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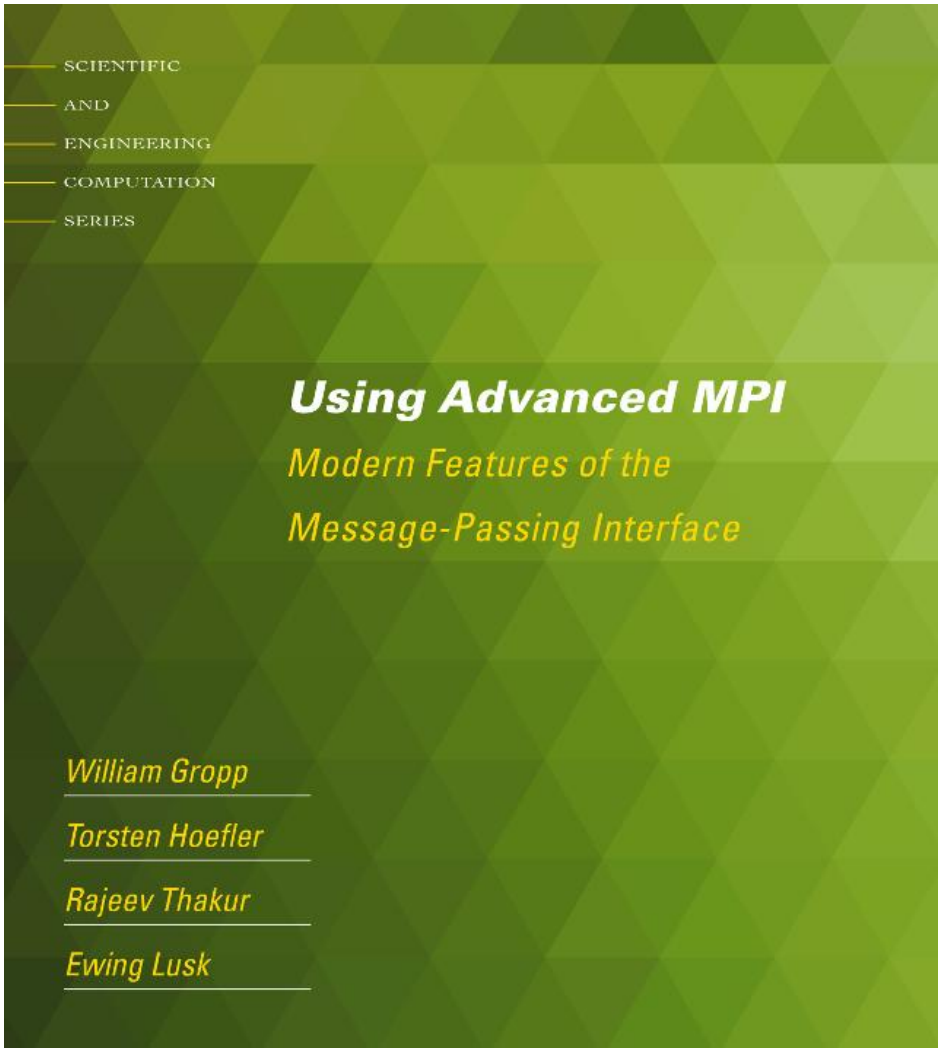
Distributing the Data Plane for Remote Storage Access

