Performance critical part rewritten memory management, task management, virtual memory management
- Linux ABI and syscall compatible
- Like Linux striping way



Compute Node Kernel (CNK) (2004)

- For Blue Gene/L, Blue Gene/P, Blue Gene/Q
- Provide Linux-like environment while keep LWK advantages
  - Libc and syscall level
- IO/service proxy
  - Delegated to IO/service nodes
- Performance critical
  - Non-preemptive scheduler
  - Static TLB mapping
  - Big memory allocation



LWK Focuses on performance

- Design space:
  - HPC is more for space-sharing rather than time-sharing
- Process schedule
  - Non-preemptive
    - Pros: low noise, high scalability – good for HPC
    - Cons: limit different combination of threads, overcommit of threads – do not care
- Memory management、Simple memory mapping
  - Large page
    - Pros: less TLB/cache miss – good for HPC
    - Cons: more memory waste – do not care

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Full-weight Kernel

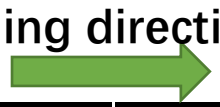
- Commodity clusters over MPP
- Linux dominated
  - Commodity clusters and hardware
  - Applications need Linux environment
- Various Commodity hardware is driven by Linux
  - A burden work for HPC world to adapt their OS to
- Application developers assume Linux environment
  - Various code base and support
  - Out-of-the-box running
- Tuning Linux to achieve high performance and scalability

95% Top500 are Linux-like

Operating System	# of Systems	Percentage
Linux	456	91.20%
Unix	22	4.40%
Windows	6	1.20%
BSD Based	1	0.20%
Mixed	15	3.00%

Full-weight Kernel

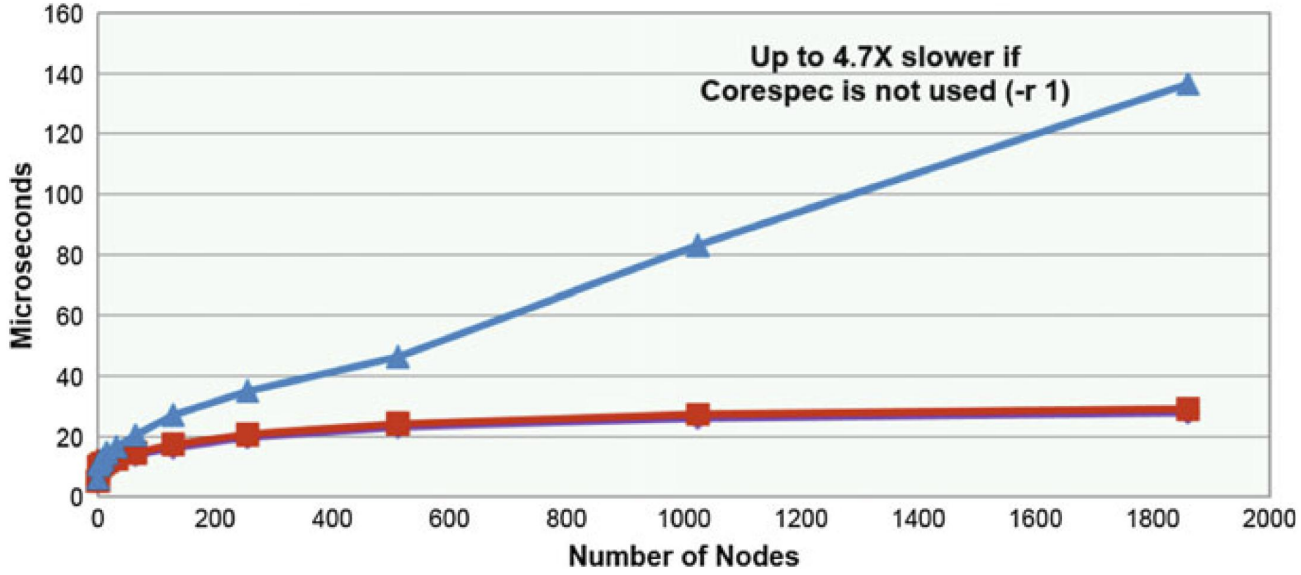
- The design choices of OSs were most often trade-offs
- Linux is designed for server market, need to be tuned to fit HPC
- Server market vs HPC



Design concerns	Server market	HPC compute node
Process Scheduling	Max overall throughput	Max single app performance
Memory management/virtual space management	Max overall usage, lazy allocation	Max single app performance
IO	Frequent Small files access	Large file access
Message passing/network	Multi-layers, multi-protocol supported	Max message passing performance Less copy
Application compatibility	Linux environment	Linux environment

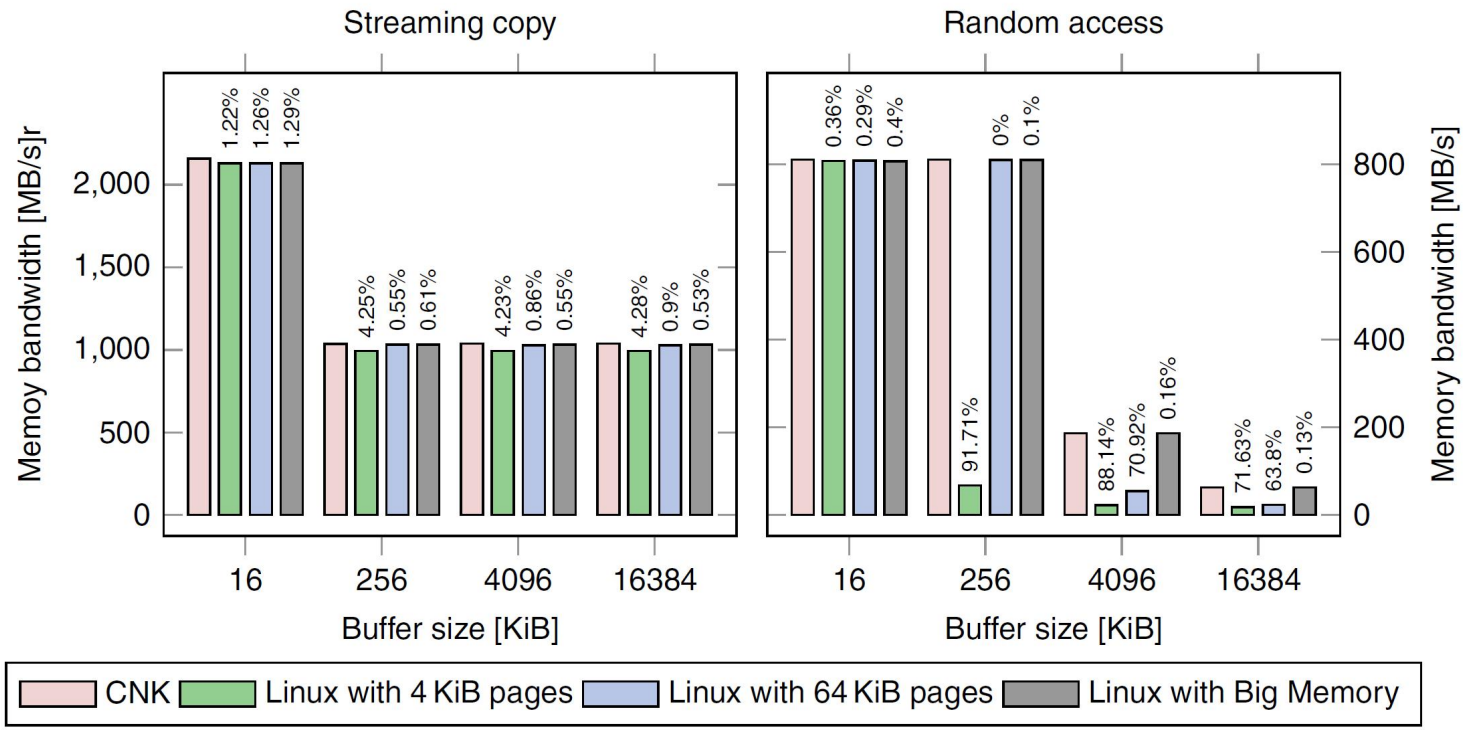
Compute Node Linux (CNL) (2005-2007)

