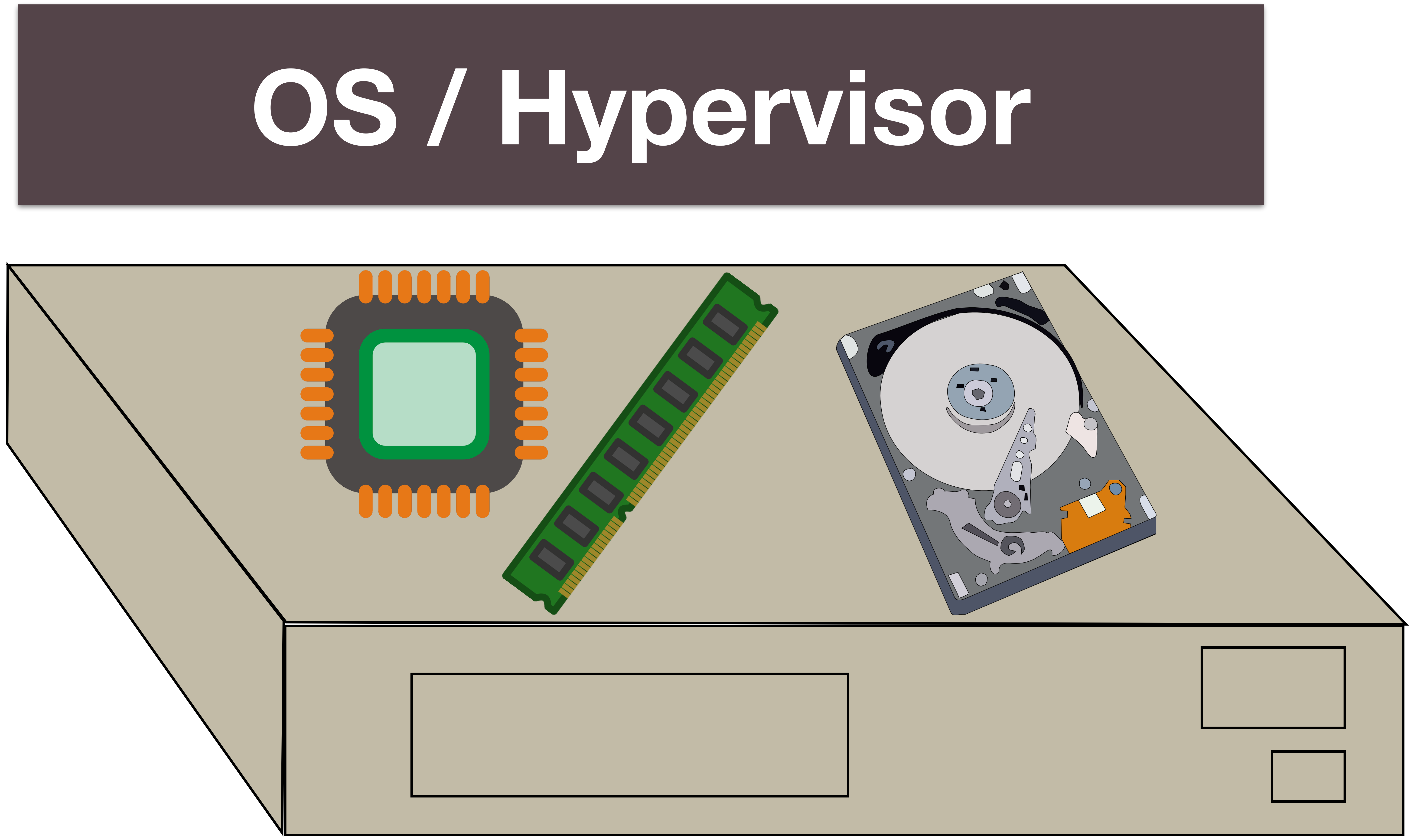
LegoOS

A Disseminated Distributed OS for Hardware Resource Disaggregation

Y4

Yizhou Shan, Yutong Huang, Yilun Chen, and Yiying Zhang

Monolithic Server



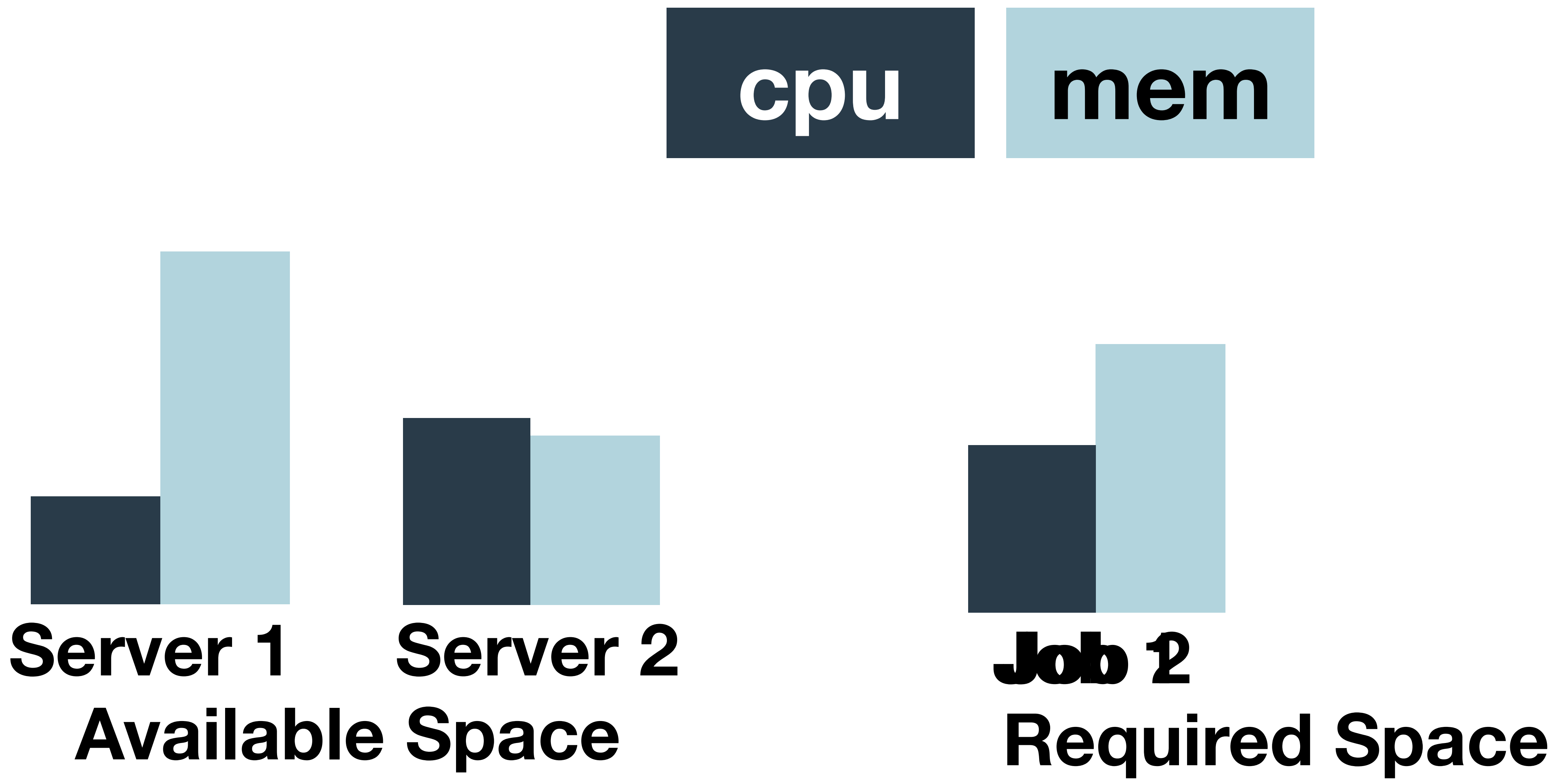
Problems?