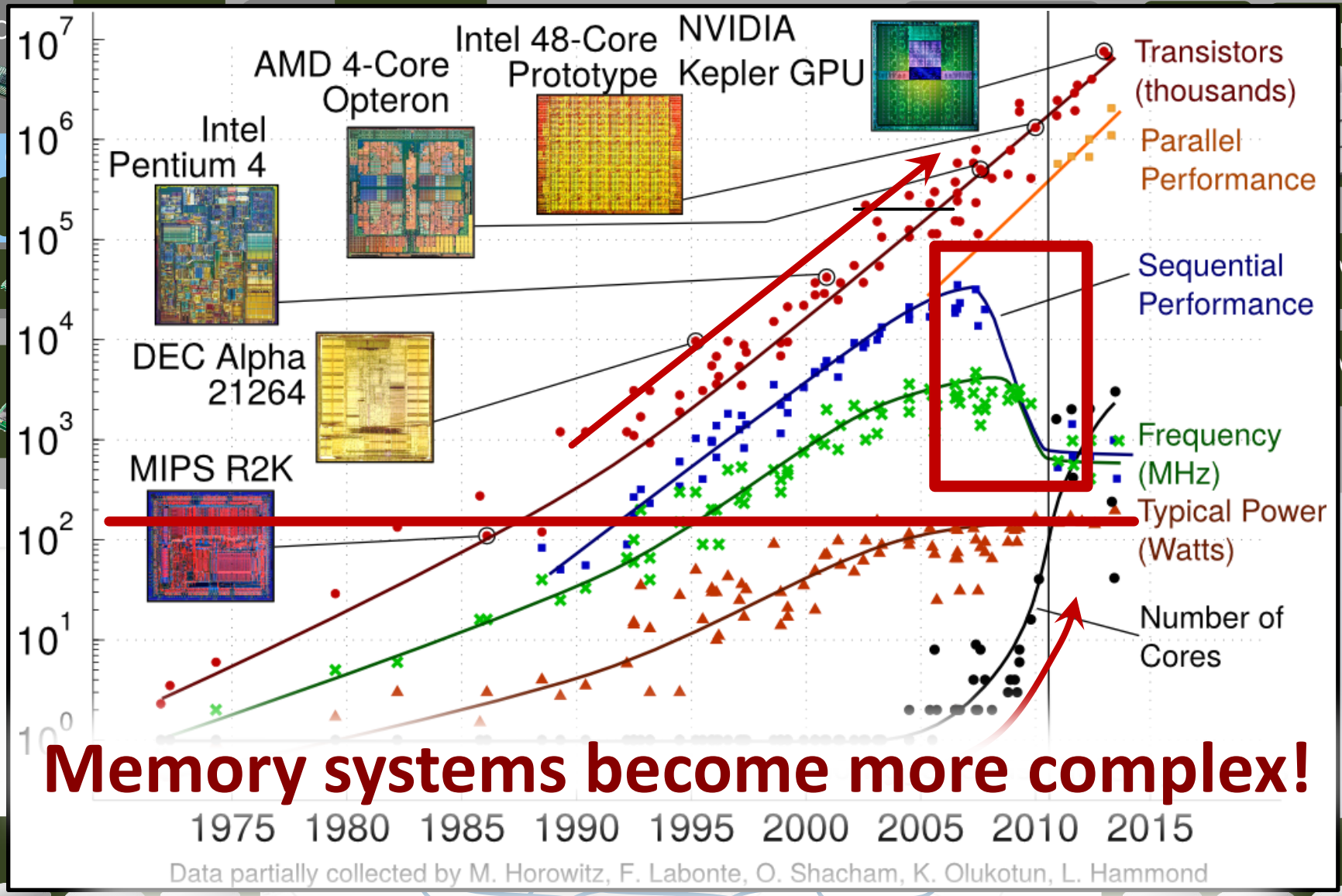
With slides input from M. Besta!