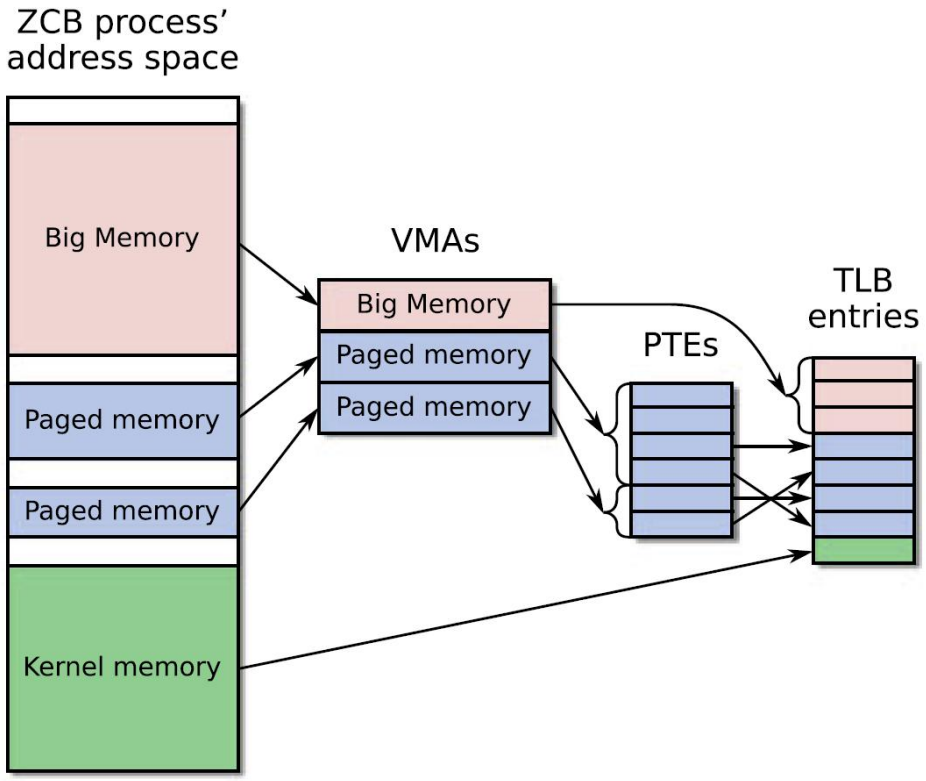
- Catamount for Cray's XT3/4 -> CNL for Cray's XT5
- Simplified scheduling, memory management, network, file system
- Large page
- Confine background kernel services and interrupt handling on some cores



ZeptoOS (2004)

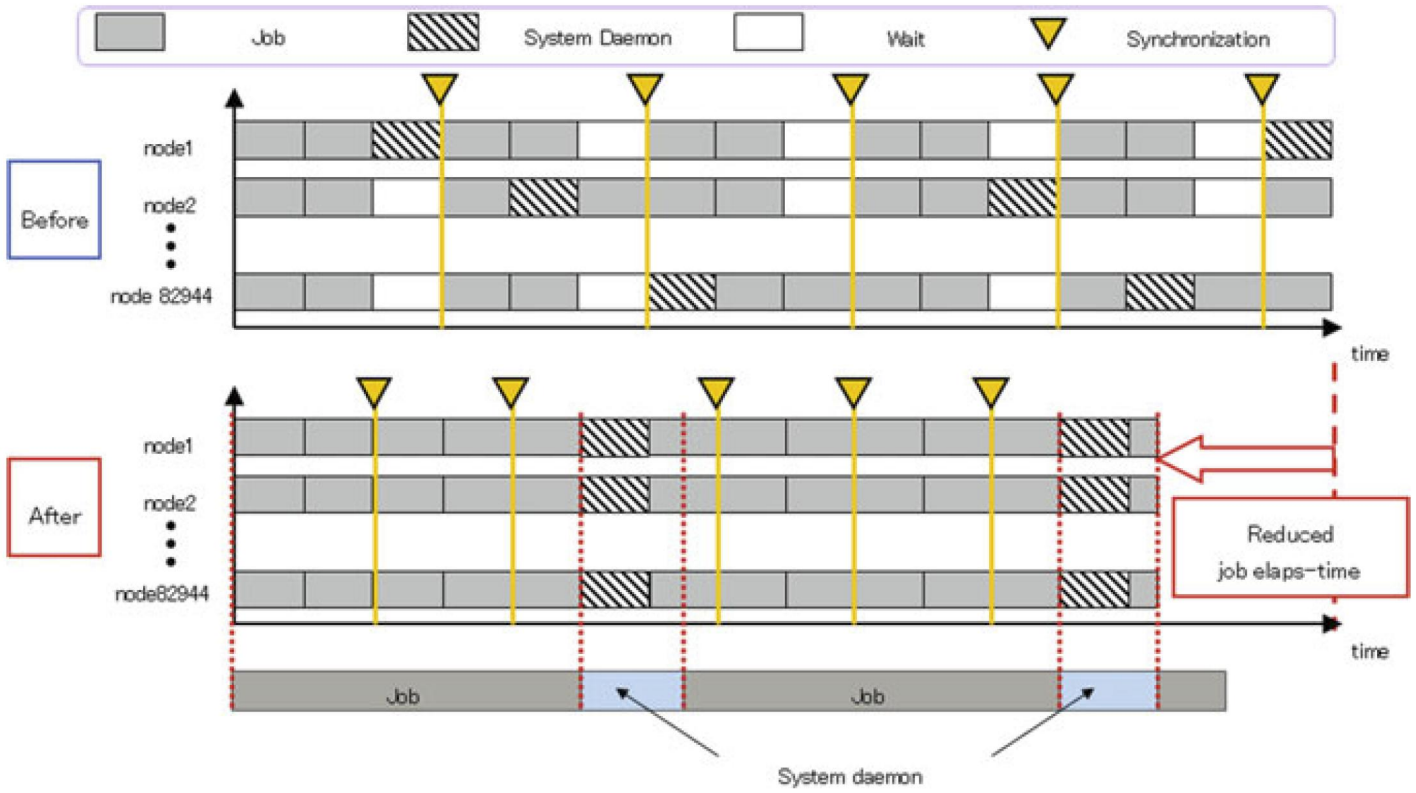
- Ported to IBM Blue Gene's compute nodes, Linux based
- Memory management: Big Memory
  - Large v-p mapping
- Linux can be performance competitive





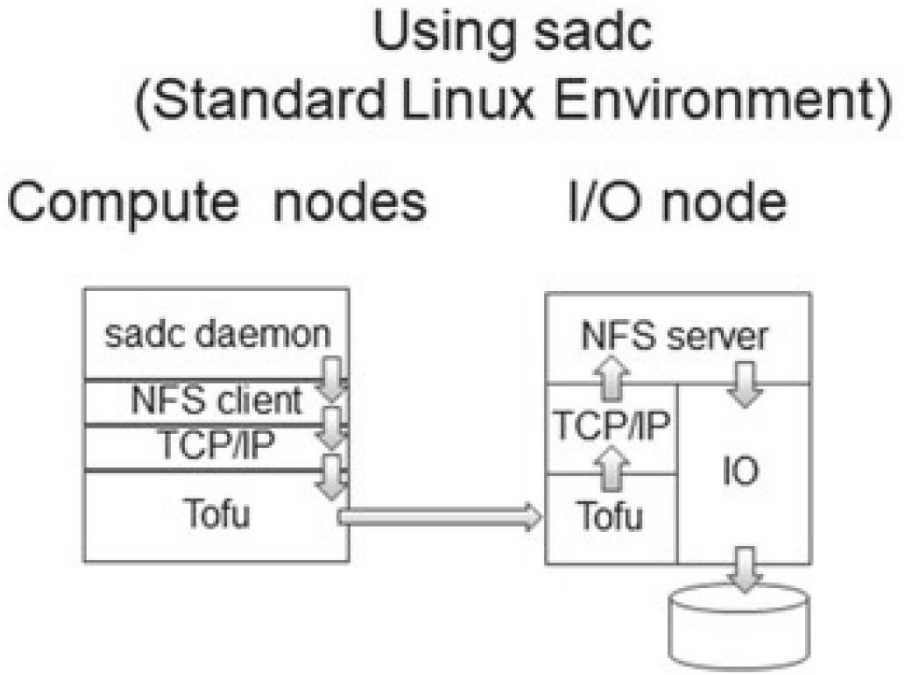
K OS (2011)