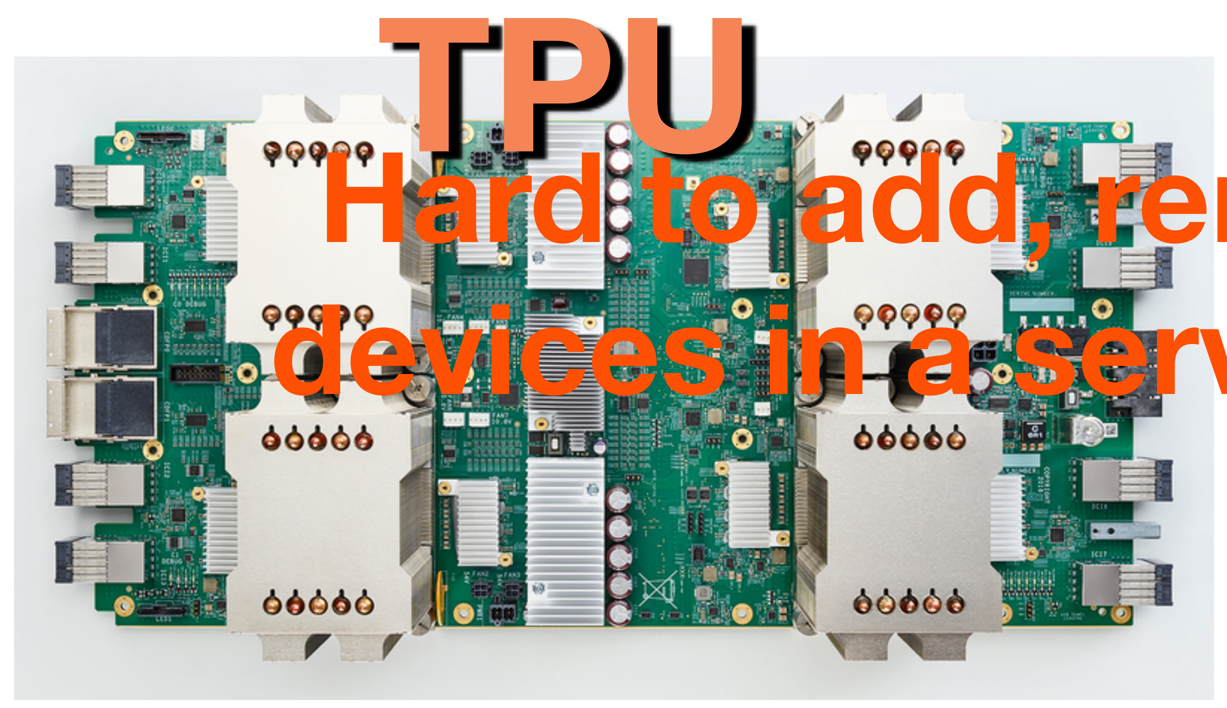
Resource Utilization

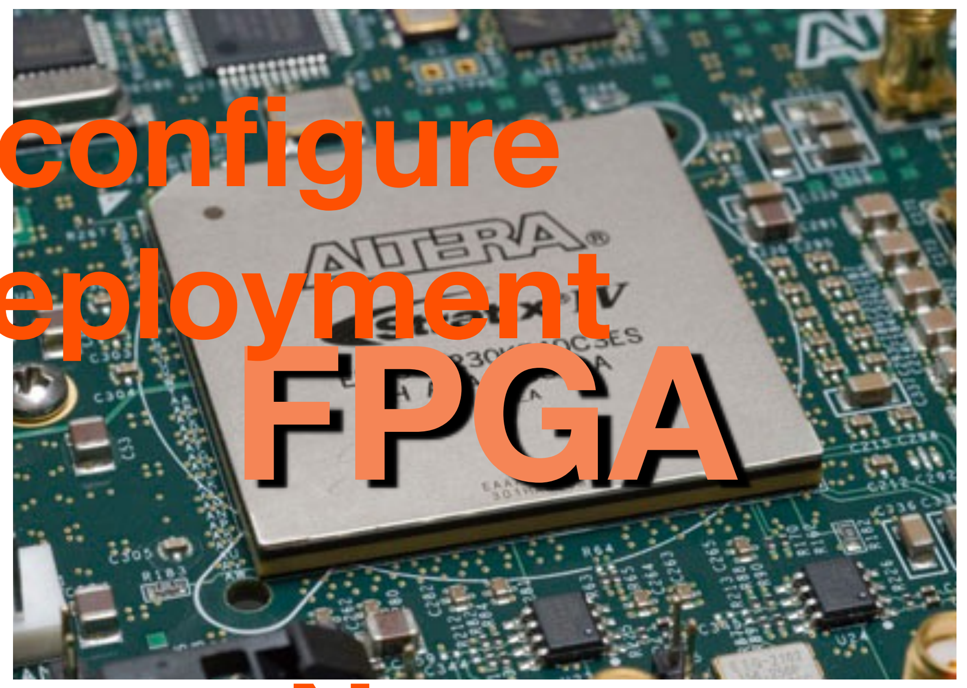
Heterogeneity

Elasticity

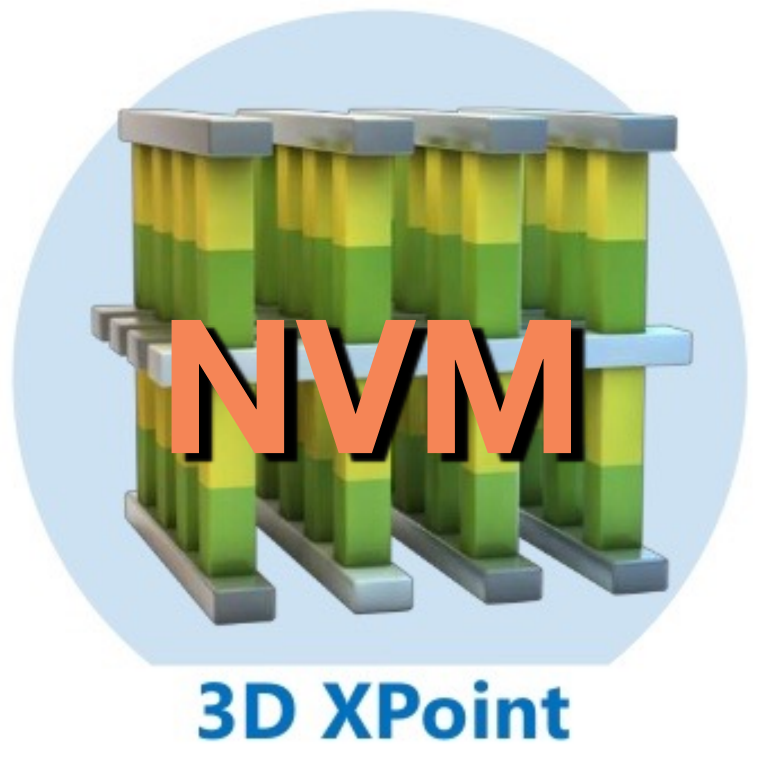
Fault Tolerance

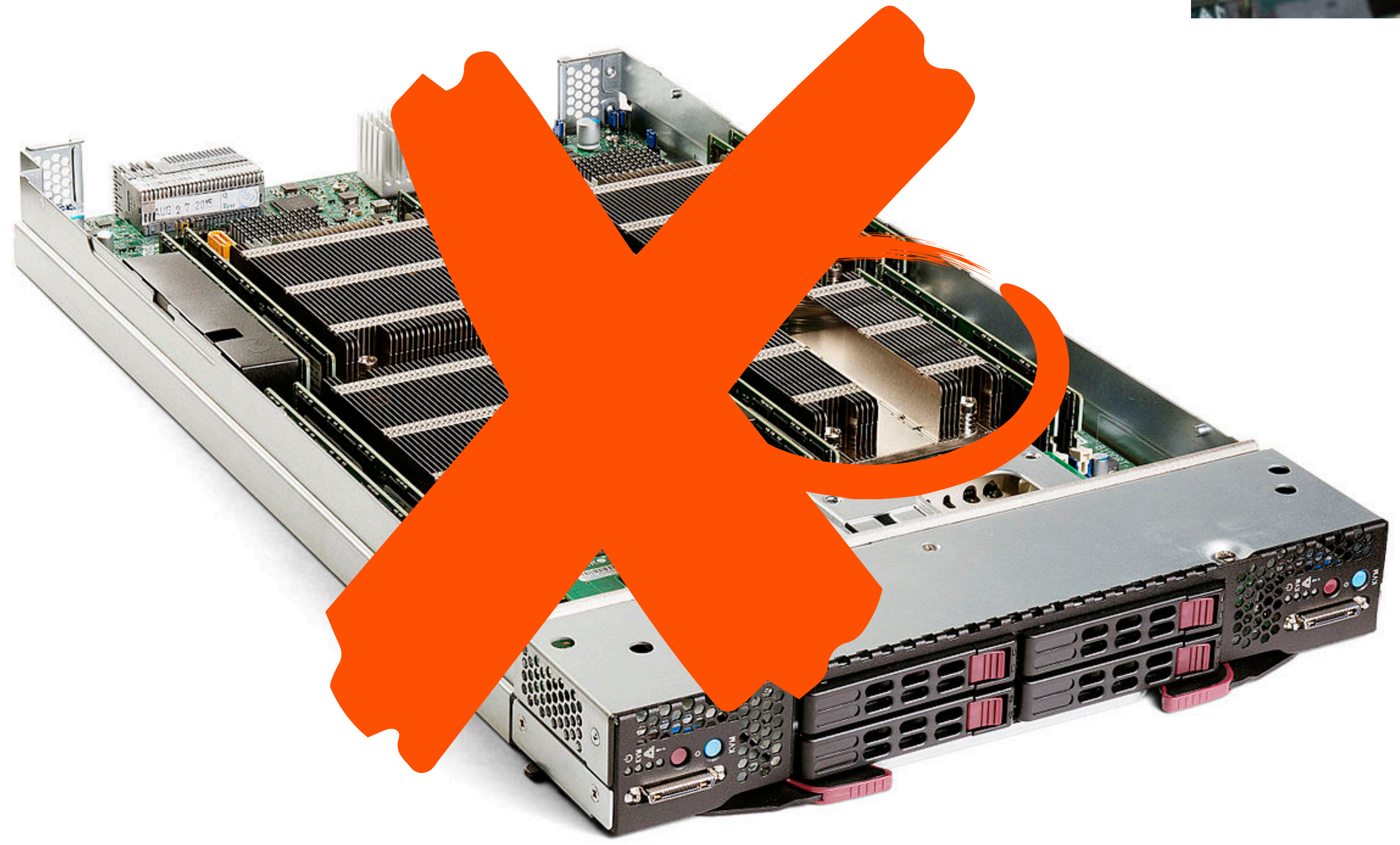






Hard to add, remove, or reconfigure devices in a servers after deployment





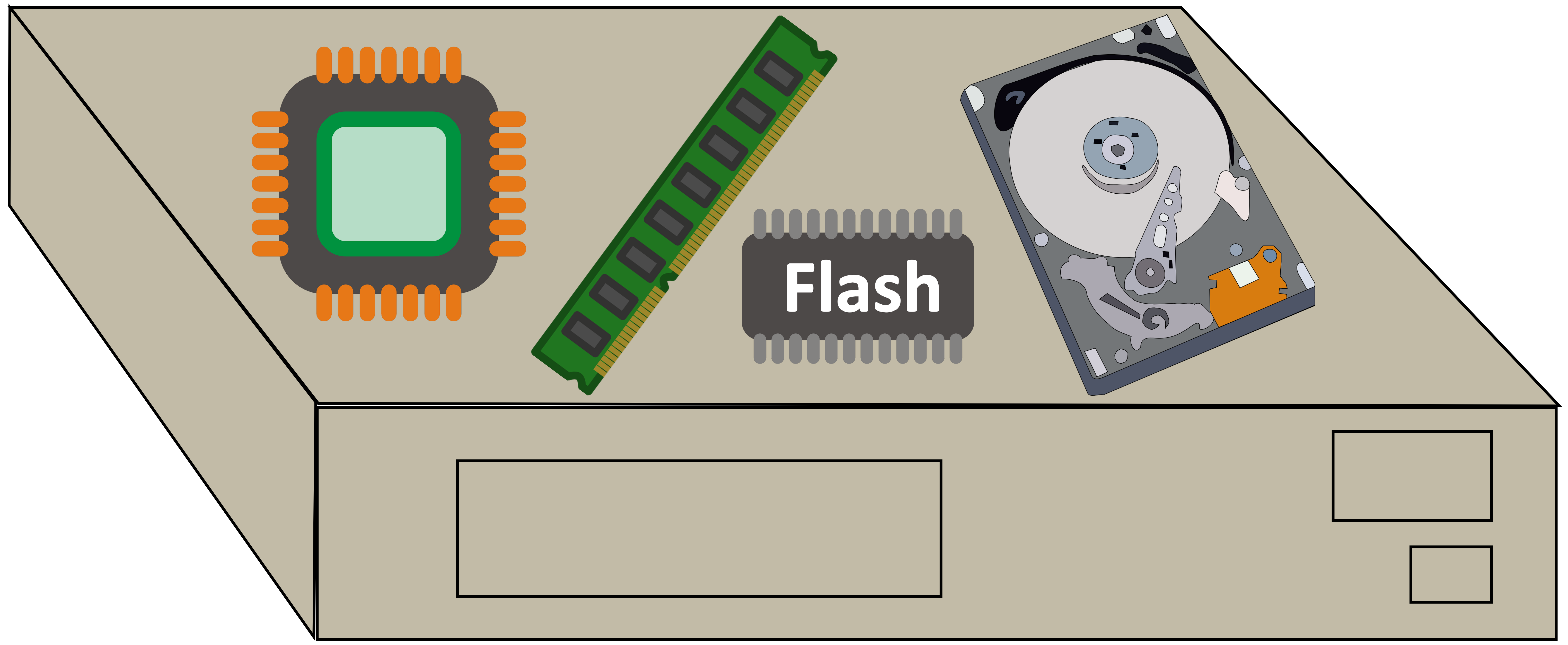
No extra PCIe slots

How to improve resource utilization, elasticity, heterogeneity, and fault tolerance?

Go beyond physical server boundary!

Hardware Resource Disaggregation:

Breaking monolithic servers into network-attached, independent hardware components


Flash

Resource Utilization

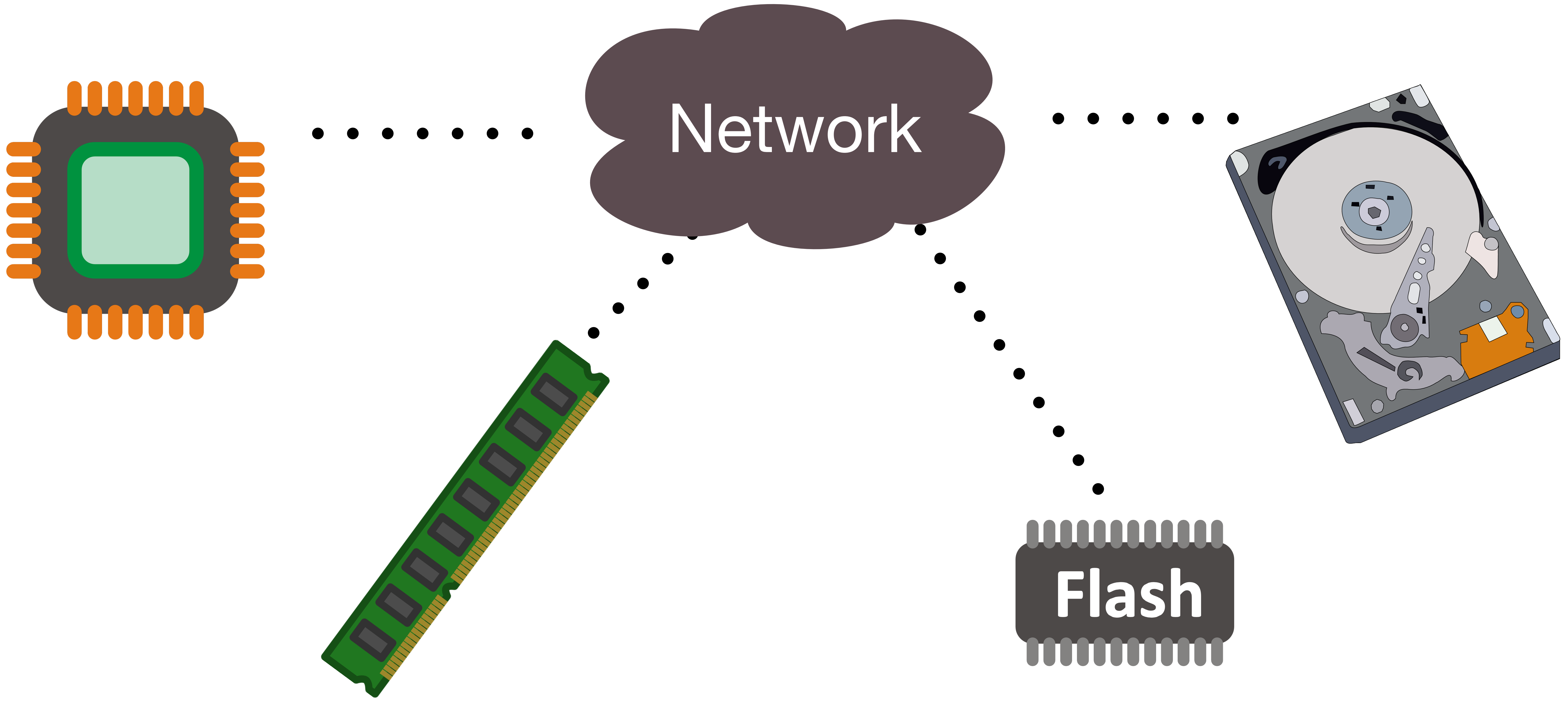
Fault Tolerance

Application

Elasticity

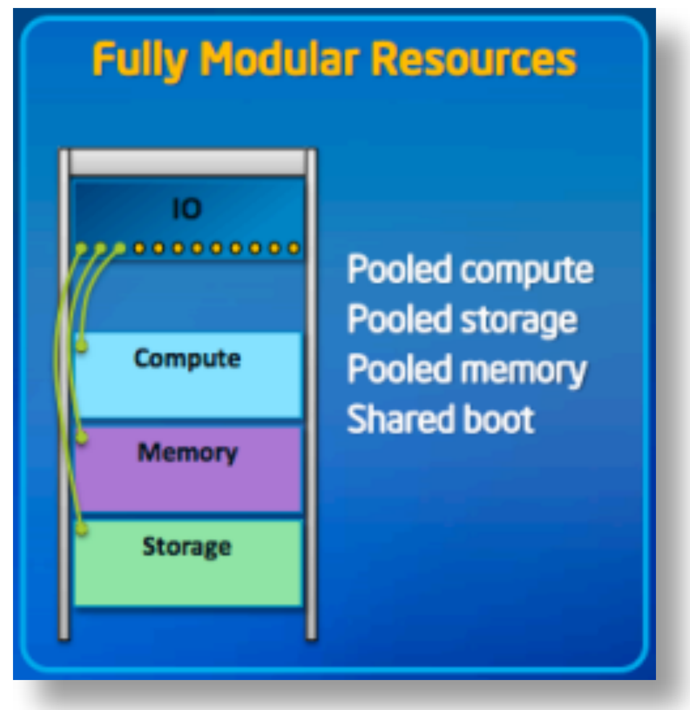
Heterogeneity

Hardware

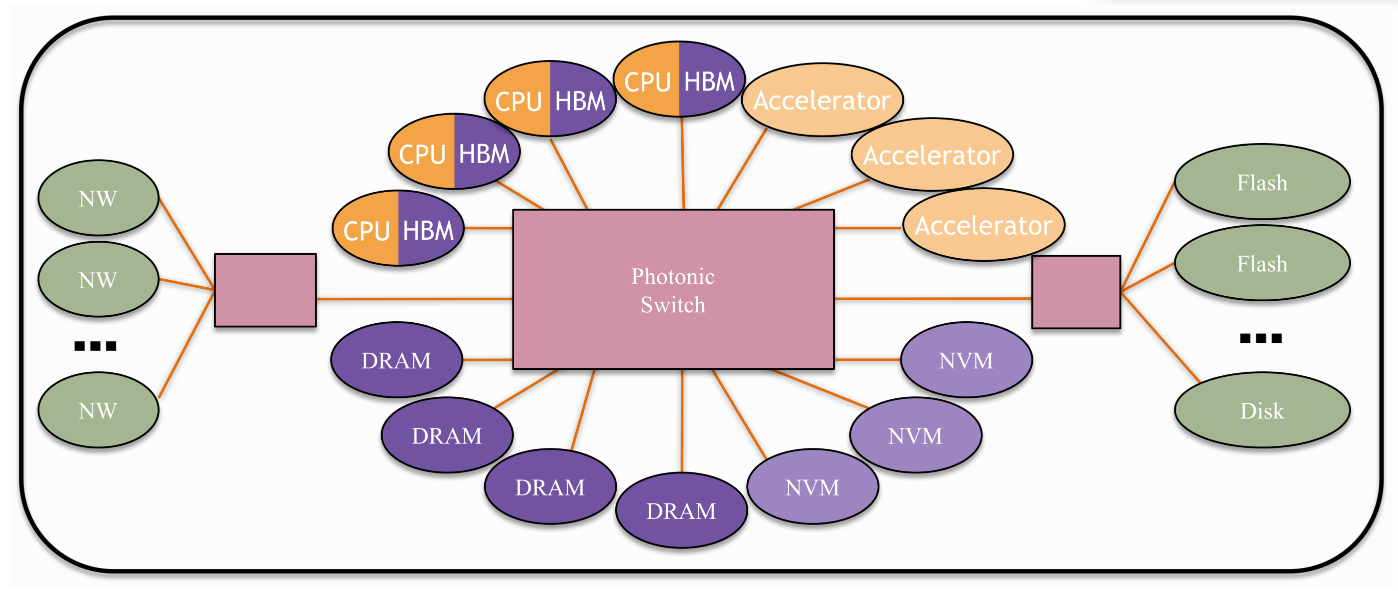


Why Possible Now?