My outing

- I'm an HPC (systems) guy

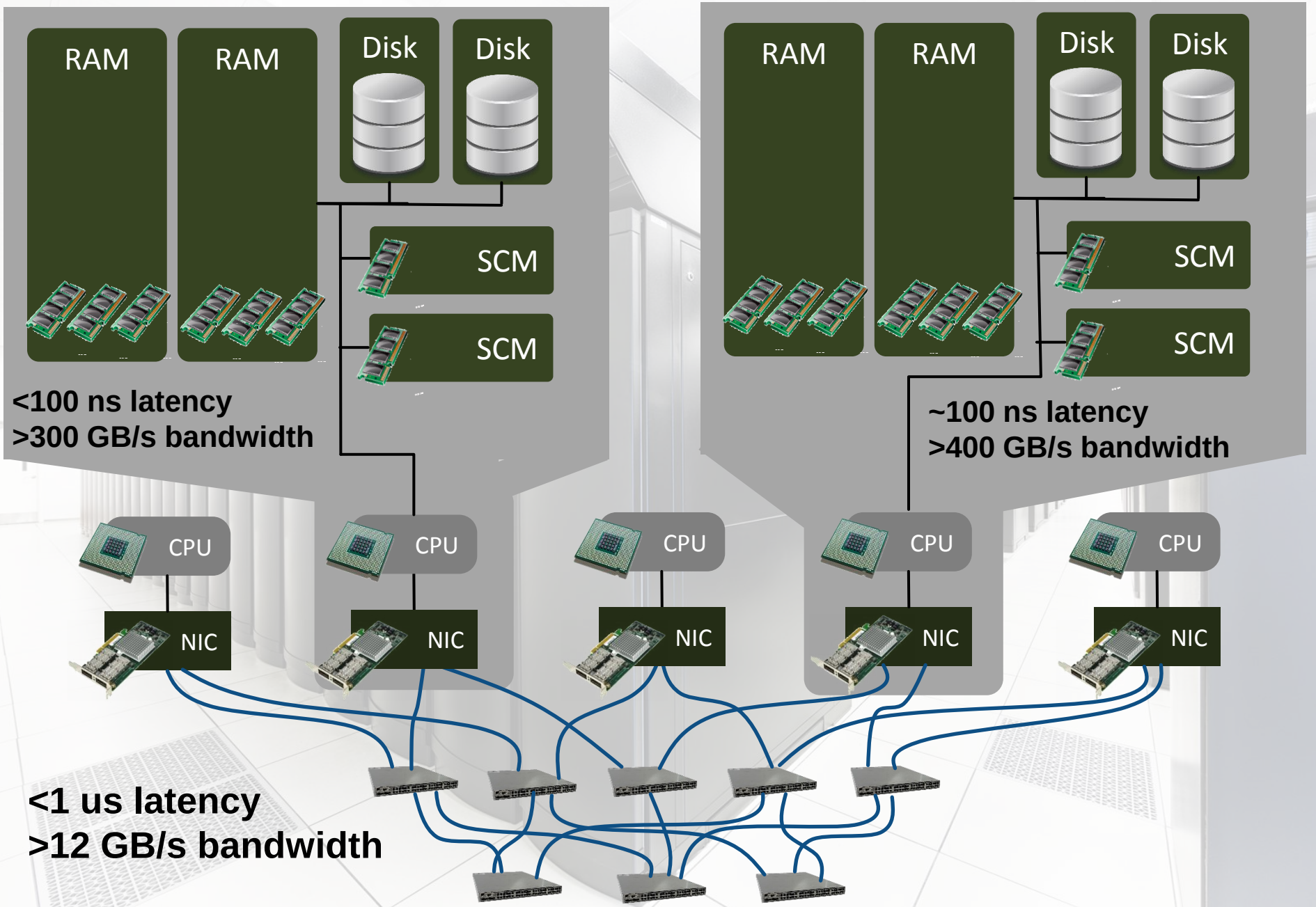


- Programming Models
- Performance Models
- Network (Models)

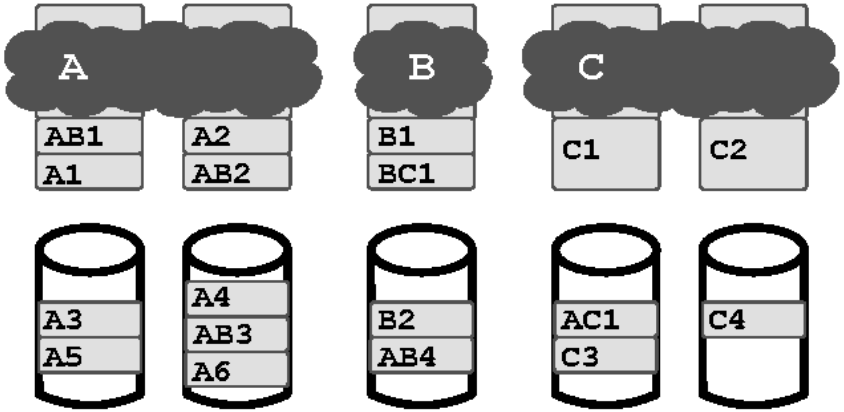


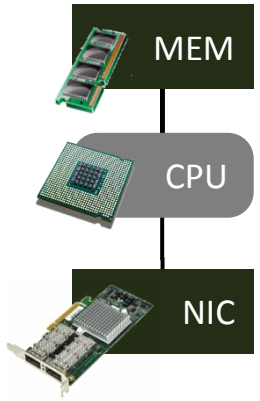
Memory systems become more complex!