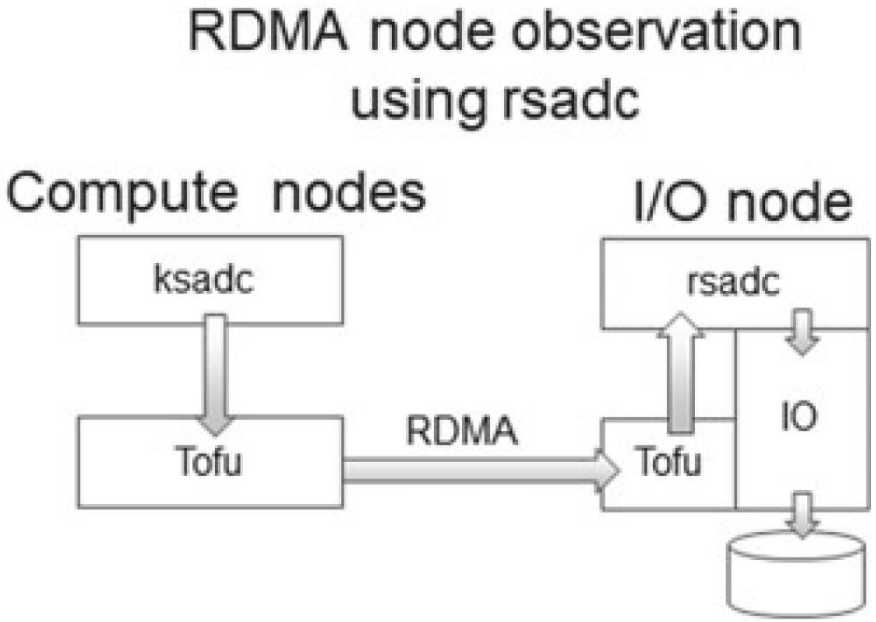
- For K
- Optimize scheduling of system Daemon



K OS (2011)

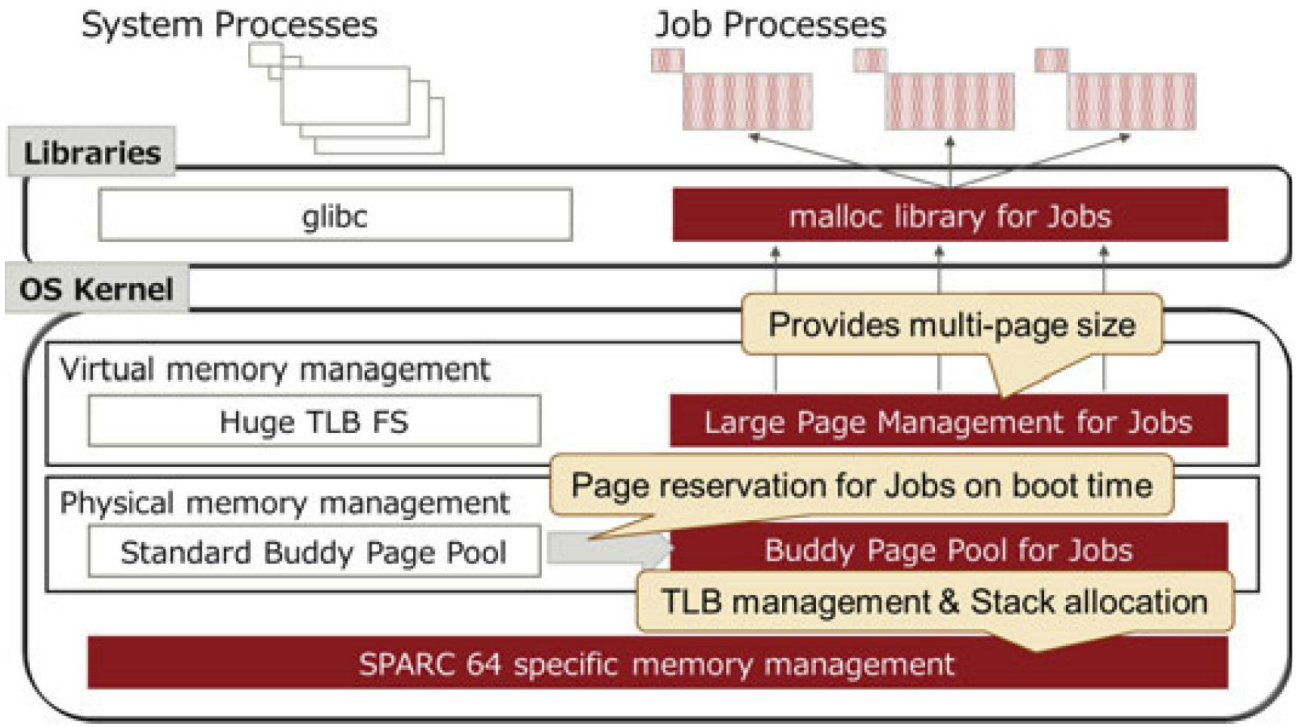
- For K
- RDMA to send data noiselessly





K OS (2011)

- For K
- Large page
  - Reserve some at boot time



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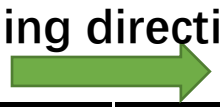