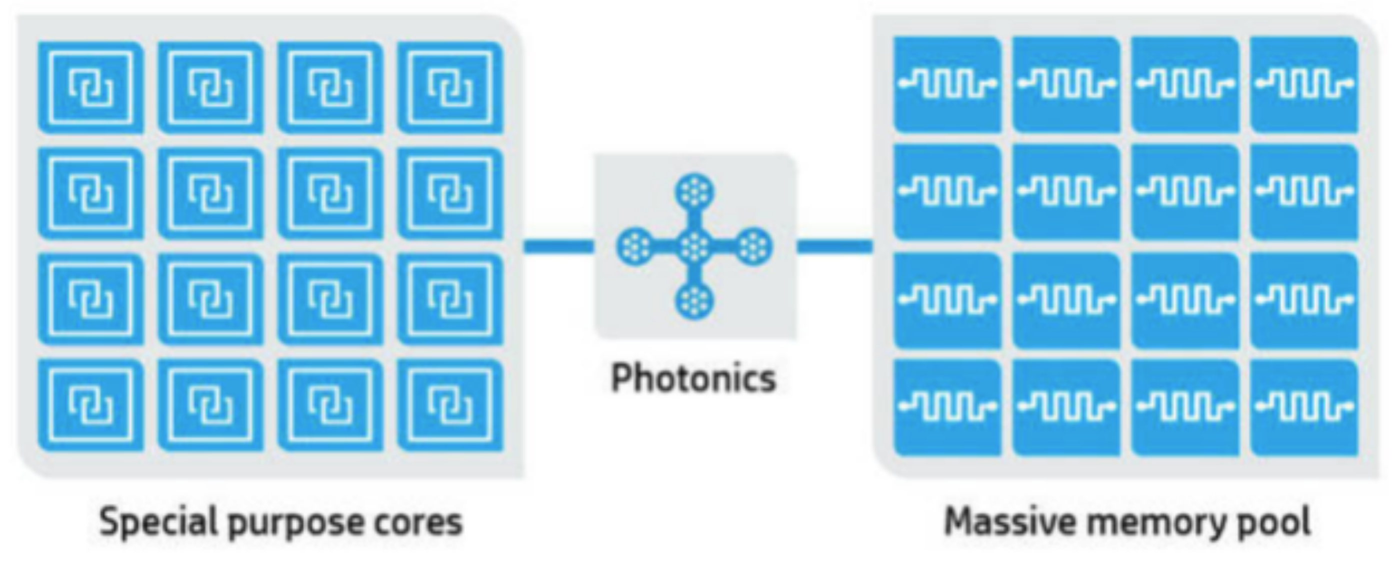
- **Network is faster**
  - InfiniBand (*200Gbps, 600ns*)
  - Optical Fabric (*400Gbps, 100ns*)
- **More processing power at device**
  - SmartNIC, SmartSSD, PIM
- **Network interface closer to device**
  - Omni-Path, Innova-2



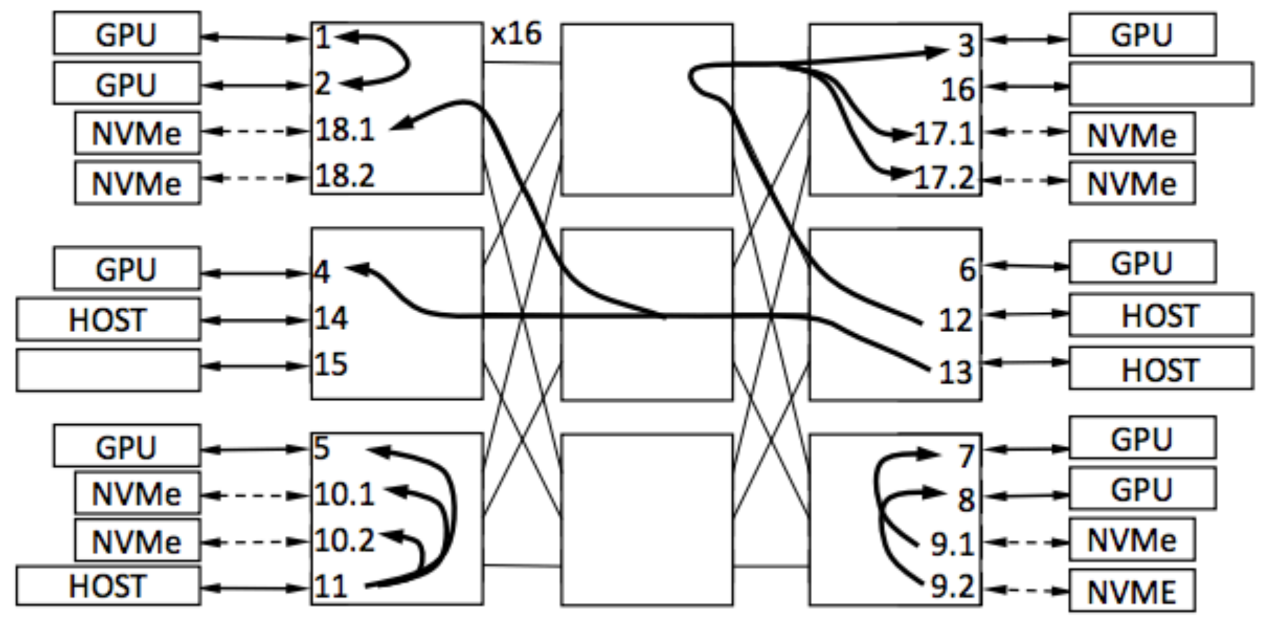
Intel Rack-Scale System



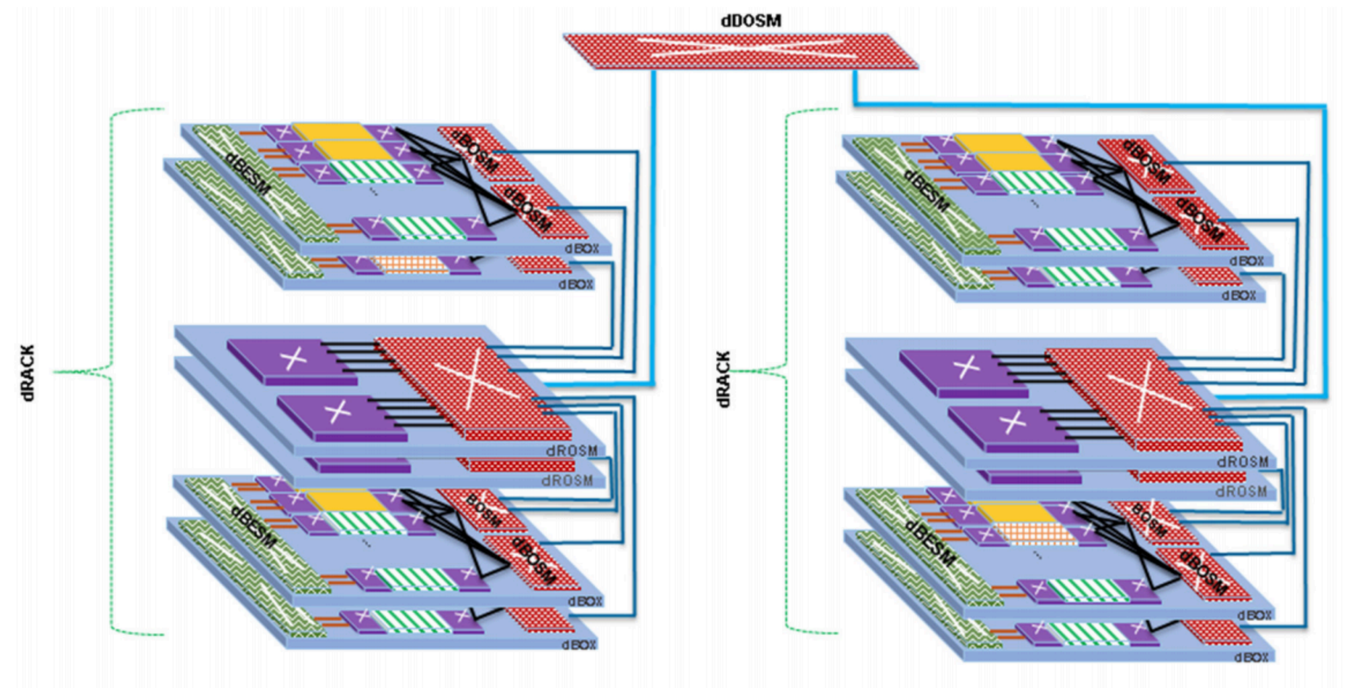
Berkeley Firebox



HP The Machine



IBM Composable System

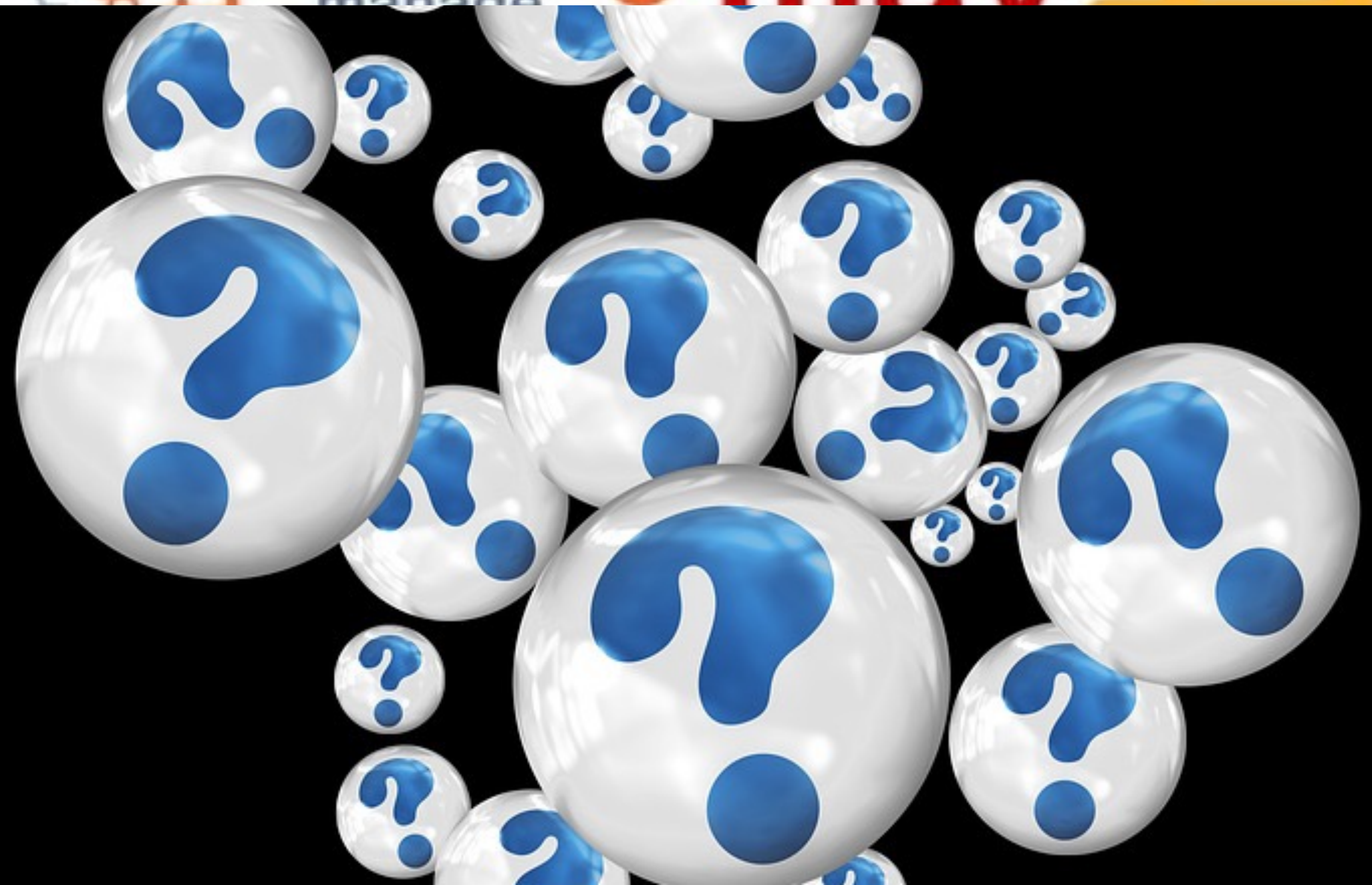


dReDBox

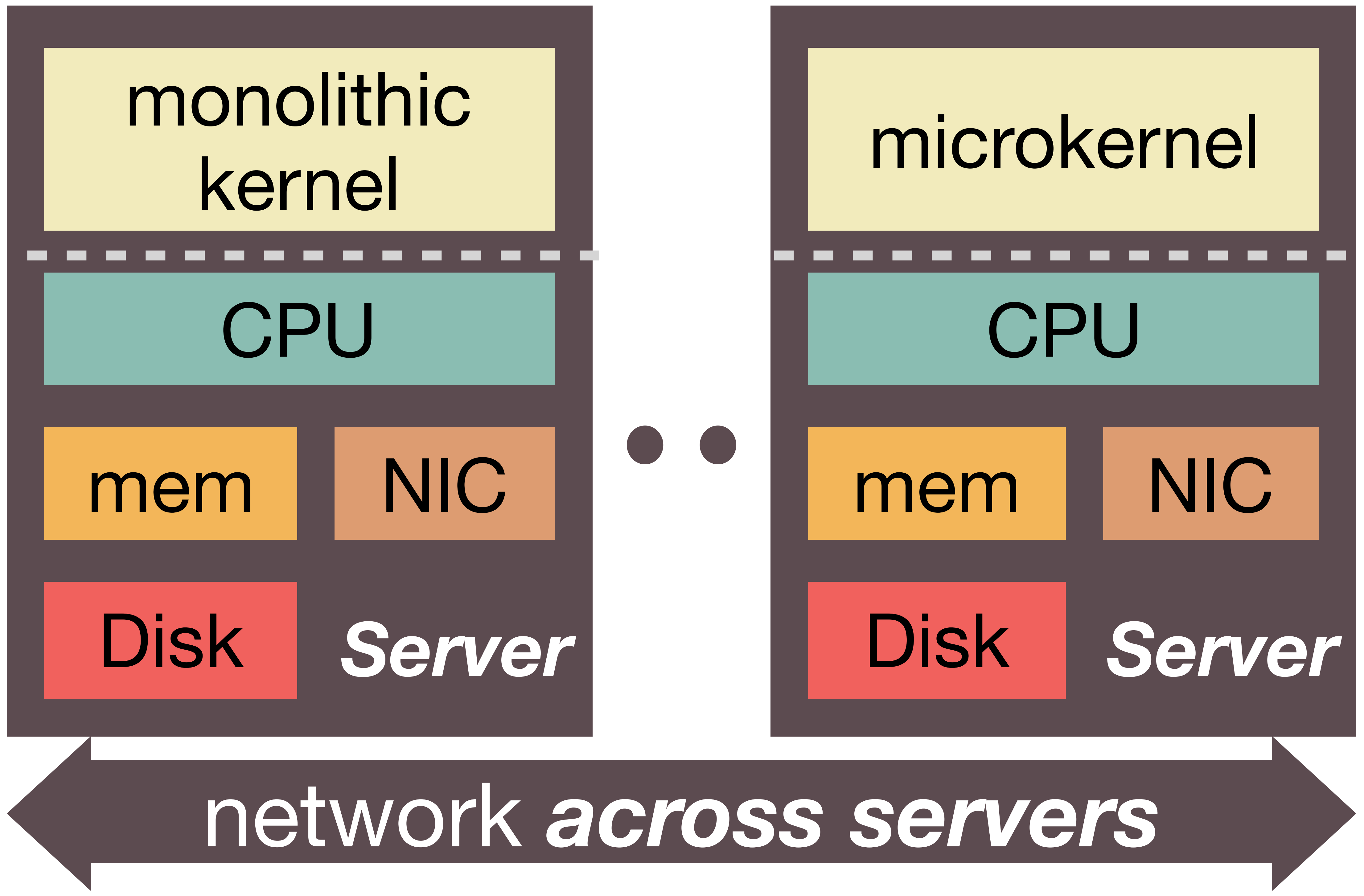
Outline

- Hardware Resource Disaggregation
- Kernel Architectures for Resource Disaggregation
- LegoOS Design and Implementation
  - Abstraction
  - Design Principles
  - Implementation and Emulation
- Conclusion