Data movement is the new challenge!


RAM
RAM
Disk
Disk
SCM
SCM
<100 ns latency
>300 GB/s bandwidth
RAM
RAM
Disk
Disk
SCM
SCM
~100 ns latency
>400 GB/s bandwidth
CPU
CPU
CPU
CPU
CPU
NIC
NIC
NIC
NIC
NIC
<1 us latency
>12 GB/s bandwidth

… but software is lacking behind.





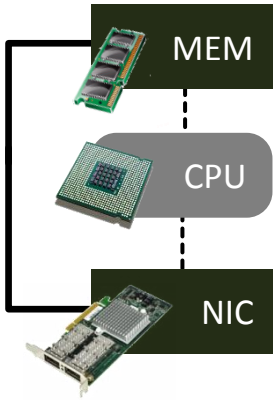
>>1 us latency

- **Our use-cases:**
  - Advanced parallel programming (e.g., MPI-IO [1])
  - Data analytics chains (e.g., DataPath [2], Niad [3])
- **File systems are served through the CPU**
  - *Access to remote persistent storage in a closely-coupled computer cluster is one of the main obstacles to scaling performance*
  - Huge overheads: *Energy, Time, Cost*

[1]: Gropp, W., TH, Thakur, R., and Lusk, E. Using Advanced MPI: Modern Features of the Message-Passing Interface. MIT Press, Nov. 2014.
[2]: Arumugam, S. et al.. The DataPath System: A Data-centric Analytic Processing Engine for Large Data Warehouses. In SIGMOD'10
[3]: Murray, D. G., McSherry, F., Isaacs, R., Isard, M., Barham, P., and Abadi, M. Naiad: A Timely Dataflow System. In SOSP'13

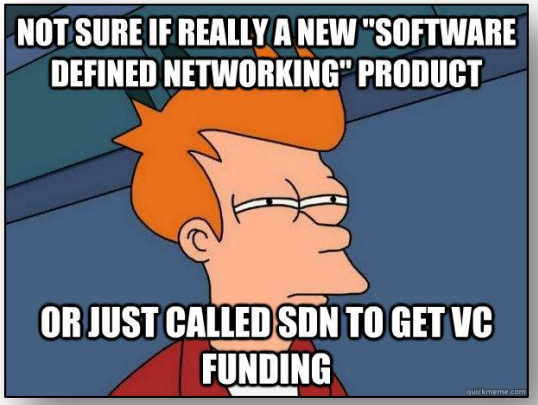
A (30-year-old) networking idea revived

- **Separating data and control plane**
  - Get the CPU/software out of the way!
  - Software-defined IO (SDIO, cf. NASD [1], Aerie [2])
  - *We set up a network route right into the device!*



<1 us latency

- **Key point is (direct) access to storage**
  - Allocation
  - Read/Write
  - Protection
  - Caching
  - Consistency, coherence, durability