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- **Multi-kernel**
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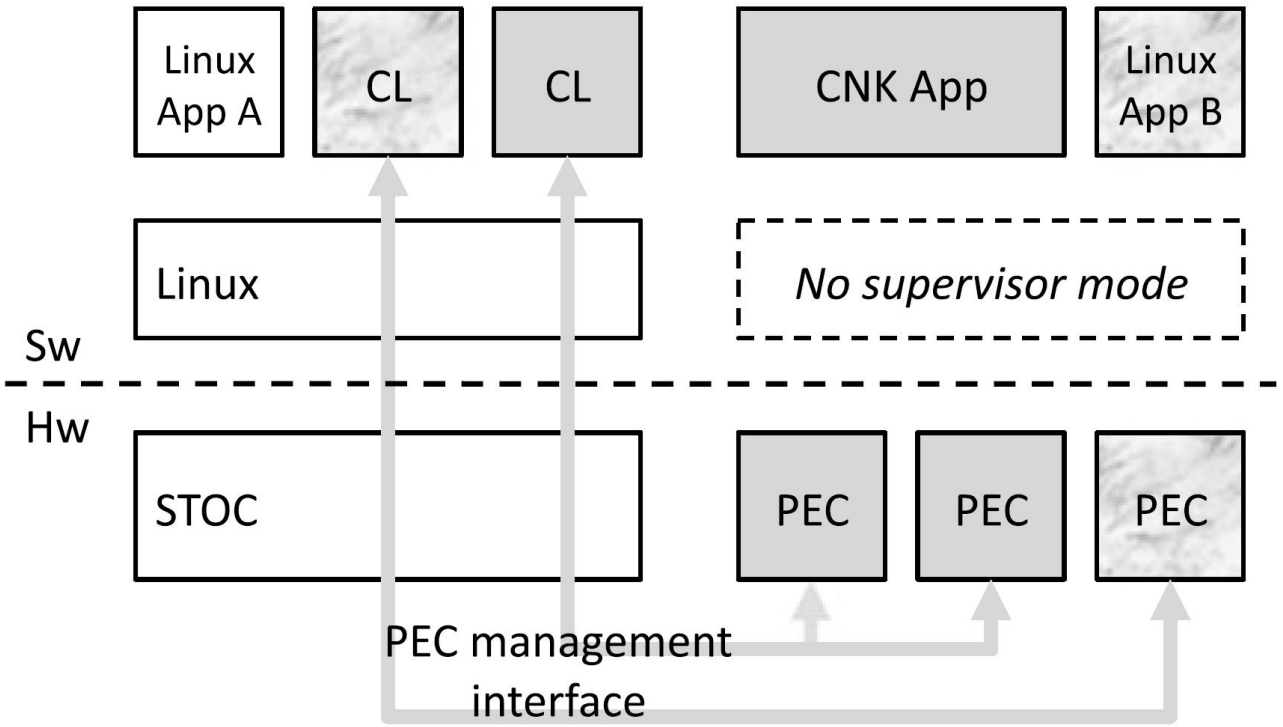
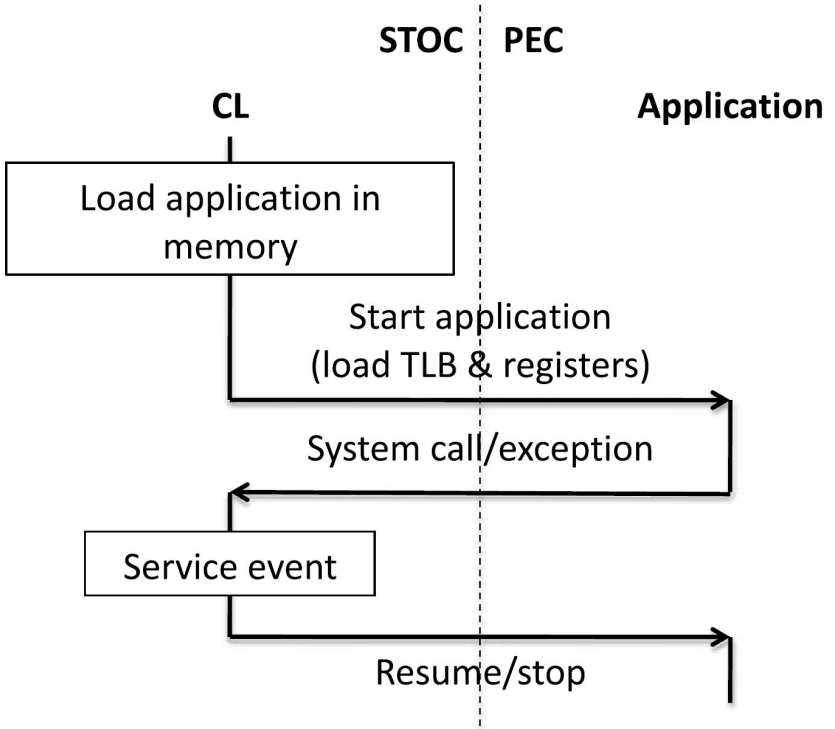
Multi-kernel

- Achieve the two contradictory goals with two kernels running on the same node
  - Performance – LWK
  - App compatibility – Linux
- Many-core and heterogeneous architecture
  - Linux on large cores for general service
  - LWK on small cores for lightweight computing

FusedOS (2011)

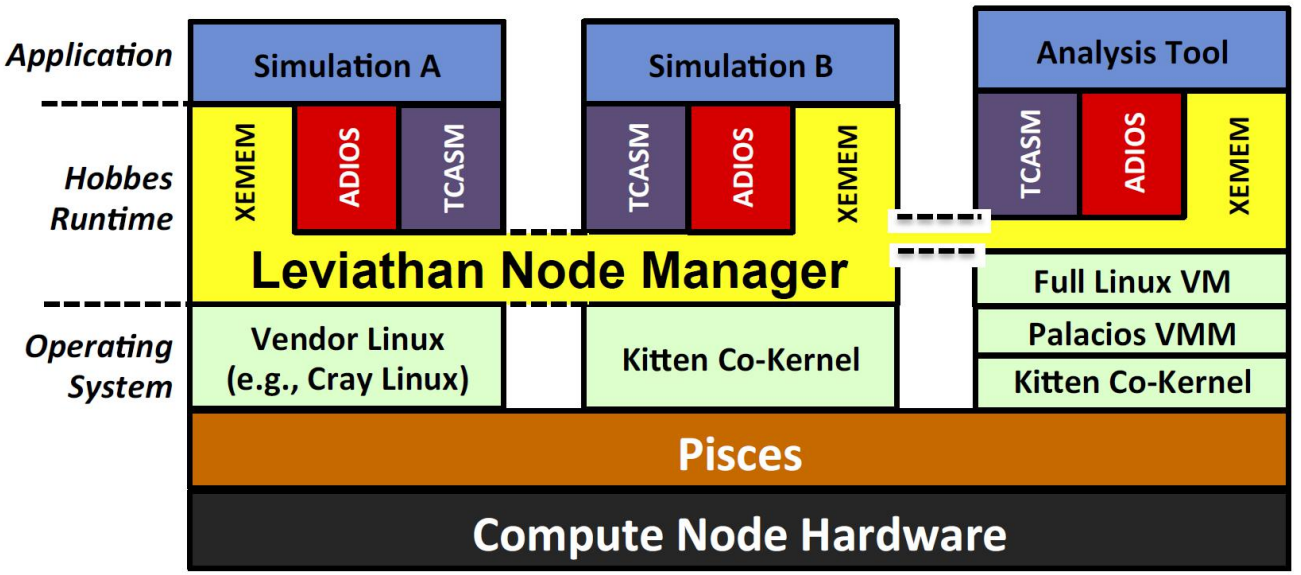
- Successor of IBM CNK
- CNK library (CL) as proxy process
  - Syscall offloaded to CL





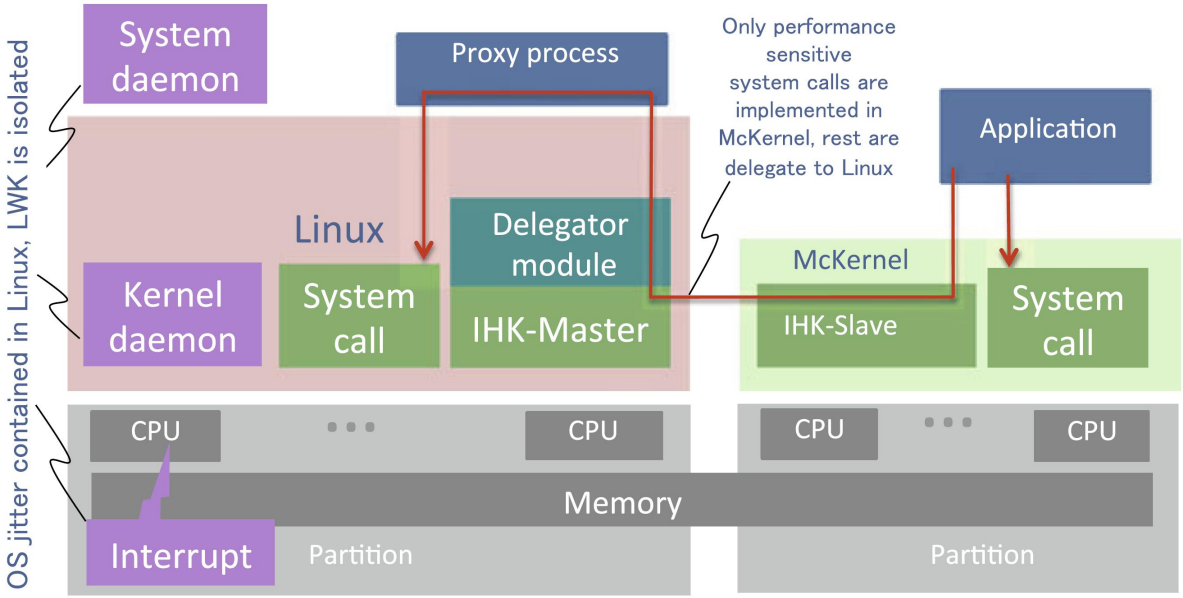
Hobbes (2013)