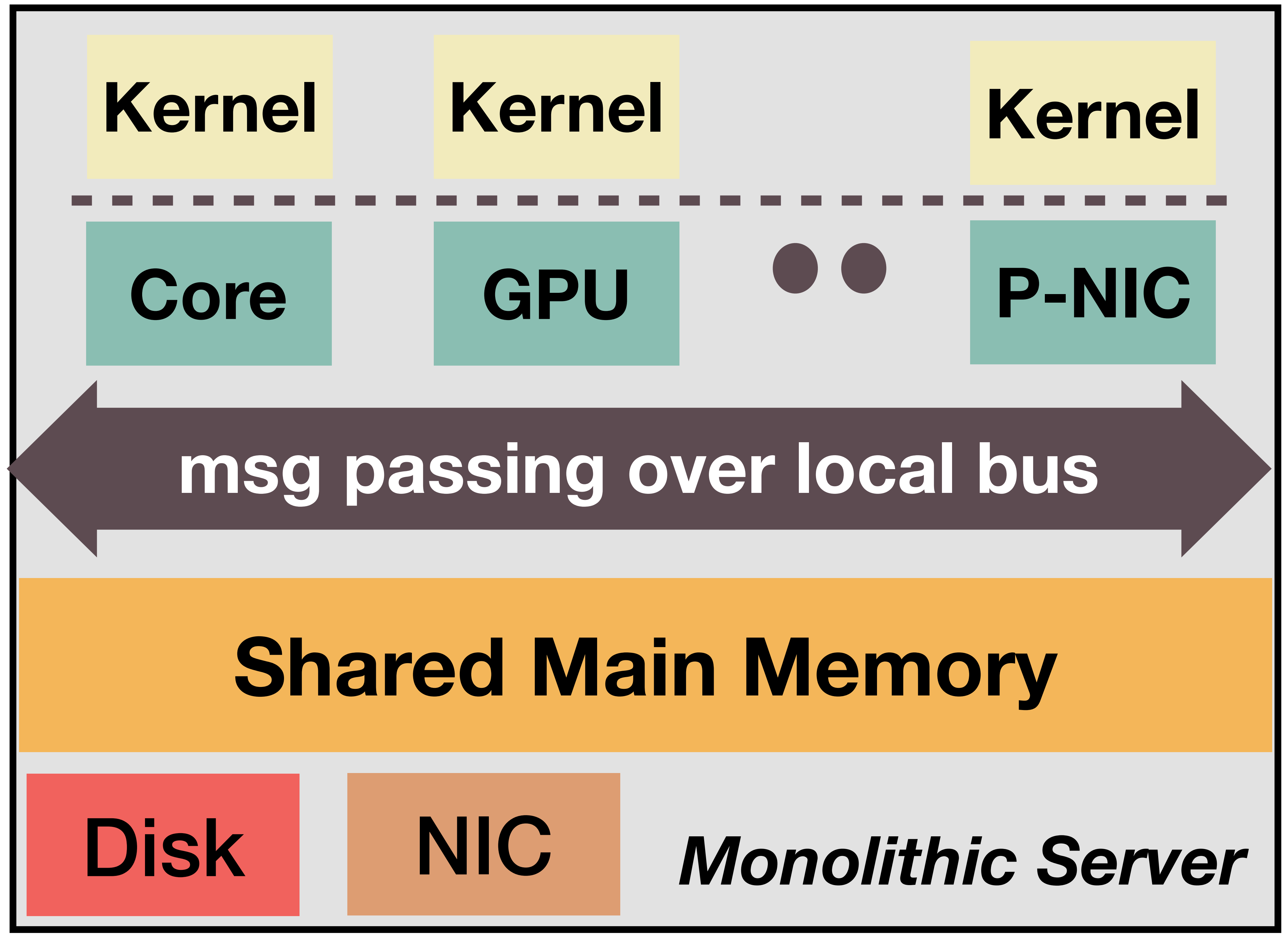
Operating
System
hardware
systems
machine
large
request
responsible
game
interact
gooey
Almost
activities
like
computer
acts
typing
makes
sharing
command
type
operation
portable
media
offer
generally
Unix
appliances
os
applications
implemented
programming
embedded
computing
use
programs
calls
data
host
details
using
however
kind
device
also
disk
machines
consoles
run
CLI
purposes
contention
players
washing
only
including
interfaces
one
may
graphical
supercomputers
management
pronounced
handheld
considered
easier
commands
pass
well
included
robots
APIs
runs



Can Existing Kernels Fit?

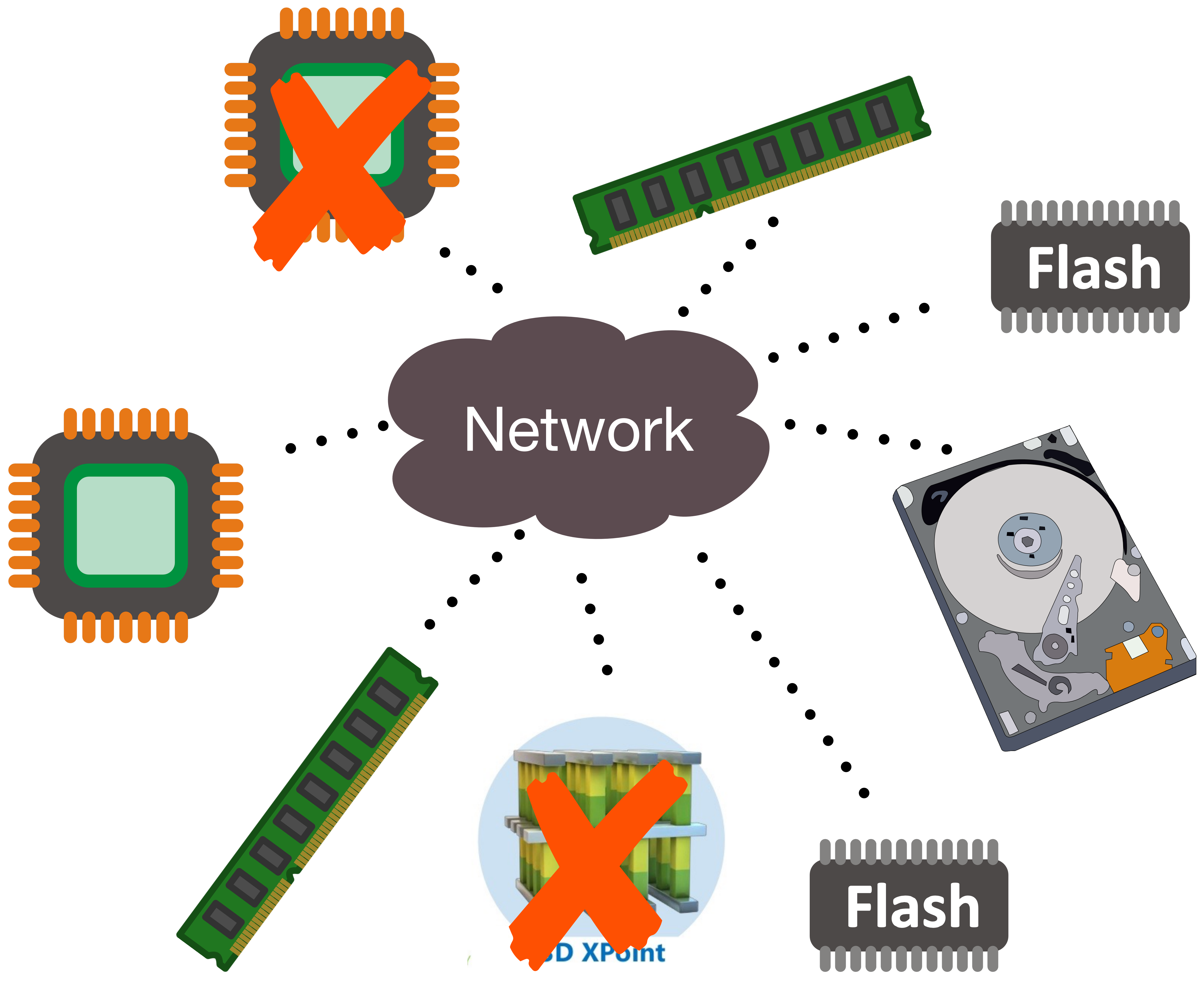


Monolithic/Micro-kernel
(e.g., Linux, L4)



Multikernel
(e.g., Barrelfish, Helios, fos)