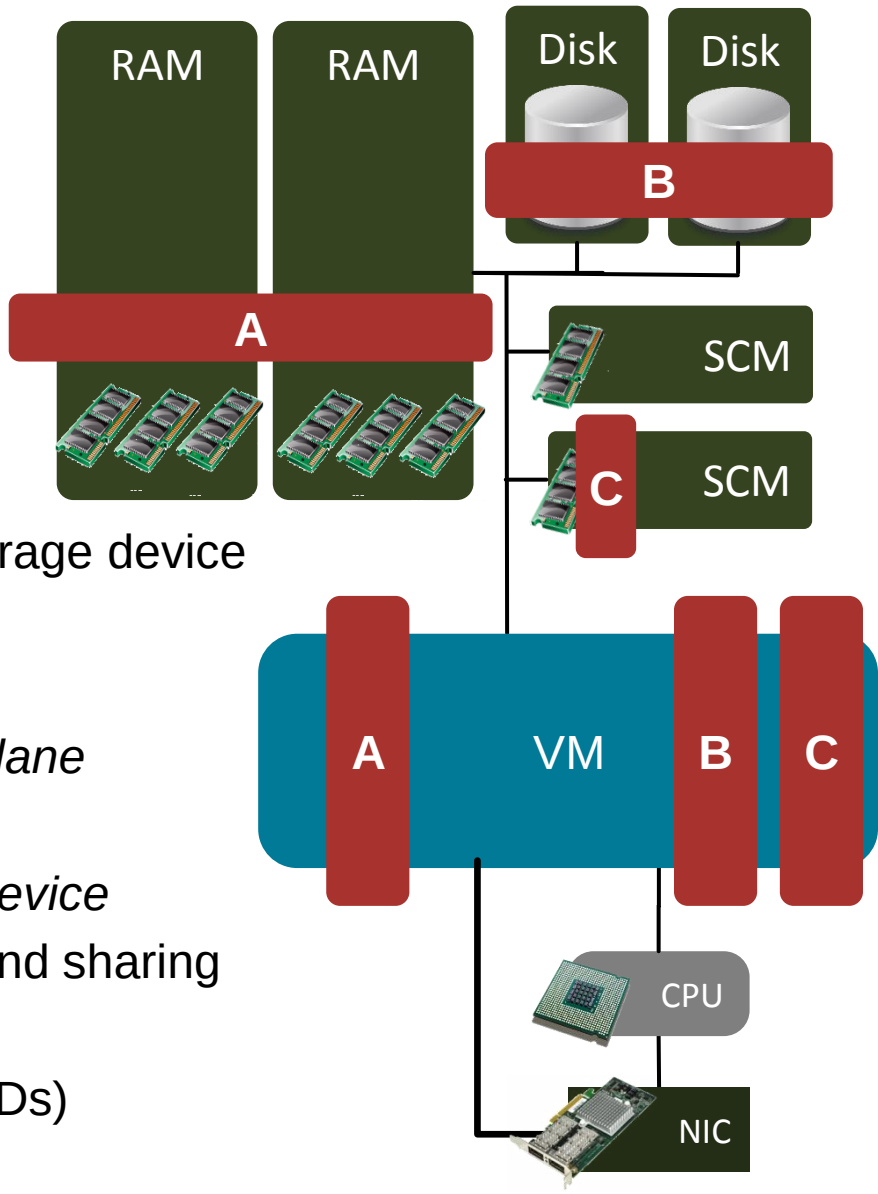


- **Our central research question:**
  - *How can we design a fast software/hardware data plane for safe, secure, direct remote access to persistent storage devices?*

[1]: Gibson, G., et al. A Cost-effective, High-bandwidth Storage Architecture. SIGPLAN Not. 33, 11 (Oct. 1998)
[2]: Volos, H., et al.. Aerie: Flex-ible File-system Interfaces to Storage-class Memory, EuroSys'14