- Different jobs in an app calls for different environments
- Key components
  - Pisces resource management – hardware resource partitioning
  - Kitten LWK
  - Palacios VMM
- Kitten LWK + Linux over VMM
  - LWK + FWK



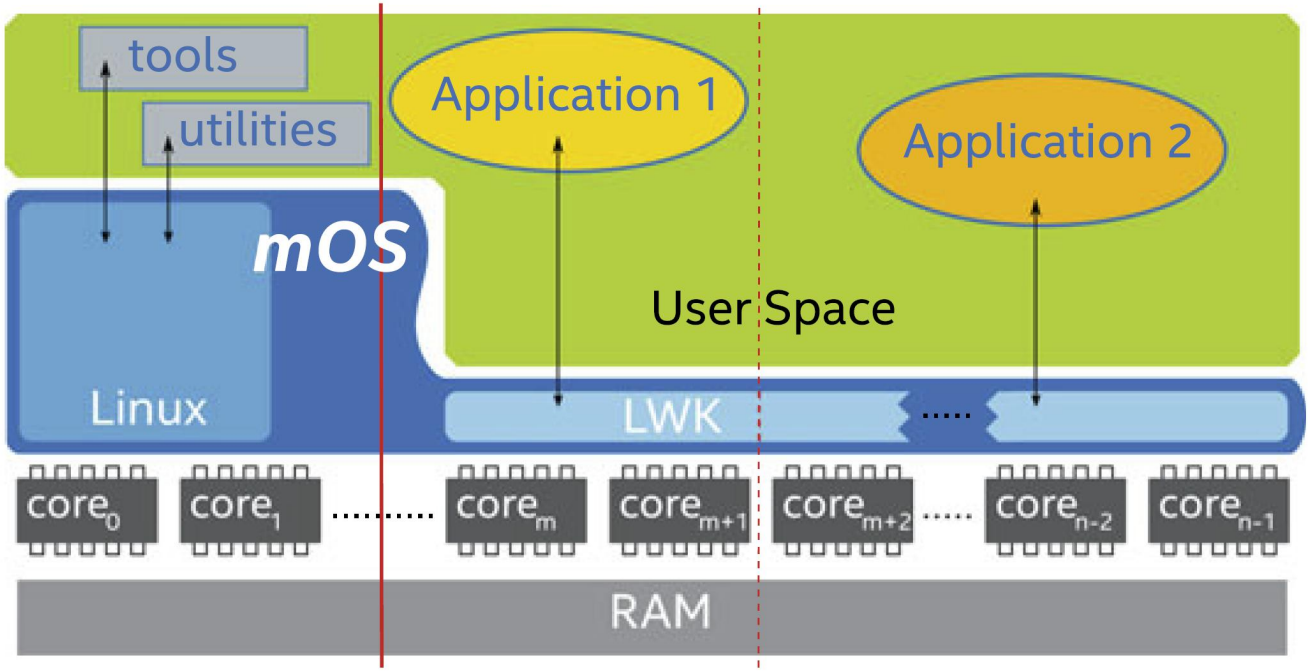
McKernel (2012)

- Manages compute node of Fugaku
- McKernel LWK implements
  - Performance critical syscall
    - Others offload to Linux
  - CPU and memory management
  - Independent of Linux, standalone code
- Interface for Heterogeneous Kernels (IHK)
  - Communication between FWK and LWK
  - Partition of resource



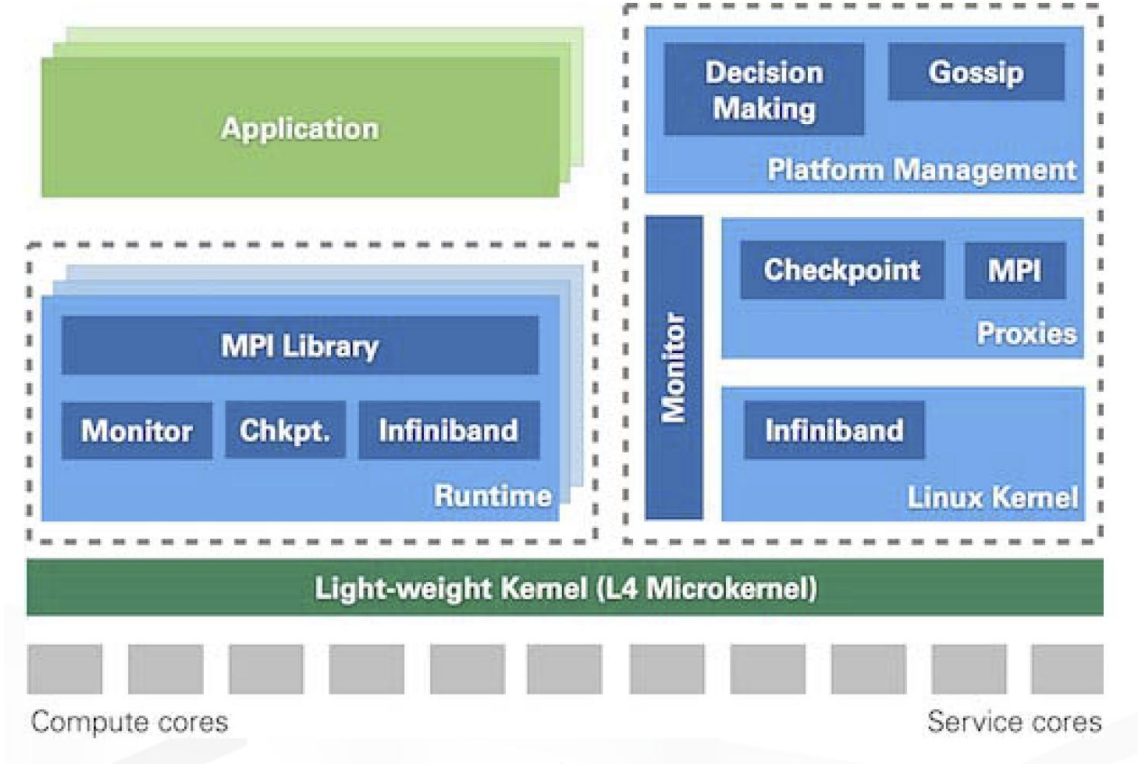
mOS (2014)

- Code integrated into Linux
  - Leverage Linux process struct
  - Leverage most Linux
- LWK implement performance critical part
  - Scheduling
  - Memory management
- Syscall delegation
  - by migrating process to FWK