Existing Kernels Don't Fit



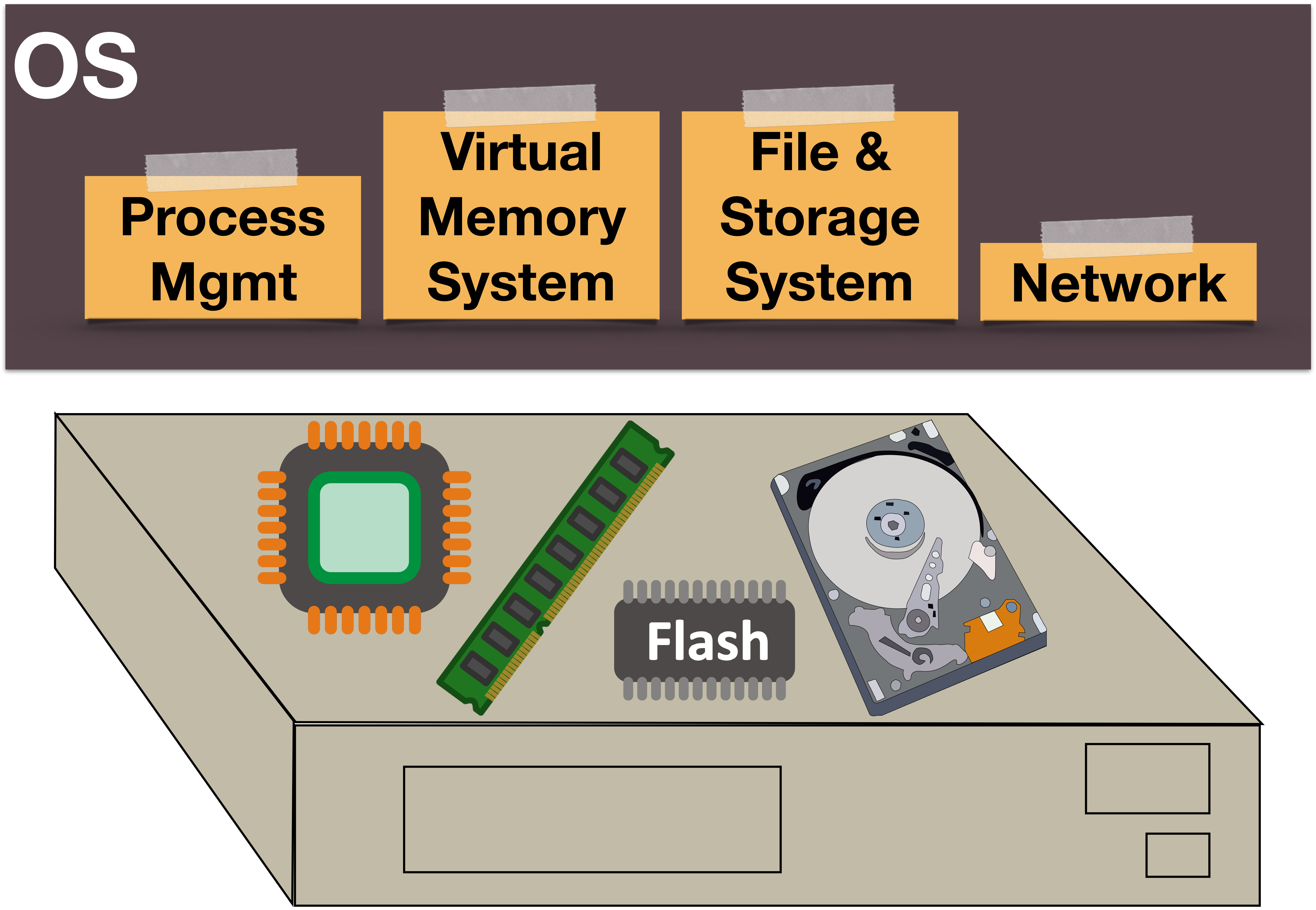
~~Access remote resources~~

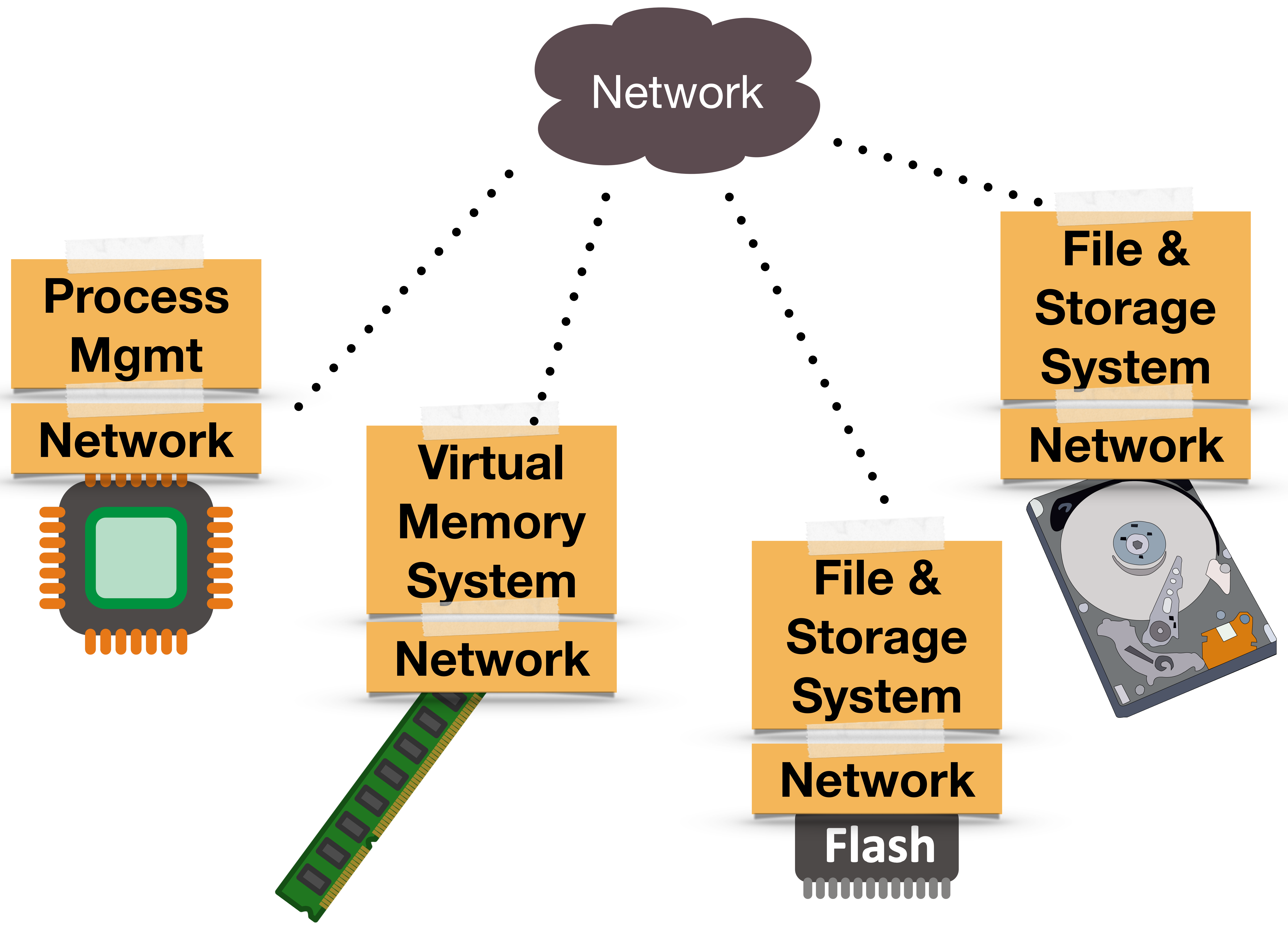
~~Distributed resource mgmt~~

~~Fine-grained failure handling~~

When hardware is disaggregated

The OS should be also


OS
Process Mgmt
Virtual Memory System
File & Storage System
Network
Flash


Network
Process Mgmt
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Virtual Memory System
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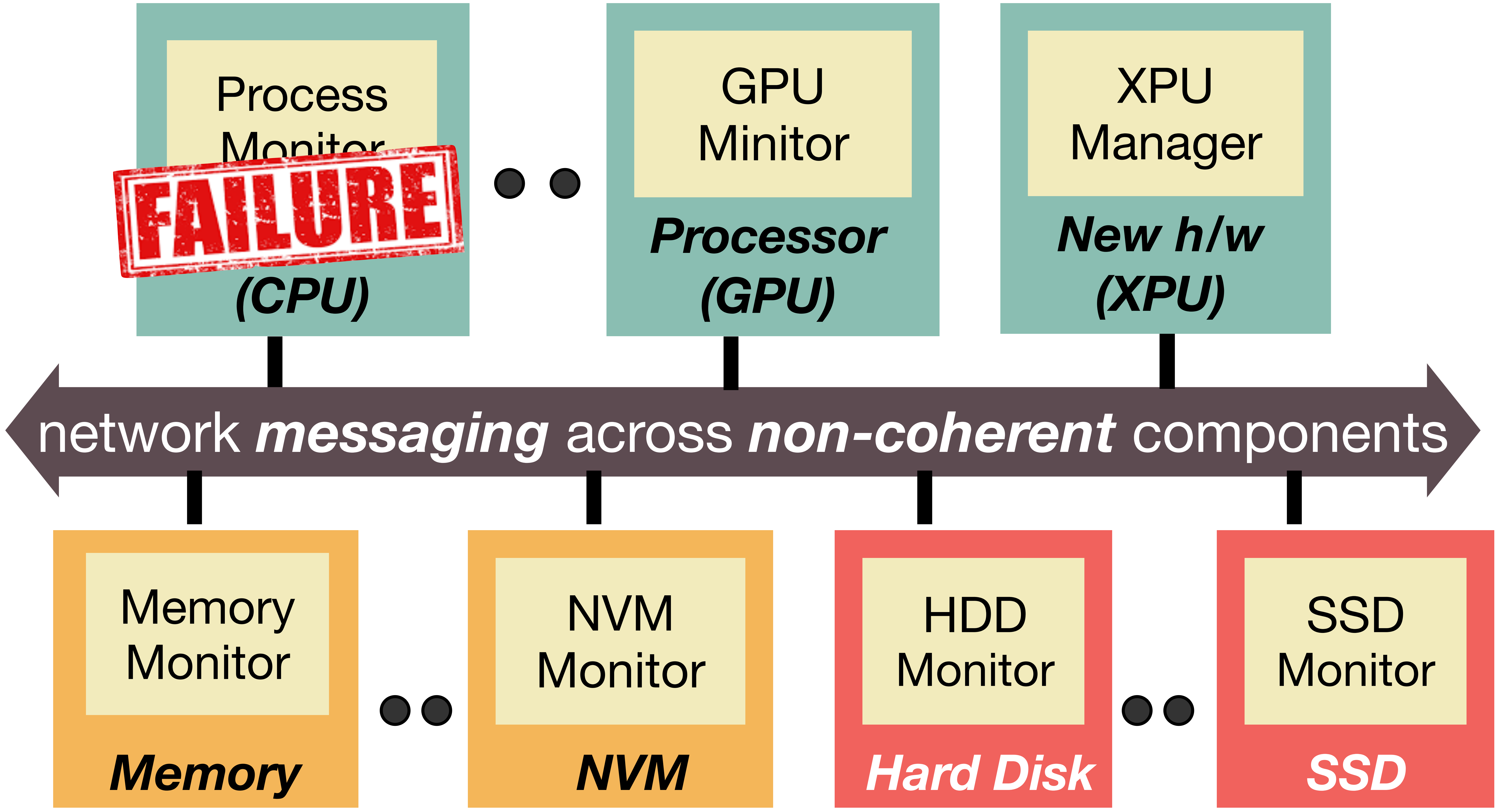
File & Storage System
Network

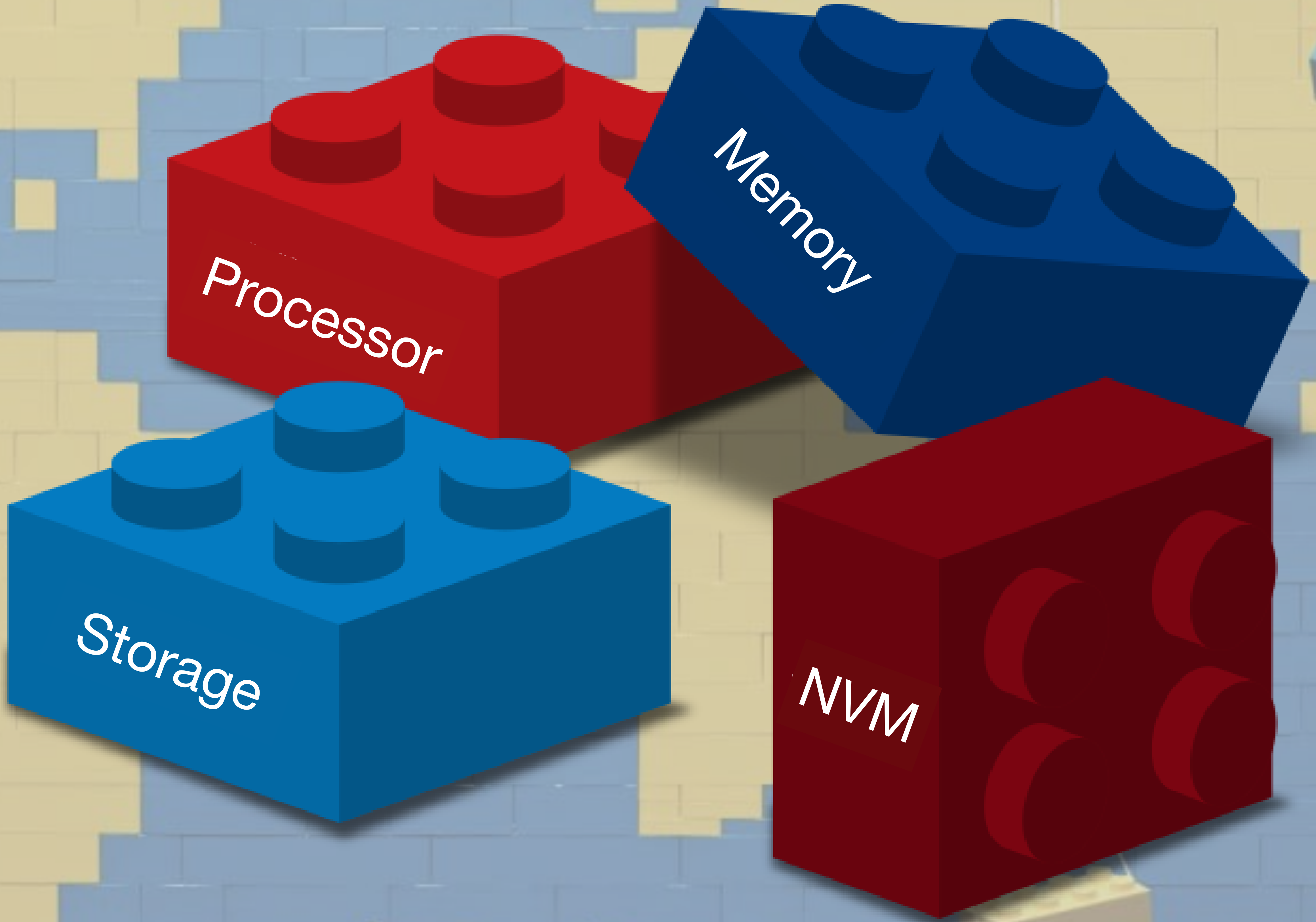
The Splitkernel Architecture



- Split OS functions into ***monitors***
- Run each monitor at h/w device
- Network messaging across non-coherent components
- Distributed resource mgmt and failure handling

LegoOS

The *First* Disaggregated OS



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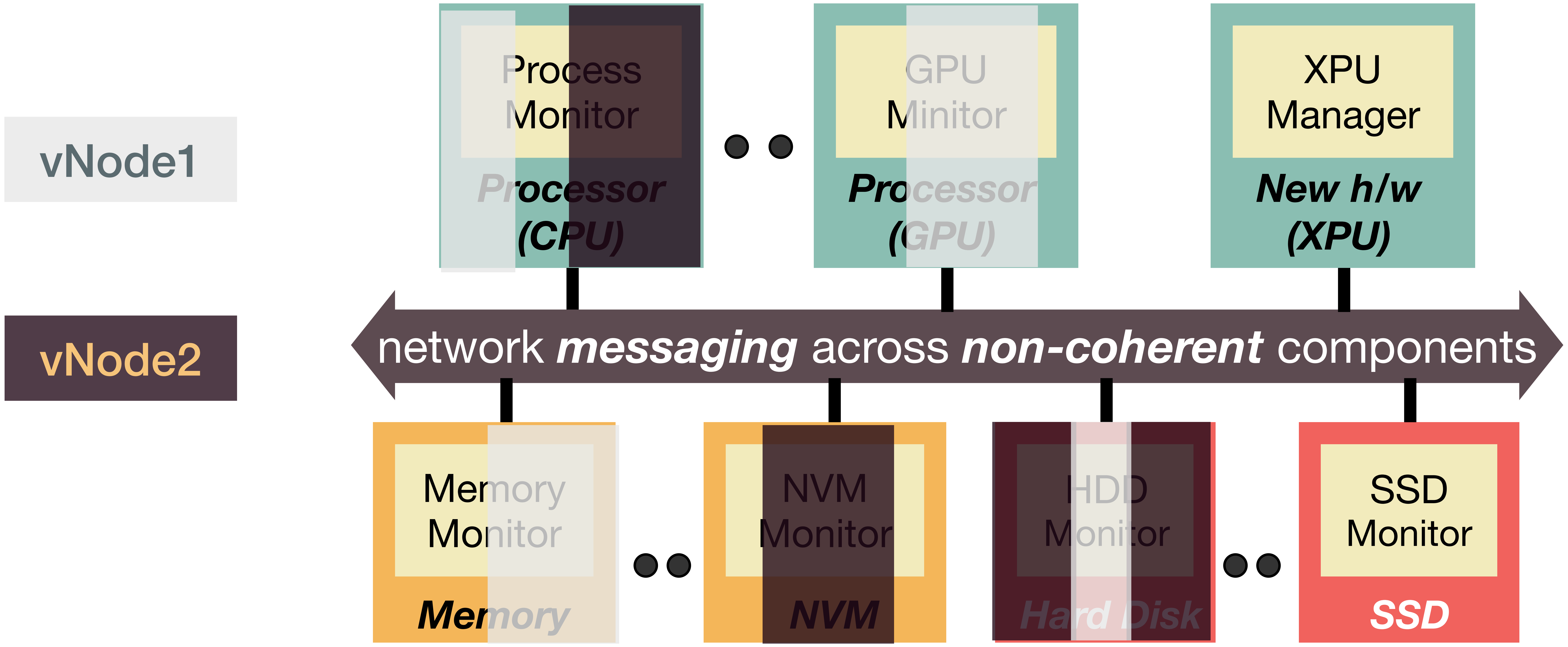
How Should *LegoOS* Appear to Users?

As a set of hardware devices?

As a giant machine?

- Our answer: as a set of virtual Nodes (***vNodes***)
  - Similar semantics to virtual machines
  - Unique vID, vIP, storage mount point
  - Can run on multiple processor, memory, and storage components

Abstraction - vNode



One vNode can run multiple hardware components

One hardware component can run multiple vNodes

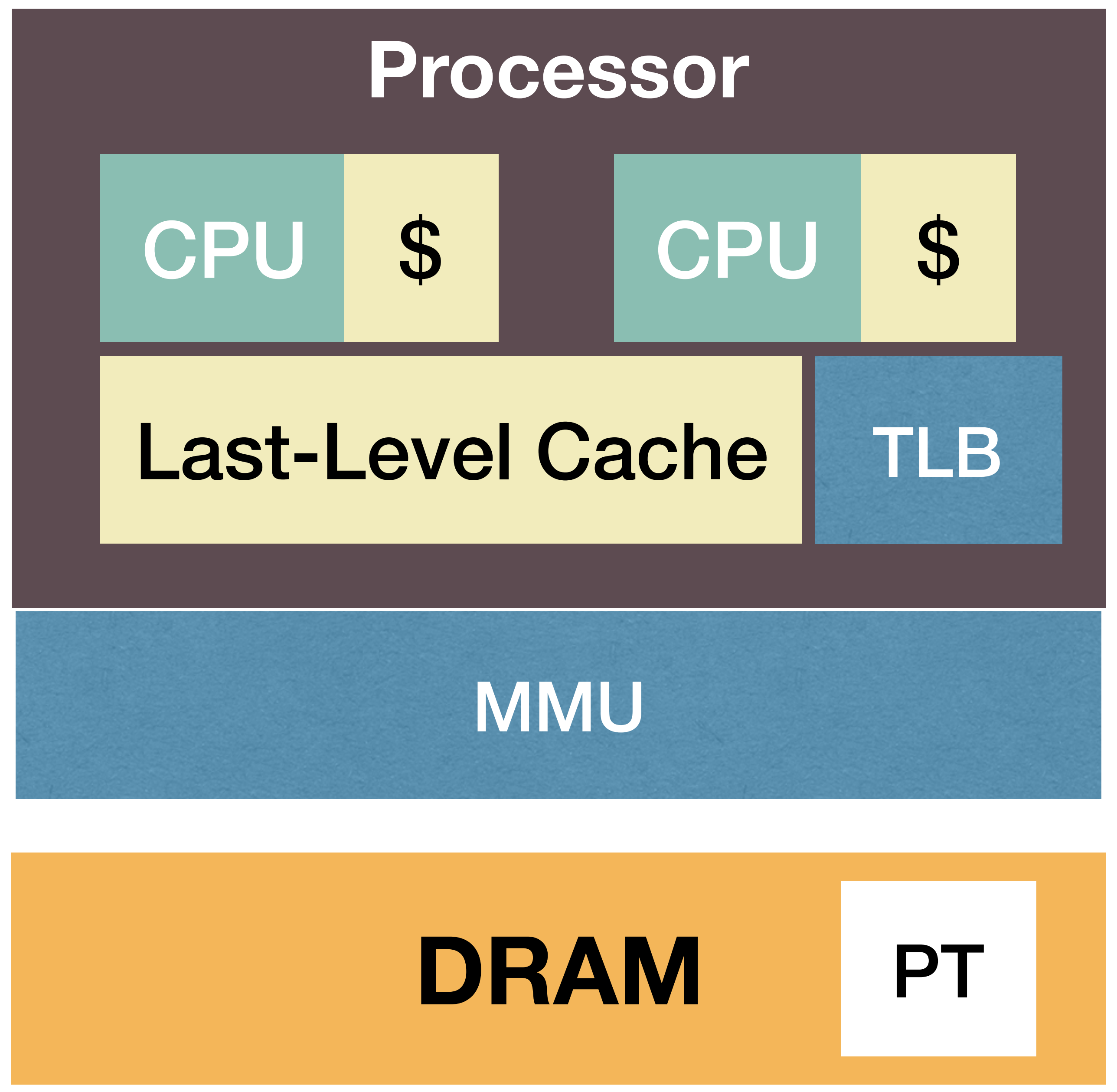
Abstraction

- Appear as vNodes to users
- Linux ABI compatible
  - Support ***unmodified*** Linux system call interface (common ones)
  - A level of ***indirection*** to translate Linux interface to LegoOS interface