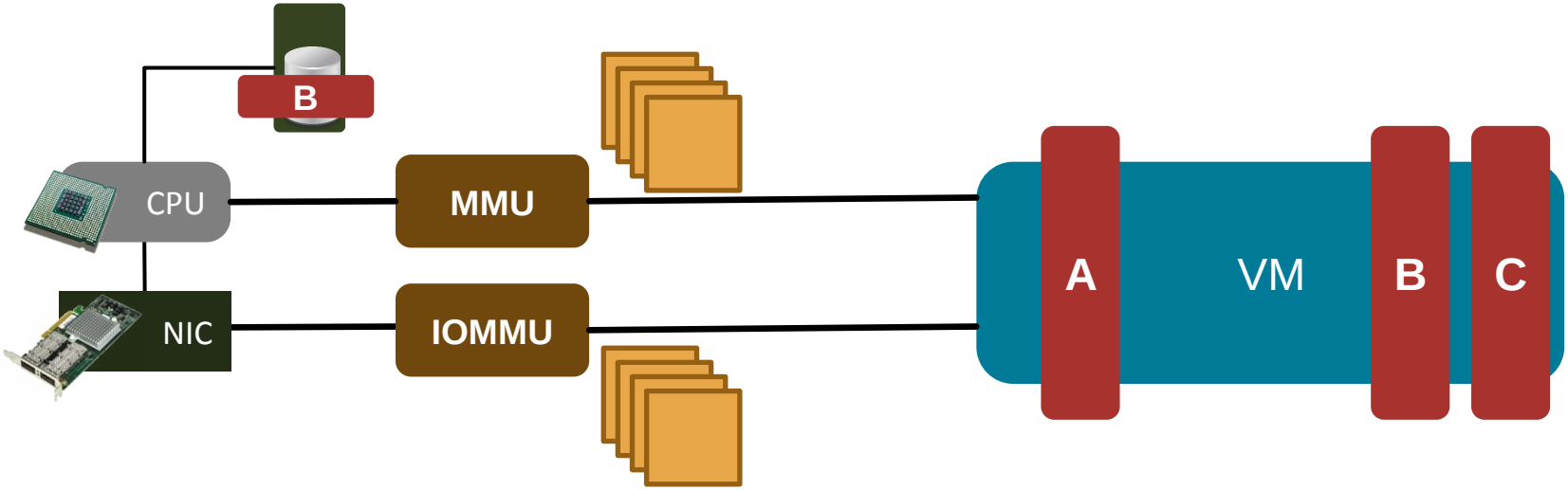
(1) Device allocations

- **Exokernel-like filesystem library**
  - Data path 100% in user-level
    Manages metadata, data, and coordination
  - Data is stored in allocations
- **An allocation …**
  - Is an area of main memory or on a storage device
    Placed explicitly
  - Can be created, opened, or closed
    Using a central or distributed control plane
  - Has a contiguous address space
    Block translation implemented in the device
  - Is the smallest unit of access control and sharing
    Named in a global namespace
  - Access through capabilities (e.g., IB PDs)



(2) Read/Write and protection

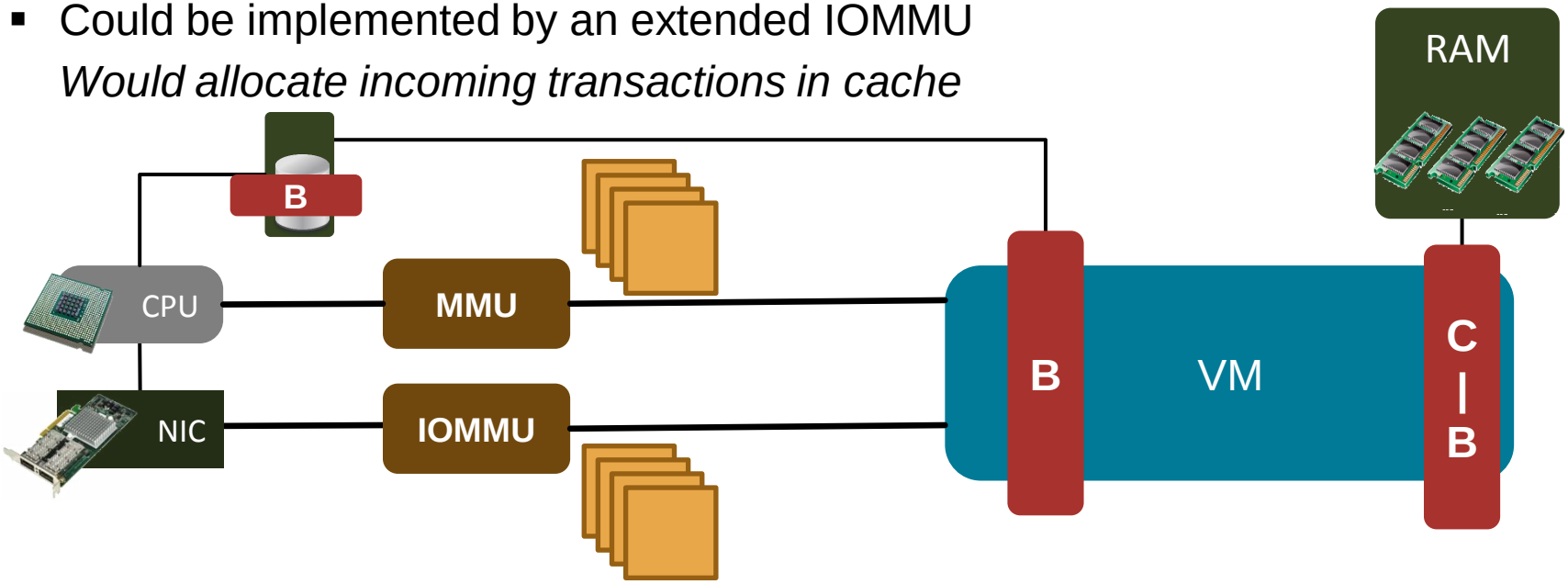
- **Allocations are accessed …**
  - Locally via MMU-mappings (cf. Aerie)
  - Remotely via IOMMUs or other address translations
- **Not all devices are part of the physical address space**
  - Mainly legacy …. two options:
  1. Software fallback (monitor RDMA regions and keep consistency)
  2. Use IOMMU logging schemes (cf. Active Access [1])