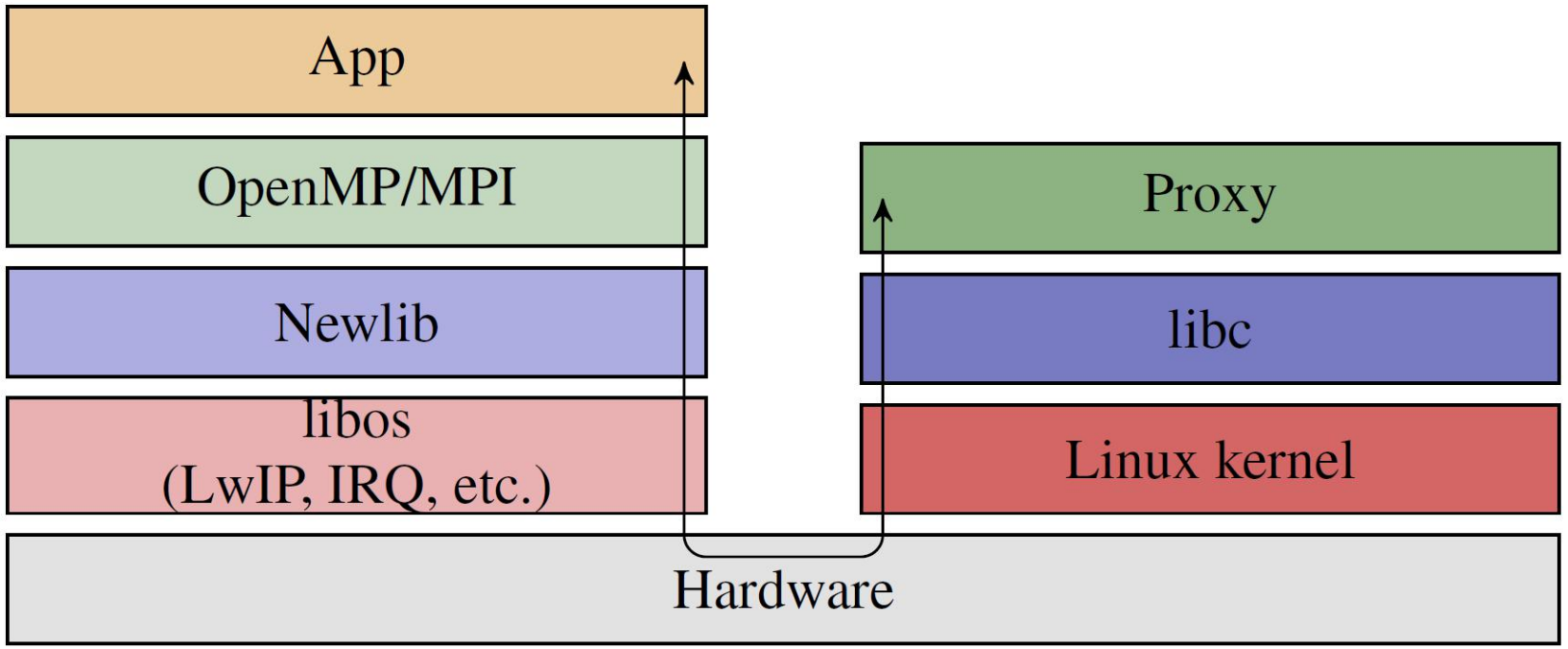
FFMK (2009)

- L4 Microkernel + l^4Linux
- LWK first manages hardware
- l^4Linux (paravirtualized) as FWK



HermitCore (2016)

- Unikernel
  - Can be run directly on bare hardware
  - Can act as LWK along with Linux



Multi-kernel

- Promising to achieve high performance and app compatibility
  - By partitioning resource and designs to cater to different needs
  - What about FWK + several LWK
    - many kernels
    - To cater to different needs

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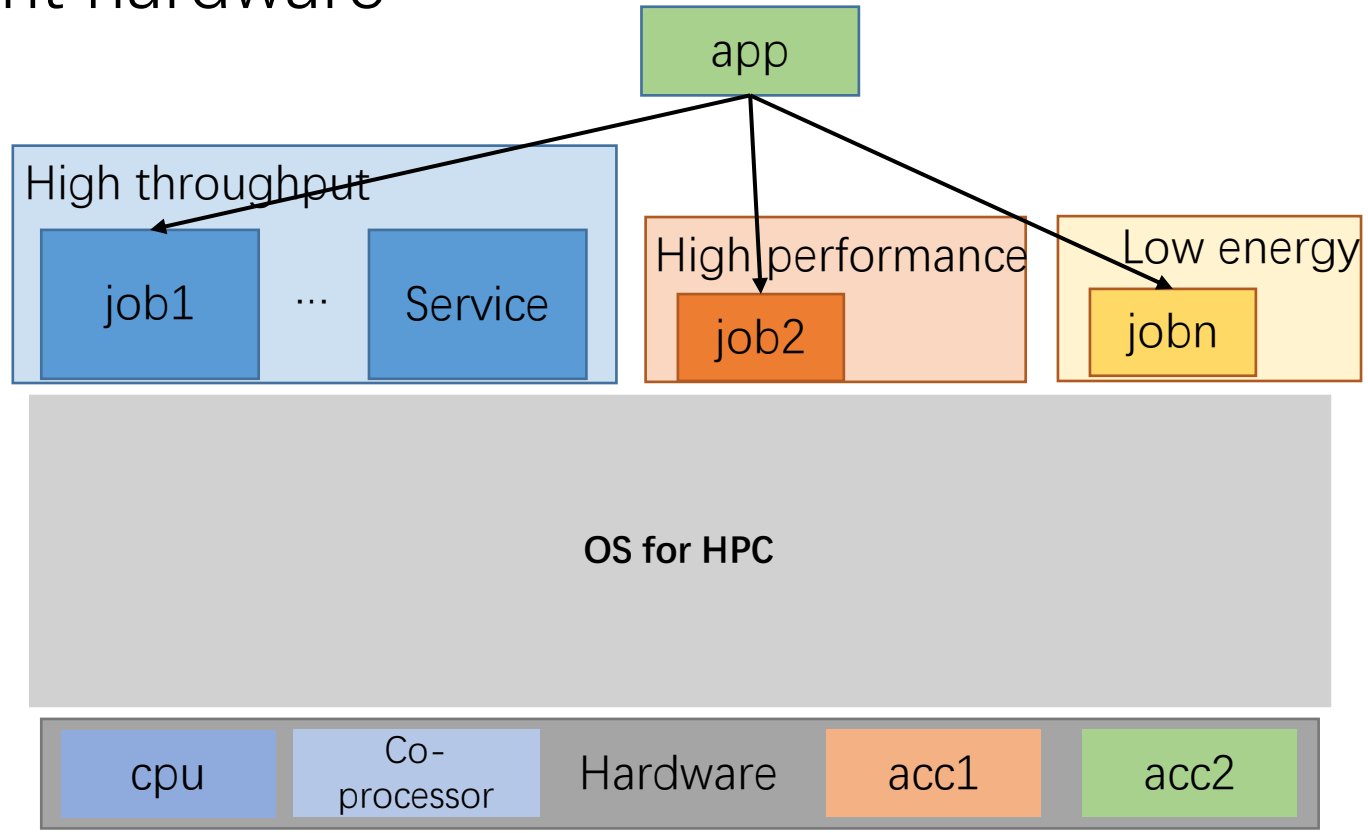
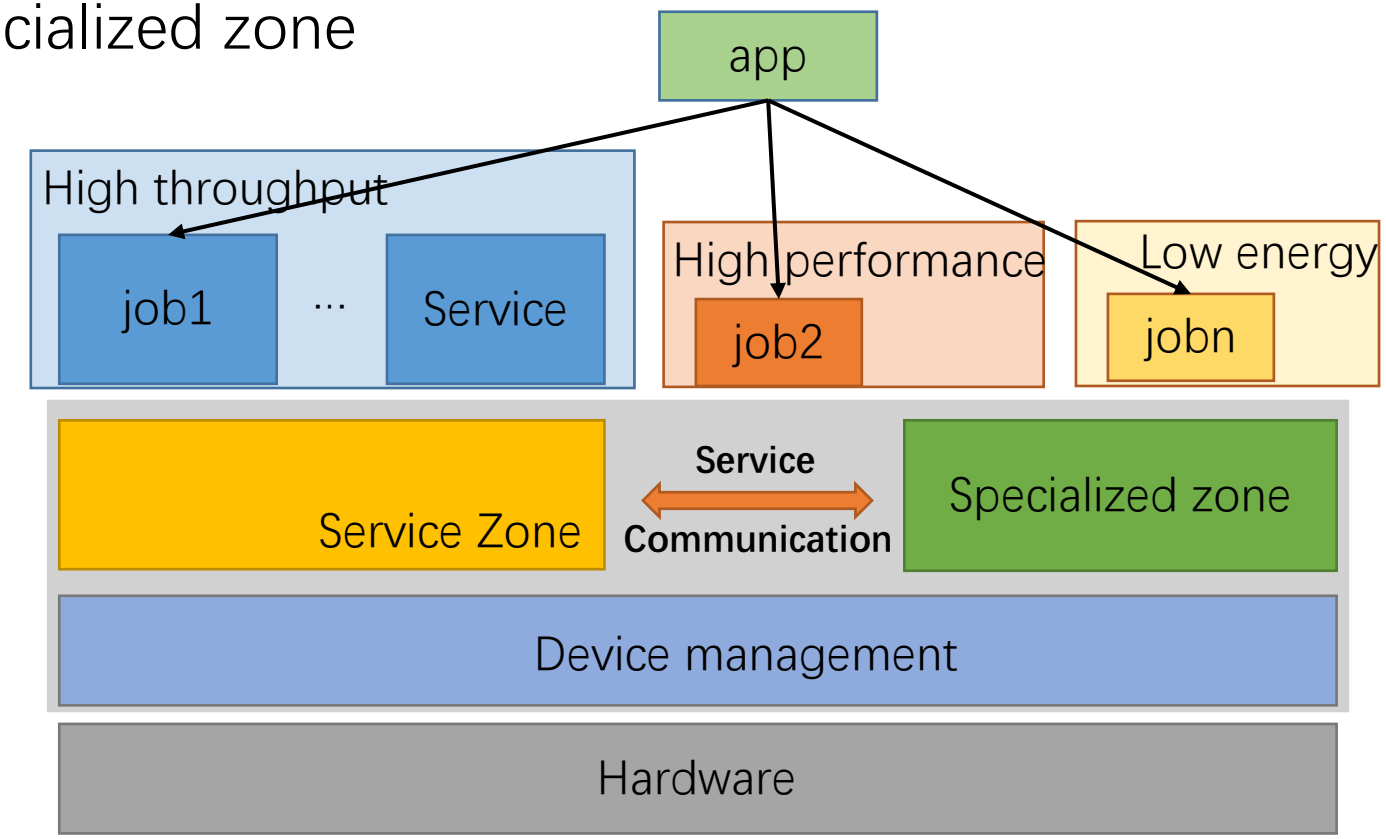
Our attempt