LegoOS Design

1. Clean separation of OS and hardware functionalities
2. Build monitor with hardware constraints
3. RDMA-based message passing for both kernel and applications
4. Two-level distributed resource management
5. Memory failure tolerance through replication

Separate Processor and Memory



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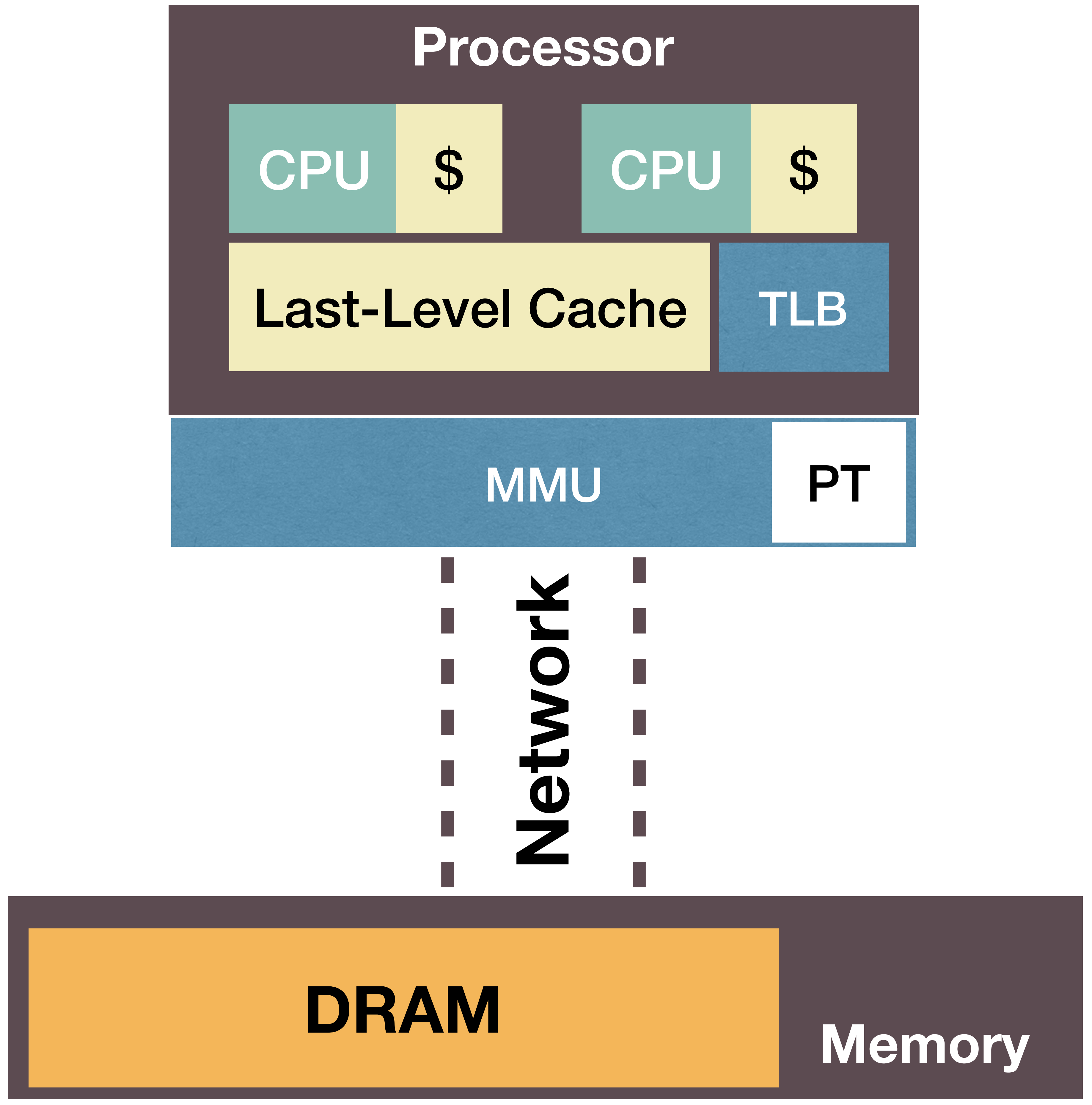
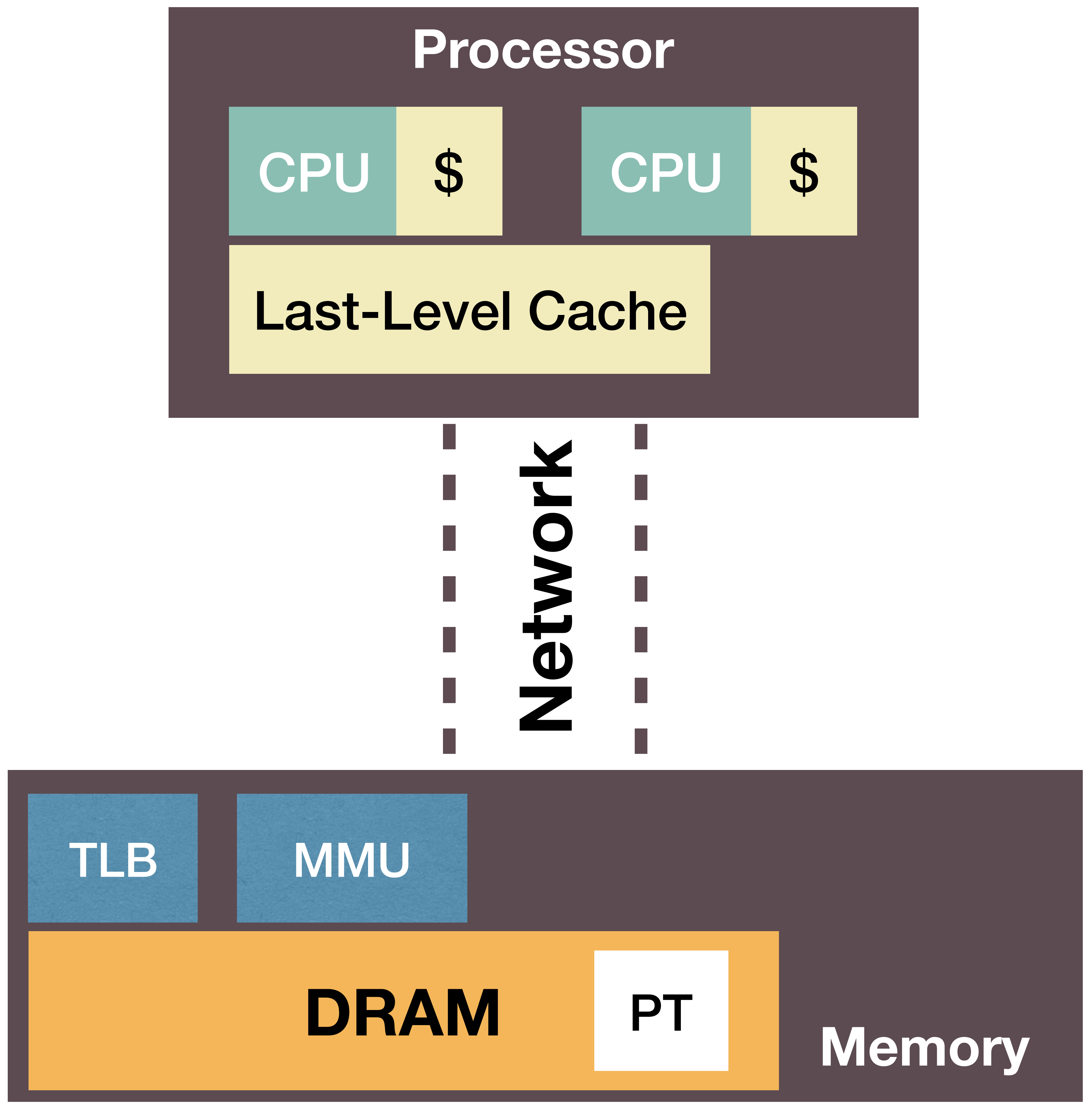