[1]: M. Besta, TH: Active Access: A Mechanism for High-Performance Distributed Data-Centric Computations, ACM ICS'15

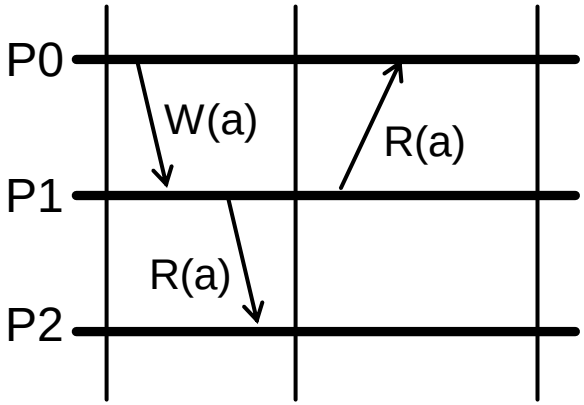
(3) Caching

- **Software caching**
  - Explicit caching, similar to RMA programming
    Allocate local cache and access it
  - Can be application-specific or caching library (standard techniques)
- **Hardware caching**
  - Set up local memory as cache for remote allocations
    Use standard (e.g., LRU) replacement policies
  - Could be implemented by an extended IOMMU
    Would allocate incoming transactions in cache



(4) Consistency and coherence

- **Current RDMA does not support consistent atomic access**
  - At least not large enough
- **We propose a weaker consistency model**
  - All read/write accesses are nonblocking!
  - Arrange accesses into epochs separated by fence operations
    Modified data is only valid at the end of an epoch
  - The type determines the isolation level
    Shared: only consistency after epoch ends
    Exclusive: consistency + atomicity
    Persistent: consistency + durability
    Optimistic: consistency + atomicity but can fail
  - Types can be combined
    e.g., persistent + exclusive