- We are facing unprecedented diversity in new era
- Different application needs
- Different hardware



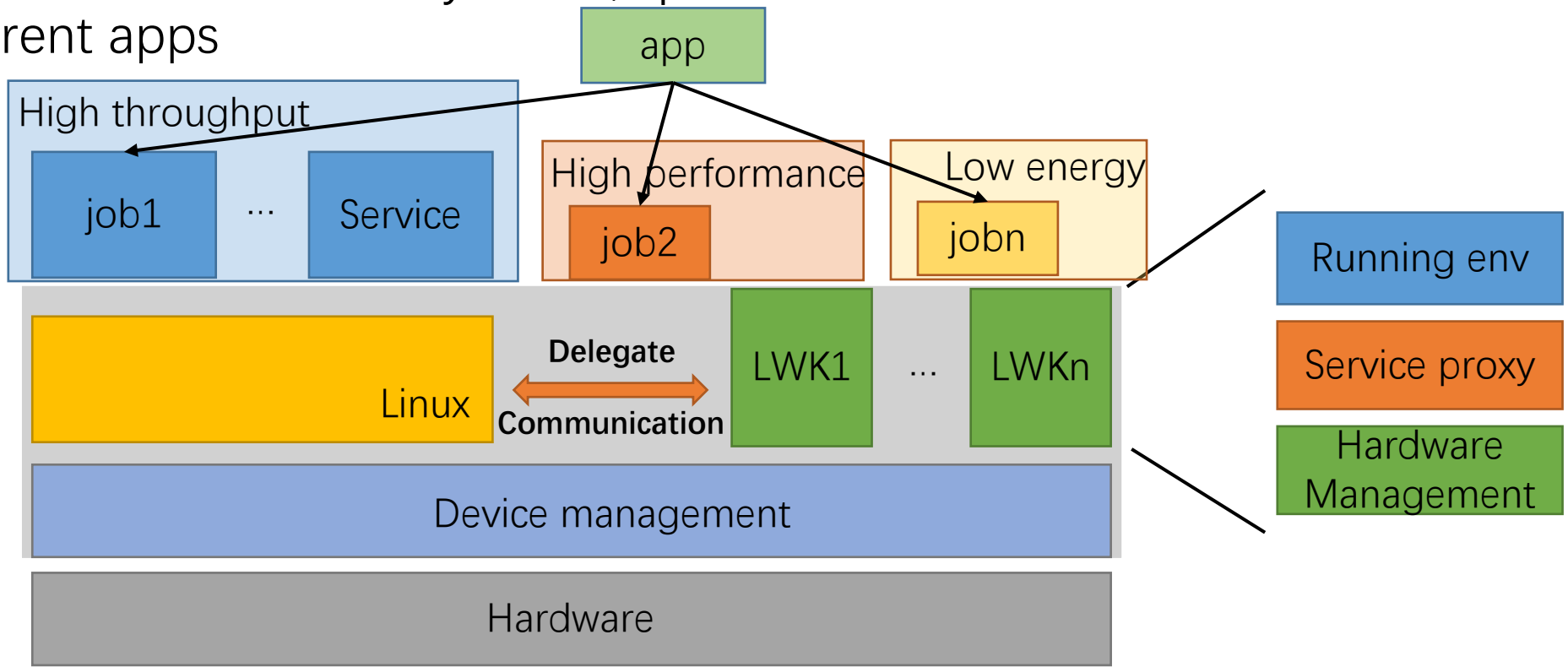
Our attempt

- Three parts
  - Device management and partition
  - Service zone
  - Specialized zone