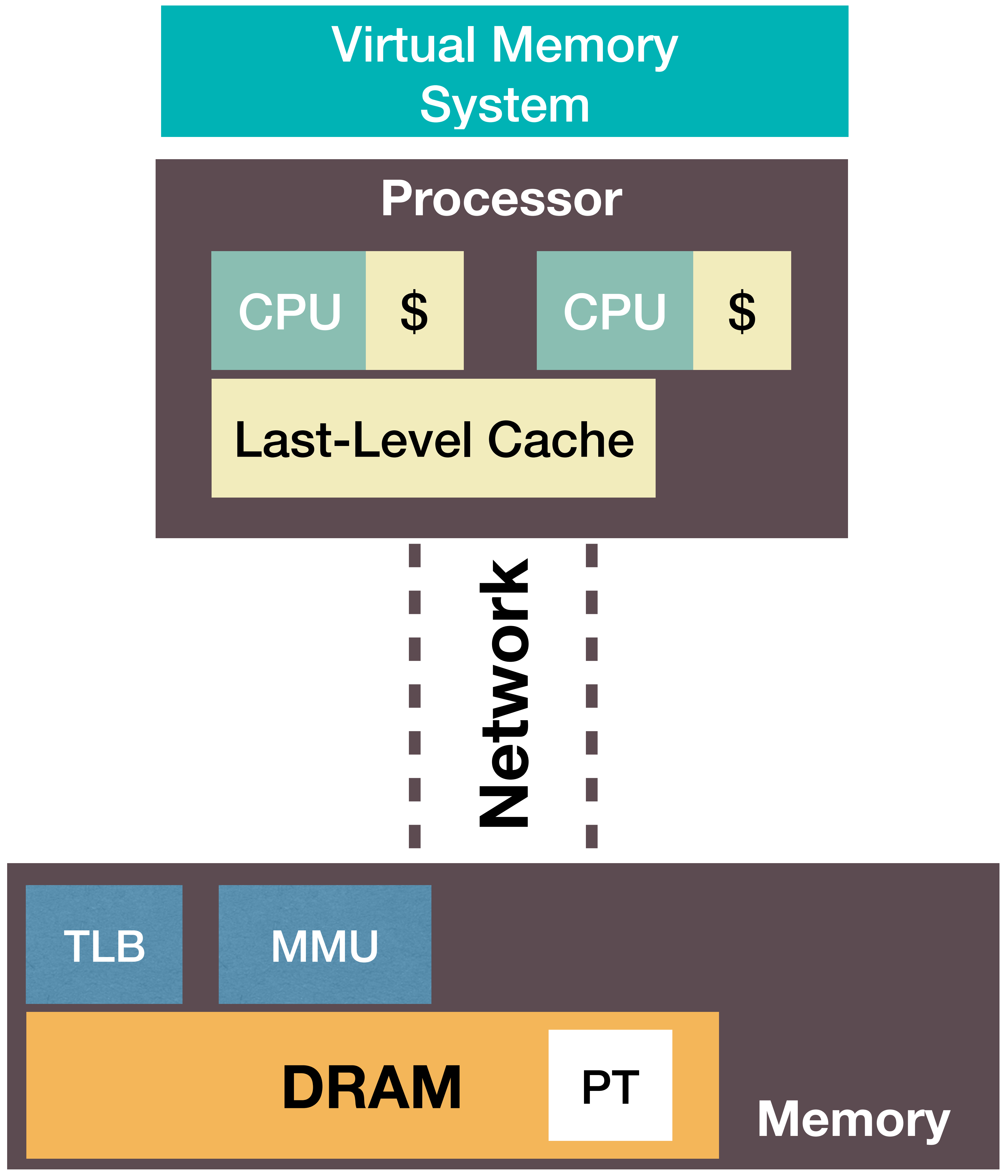
Disaggregating DRAM

Separate Processor and Memory

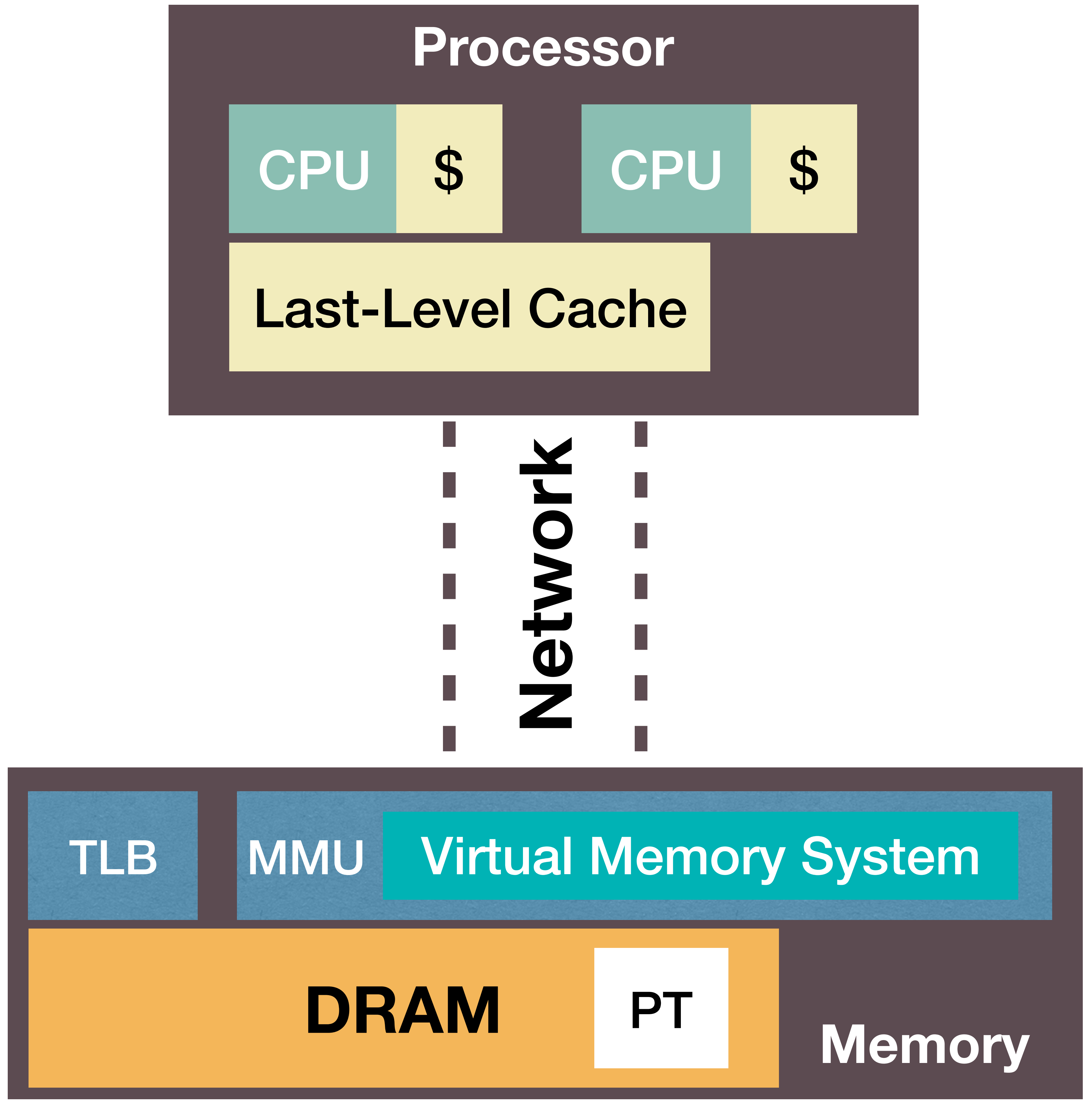


Separate and move ***hardware units*** to memory component

Separate Processor and Memory

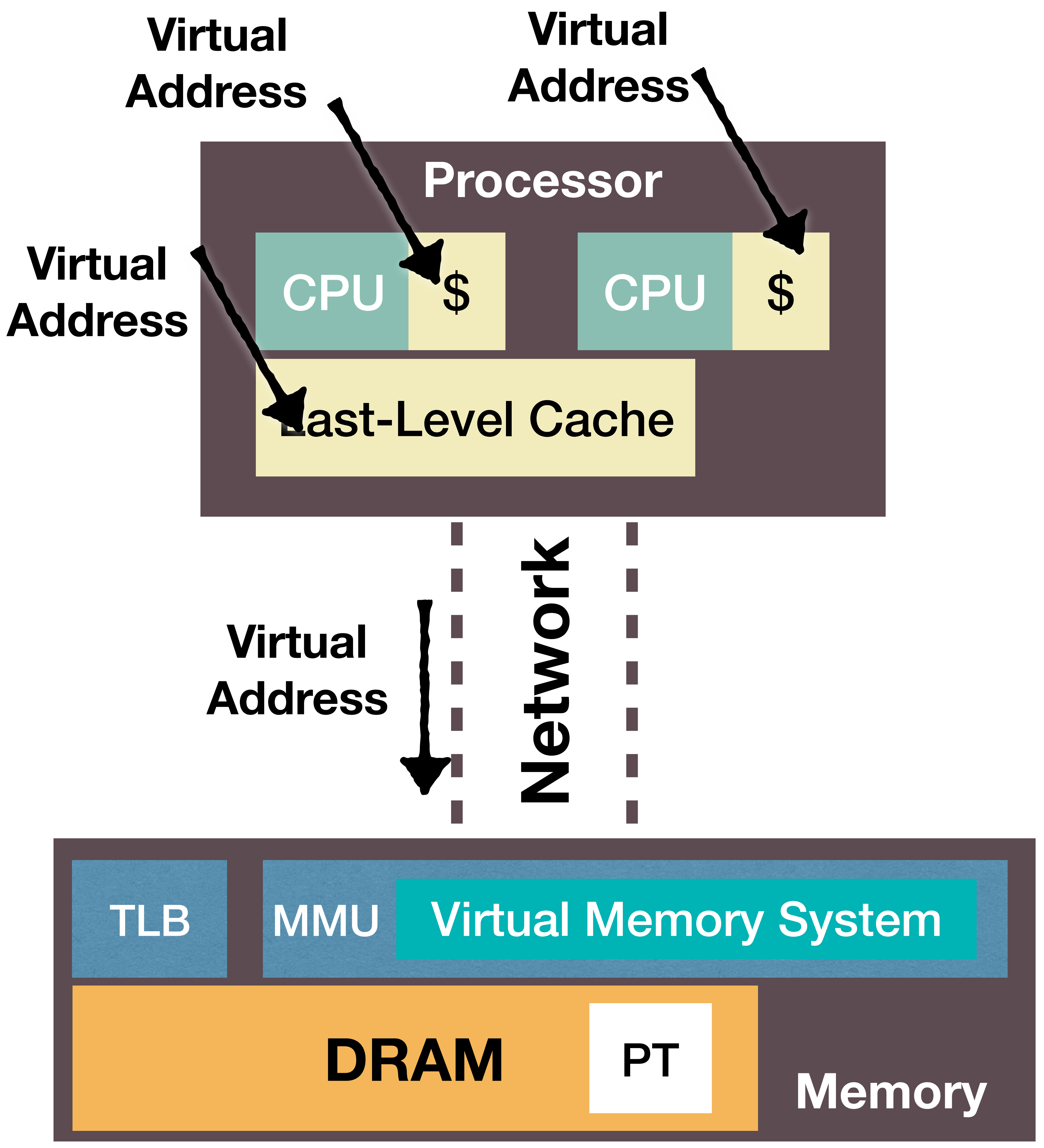


Separate Processor and Memory



Separate and move
virtual memory system
to memory component

Separate Processor and Memory



Processor components only see virtual memory addresses

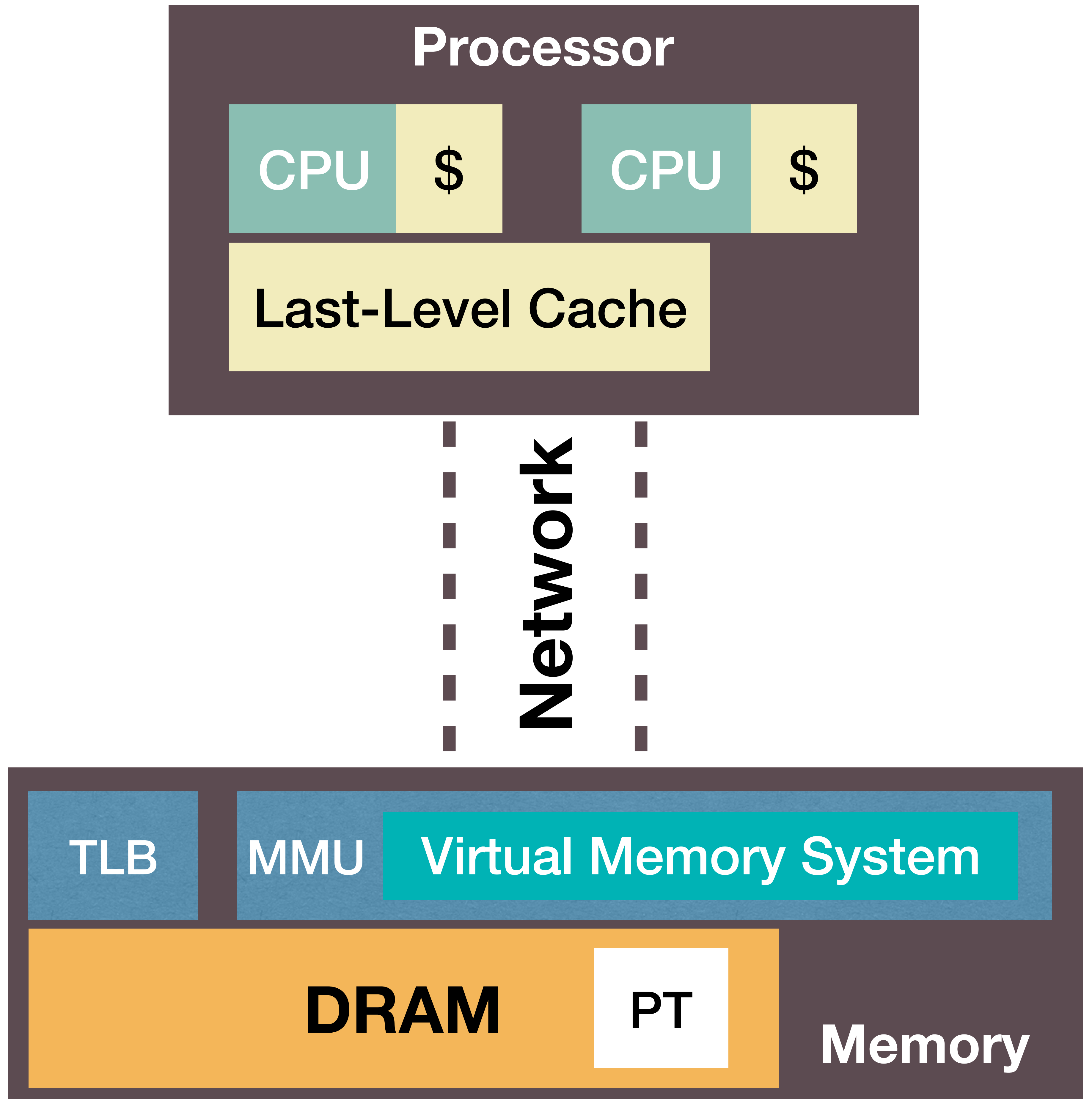
All levels of cache are ***virtual cache***

Memory components manage virtual and physical memory

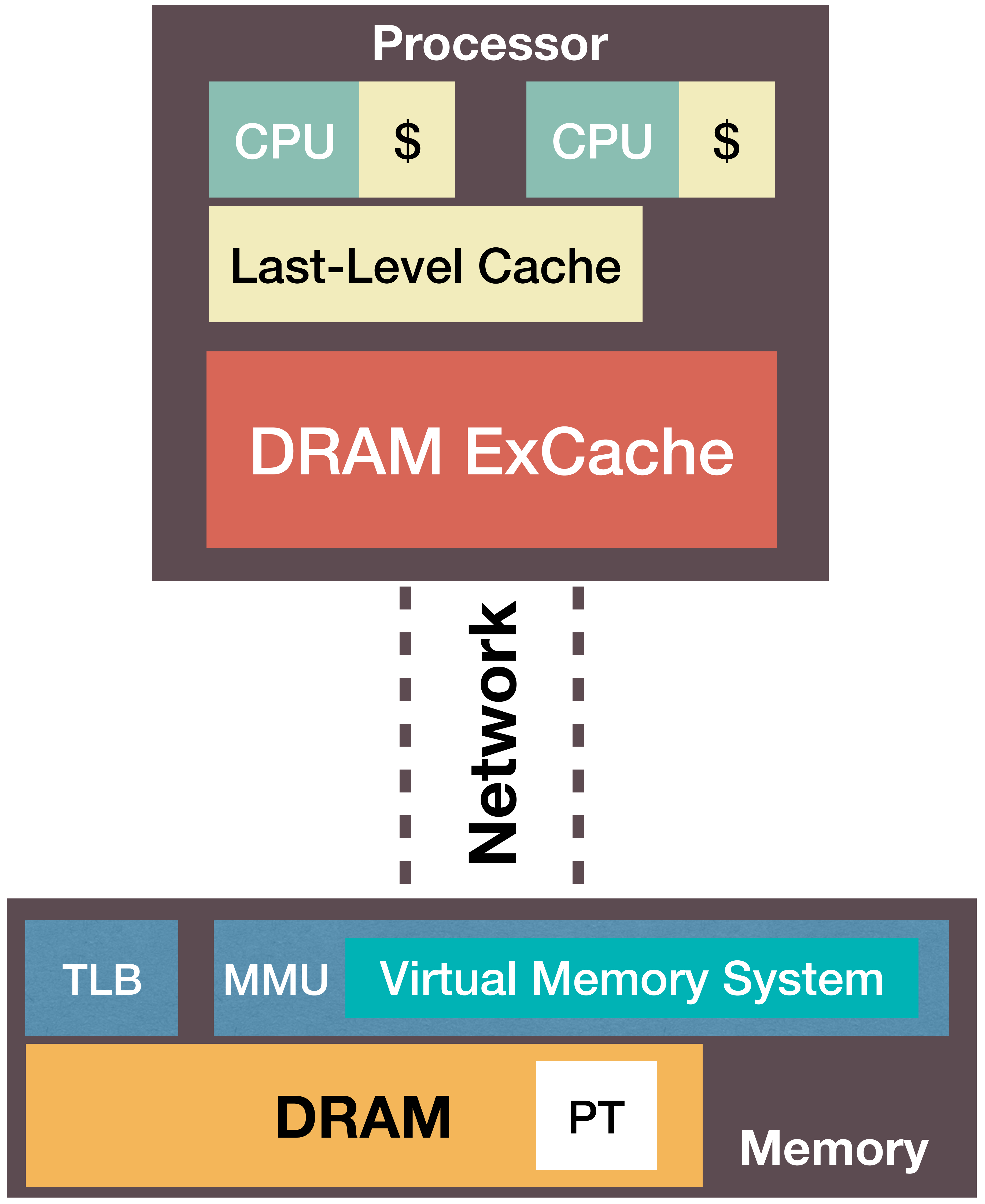
Challenge: Remote Memory Accesses

- Network is still slower than local memory bus
    - Bandwidth: 2x - 4x slower, improving fast
    - Latency: ~12x slower, and improving slowly

Add Extended Cache at Processor



Add Extended Cache at Processor



- Add small DRAM/HBM at processor
- Use it as Extended Cache, or ***ExCache***
    - Software and hardware co-managed
    - Inclusive
    - Virtual cache

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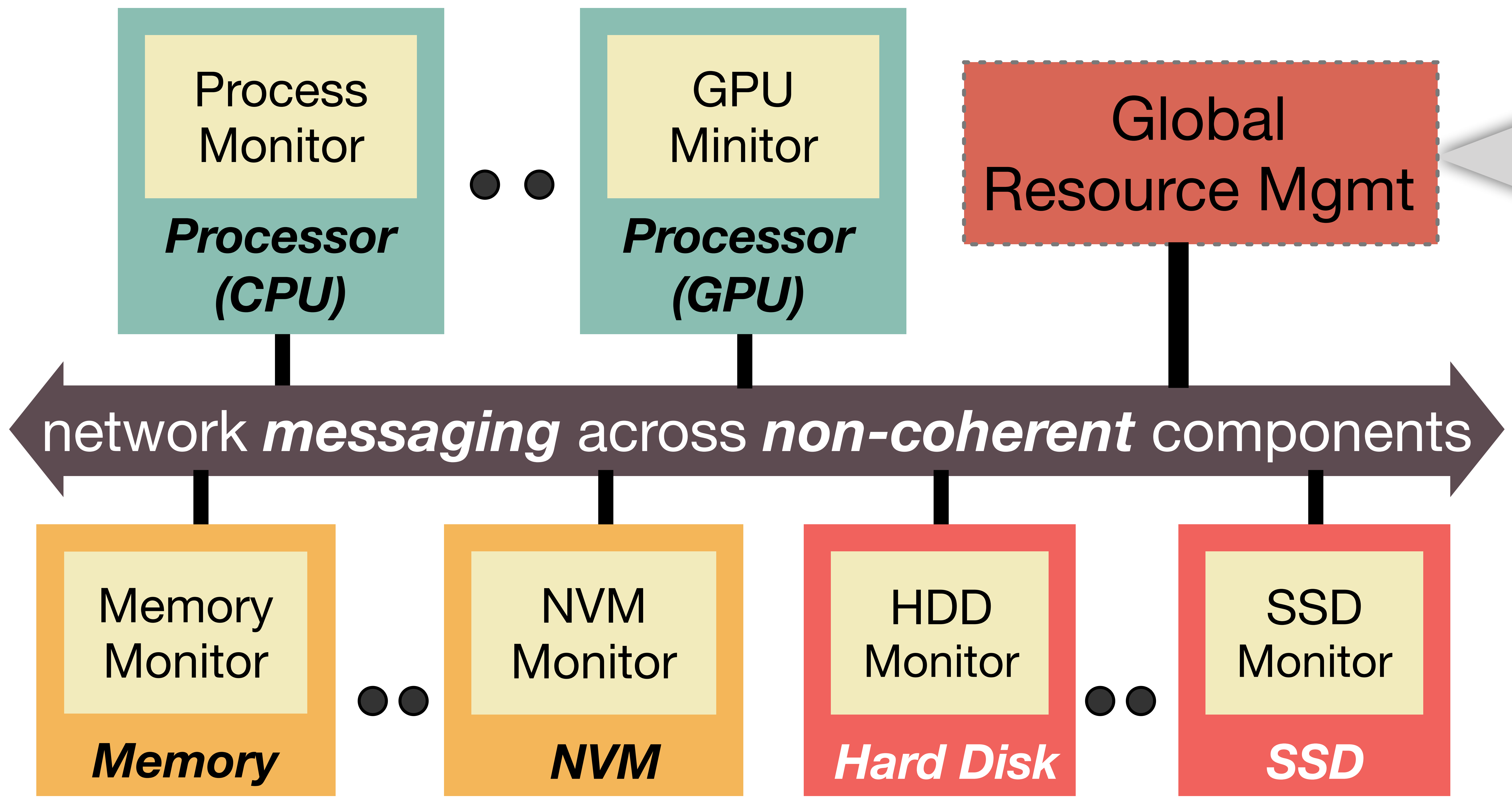
Distributed Resource Management