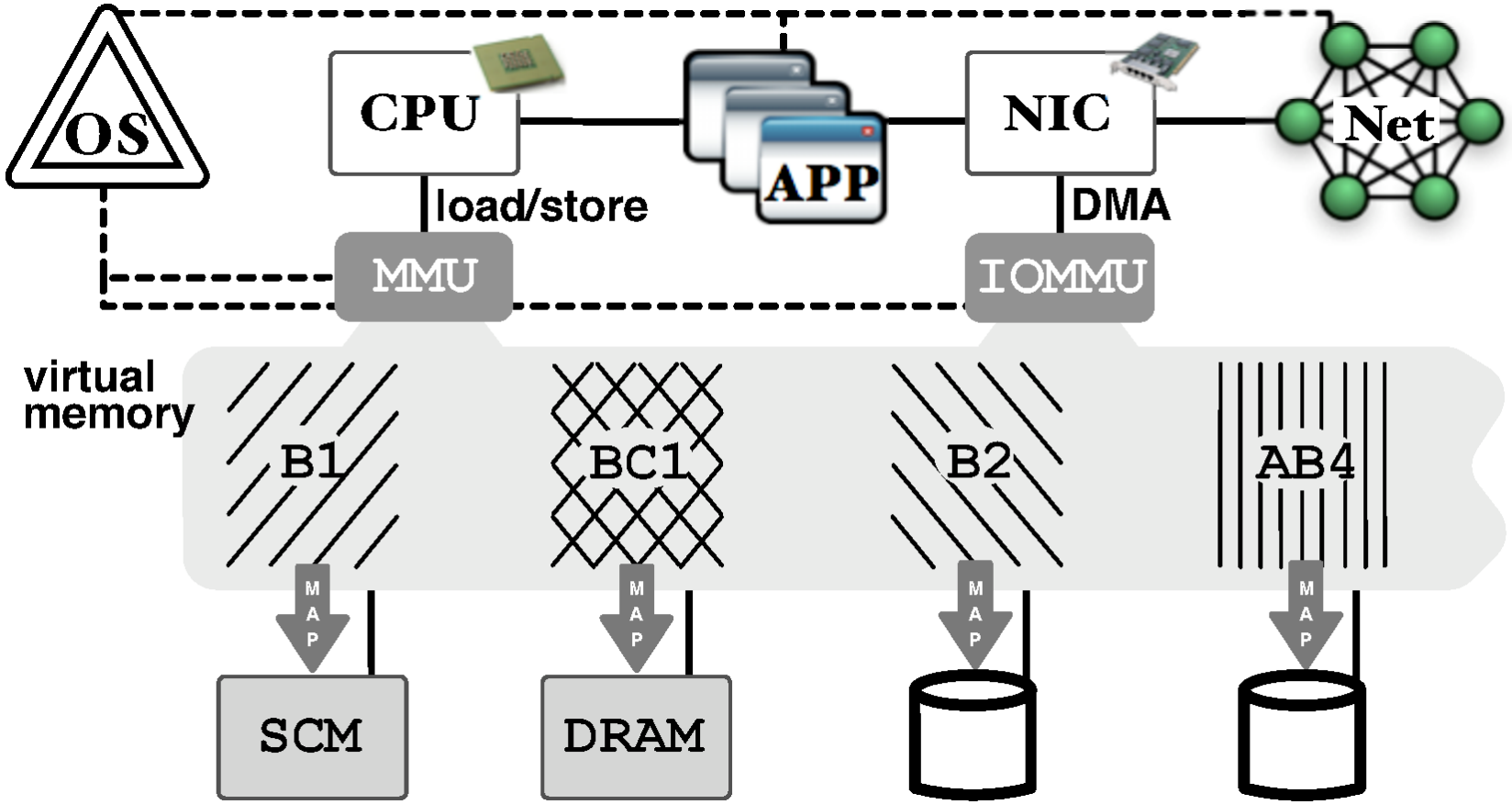
- **Implemented similar to other RMA programming models [1]**
  - May require remote flushes (in the worst case RPCs)

[1]: TH, J. Dinan, R. Thakur, B. Barrett, P. Balaji, W. Gropp, K. Underwood: Remote Memory Access Programming in MPI-3, ACM TOPC

Other filesystem requirements

- **Crash recovery**
  - Use transactional (optimistic, exclusive, persistent) epochs for metadata
  - Must ensure that locks time out if processes disappear
- **Scalability**
  - Scoping limits context of coherency/epochs (e.g., a shared file)
  - Integration with programming model (e.g., MPI-3 RMA)
- **Compatibility**
  - Provide standard library of user-level file systems
  - POSIX consistency with single-operation exclusive, persistent epochs
  - Magic byte in allocation allows automated “mounting” like files

Discussion



Merge the network transparently into the file system.