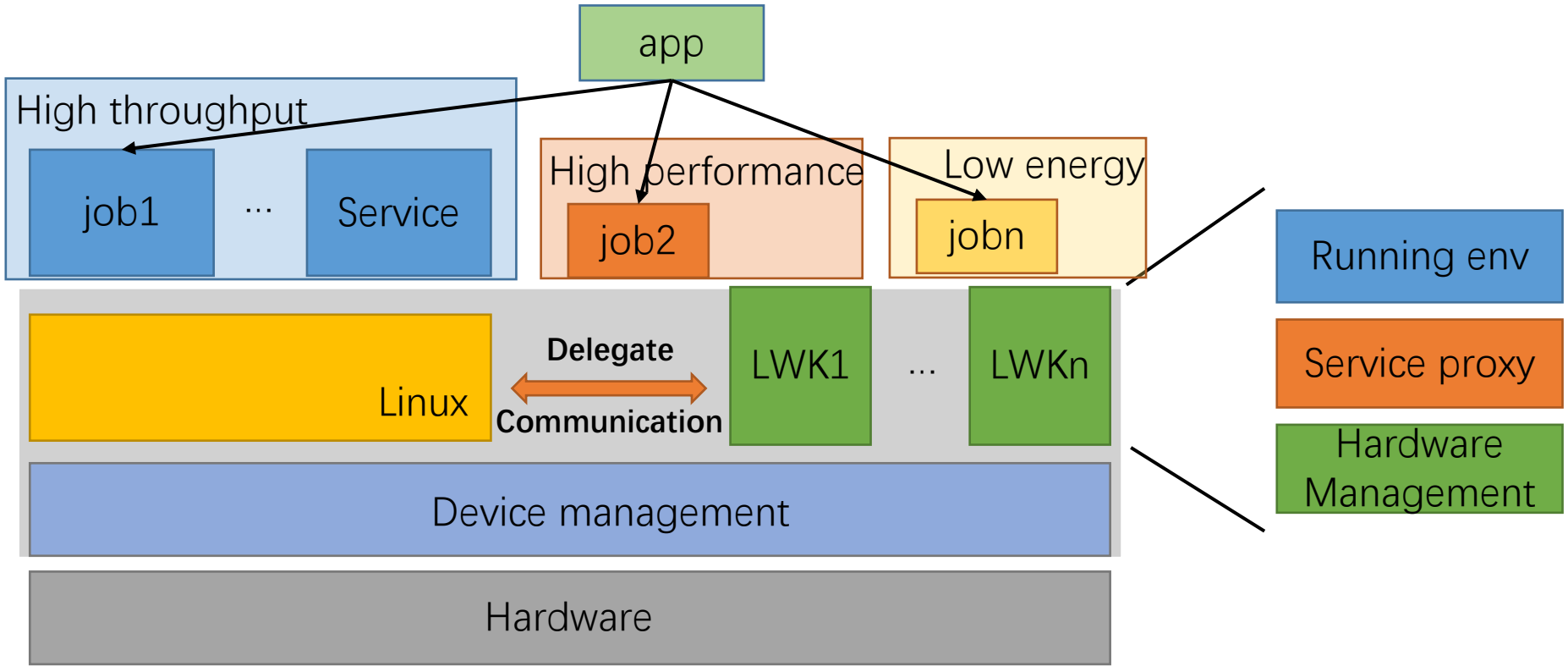
Our attempt

- Three parts
  - Device management and partition
  - Service zone – a FWK, offers Linux support
  - Specialized zone – many LWKs, specialized execution for different apps



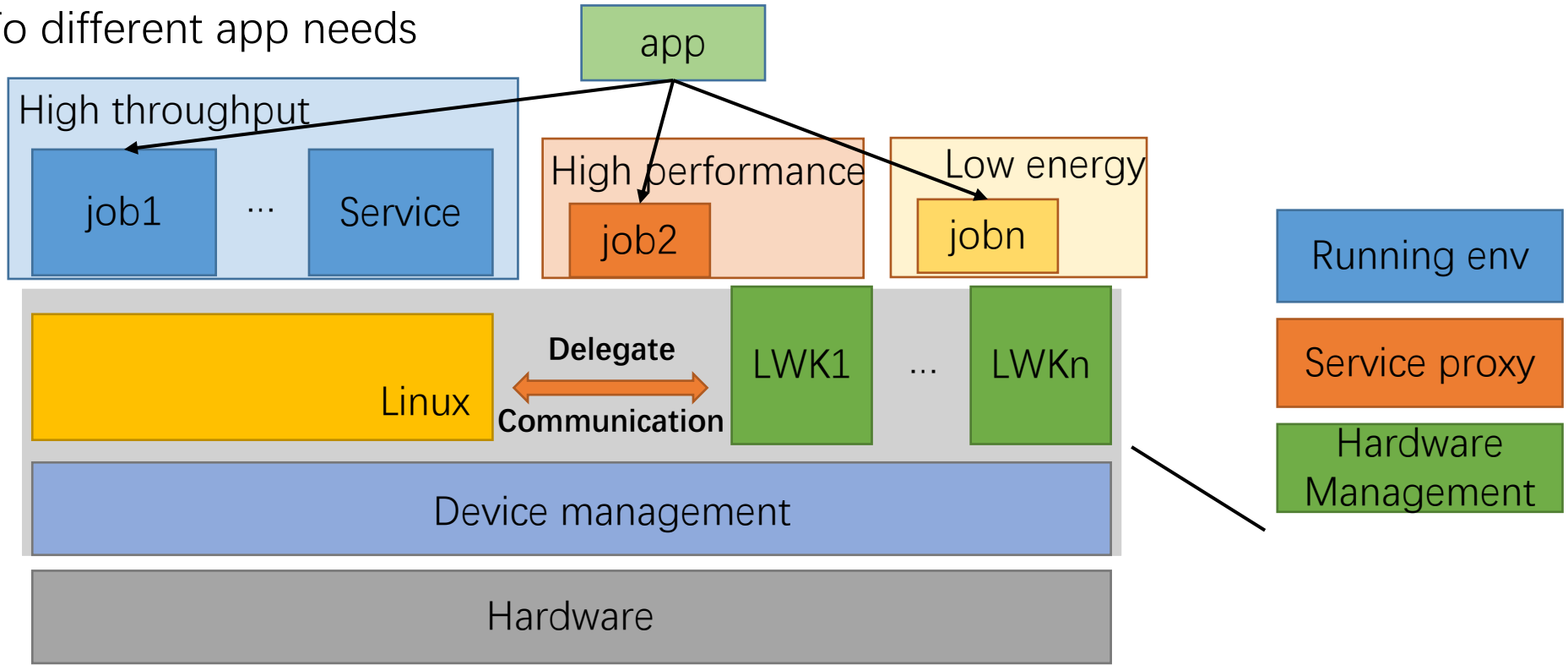
Our attempt

- To upper applications
  - Linux compatibility – provide by service proxy and Linux
  - Application running environment – provide by running env and service proxy



Our attempt

- To underlying hardware
  - Hardware management mechanism – provided by Device management
  - Hardware management policy – provided by different LWK
    - To different app needs

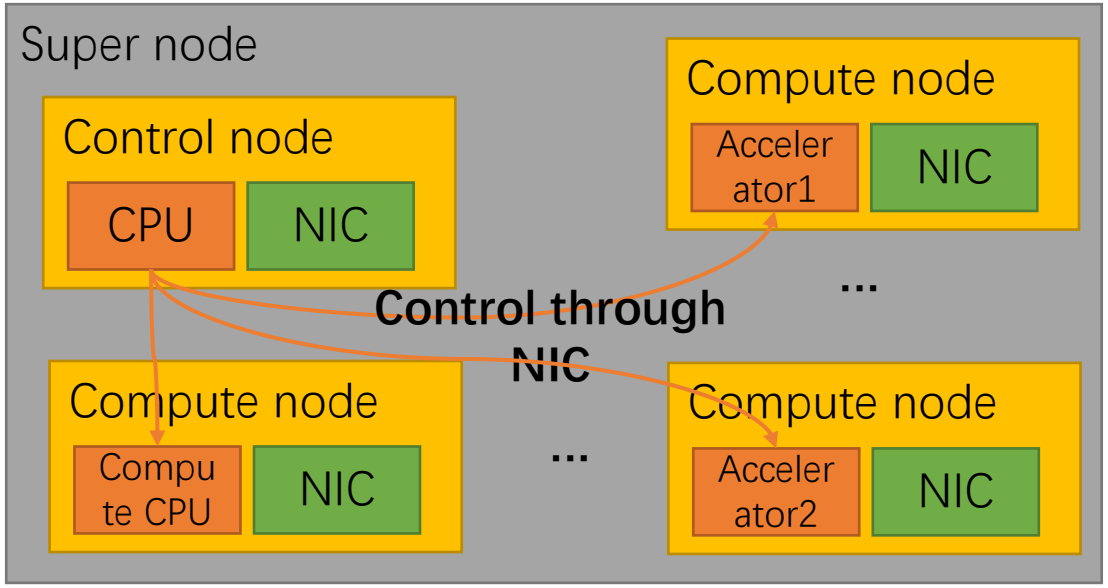


Our attempt

- Like many kernels
- Large containers
  - Contains app env as well as kernel functionalities
  - Specialized for application, in terms of both running environment and hardware management
  - Isolation

Proposal for exascale

- Very large scale, 100k+ nodes
- heterogenous, accelerator is inevitable
- CPU centered -> NIC centered
  - The control node controls multiple compute node with different computing resources
  - Different accelerators or CPUs
  - General services delegated to control node
  - Network very fast inside a supernode
    - On the same board or near



Thank you

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