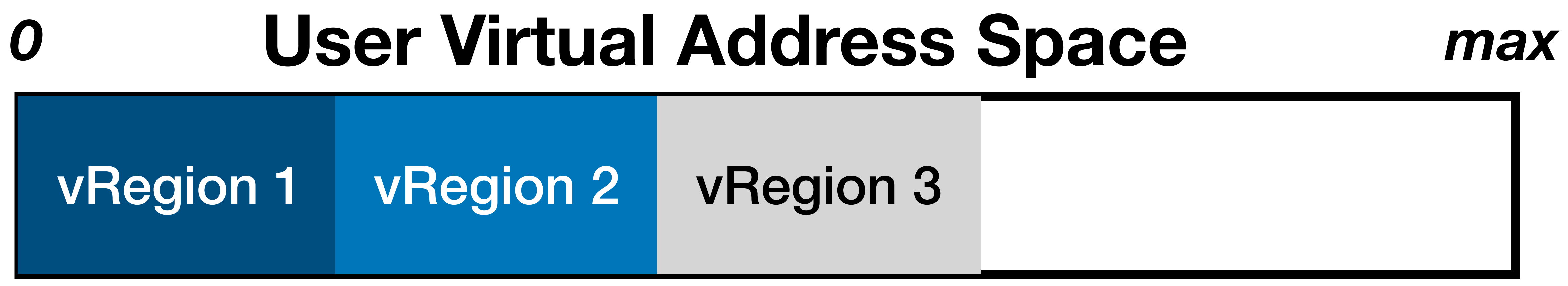
Global Process Manager (*GPM*)

Global Memory Manager (*GMM*)

Global Storage Manager (*GSM*)

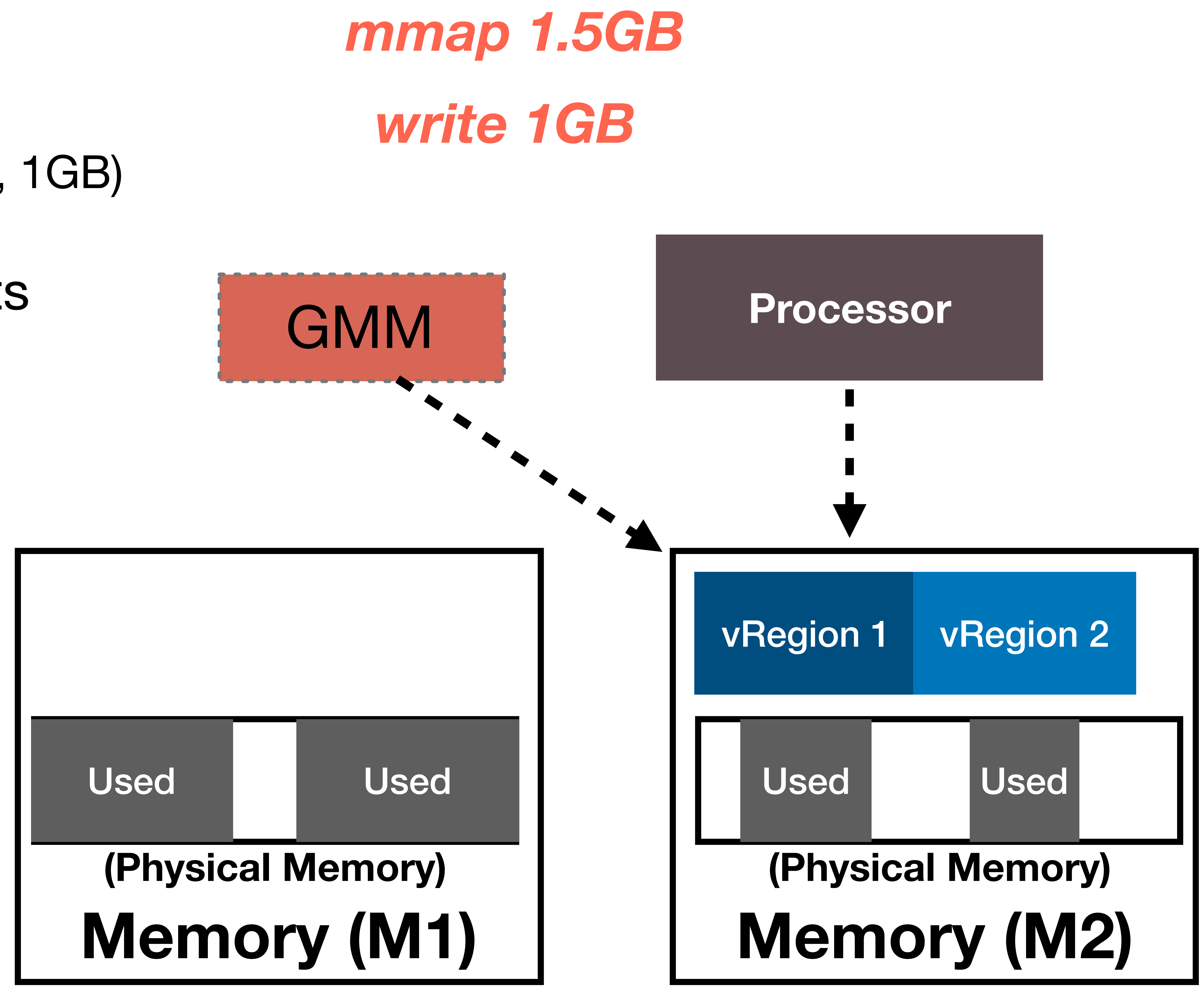
1. **Coarse-grain allocation**
2. **Load-balancing**
3. **Failure handling**

Distributed Memory Management

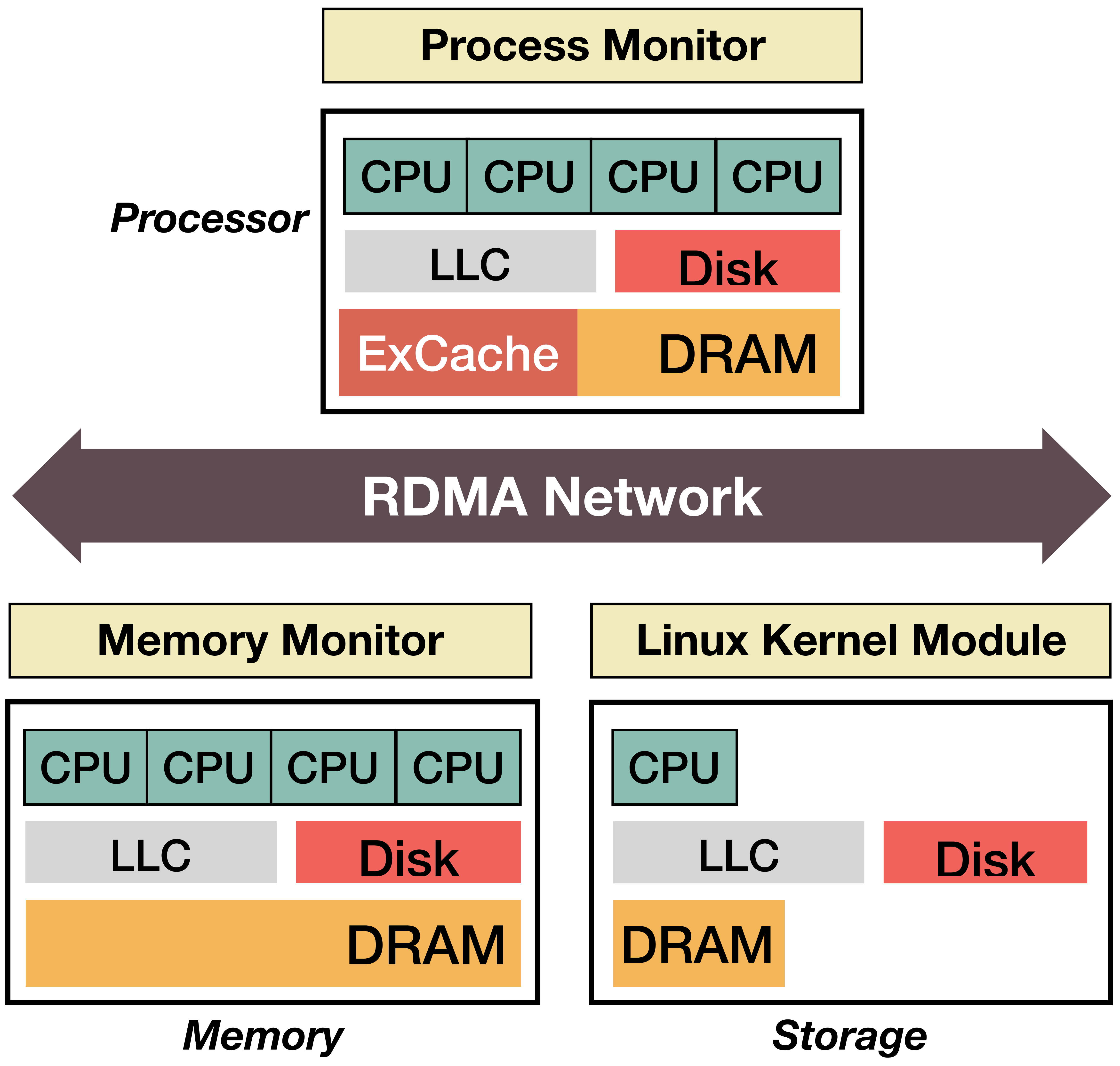


fix-sized, **coarse-grain** virtual region (***vRegion***) (e.g., 1GB)

- GMM assigns vRegions to mem components
  - On virtual mem alloc syscalls (e.g., `mmap`)
  - Make decisions based on global loads
- Owner of a vRegion
  - Fine-grained virtual memory allocation
  - **On-demand** physical memory allocation
  - Handle memory accesses

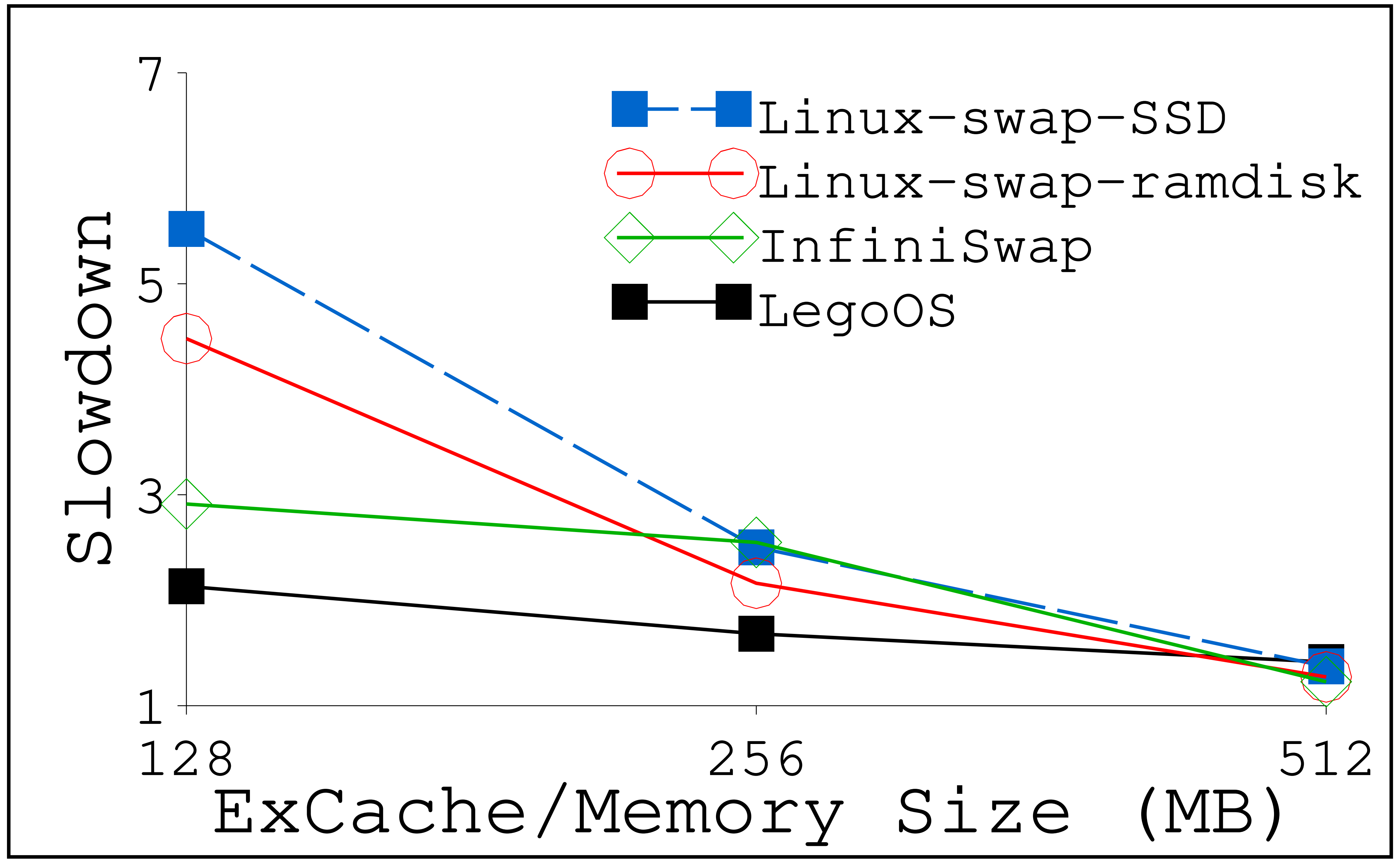


Implementation and Emulation



- **Status**
  - 206K SLOC, runs on x86-64, **113** common Linux syscalls
- **Processor**
  - Reserve DRAM as ExCache (4KB page as cache line)
  - h/w only on hit path, s/w managed miss path
- **Memory**
  - Limit number of cores, kernel-space only
- **Storage/Global Resource Monitors**
  - Implemented as kernel modules on Linux
- **Network**
  - RDMA RPC stack based on LITE [*SOSP'17*]

Performance Evaluation



LegoOS Config: 1P, 1M, 1S

- Unmodified TensorFlow, running CIFAR-10
  - Working set: 0.9G
  - 4 threads
- Systems in comparison
  - Baseline: Linux with unlimited memory
  - [illegible]

Only 1.3x to 1.7x slowdown when disaggregating devices with LegoOS

To gain better resource packing, elasticity, and fault tolerance!

Conclusion

- Hardware resource disaggregation is promising for future datacenters
- The splitkernel architecture and LegoOS demonstrate the feasibility of resource disaggregation
- Great potentials, but many unsolved challenges!

Thank you! Questions?

Open source @
LegoOS.io

Poster Tonight. Number 11.

WukLab.io

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