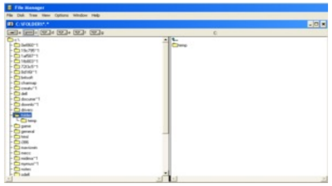
UNIVERSITY OF COPENHAGEN

Modularity through Clients and Services, RPC Techniques for Performance

ACS, Dmitriy Traytel

Do-it-yourself Recap: Fundamental abstractions

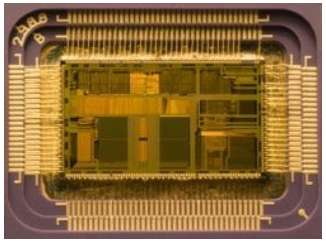




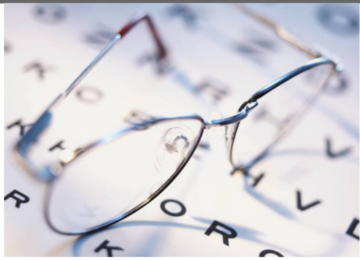
- Which were the three fundamental abstractions?
- What were their APIs?

(loop (print (eval (read))))

- Must these abstractions be implemented in a single node or can they be distributed? Give an example!



Source: Saltzer & Kaashoek & Morris (partial)



What should we learn today?

- Recognize and explain modular designs with clients and services
- Predict the functioning of service calls under different RPC semantics and failure modes
- Identify different mechanisms to achieve RPCs
- Implement RPC services with an appropriate mechanism, such as web services
- Explain performance metrics such as latency, throughput, overhead, utilization, capacity, and scalability
- List common hardware parameters that affect performance
- Apply performance improvement techniques, such as concurrency, batching, dallying, and fast-path coding

Interpreters

- ***Interpreter***
  - Instruction repertoire
  - Environment
  - Instruction pointer

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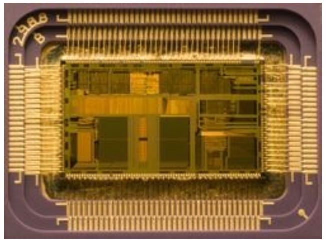


```
procedure INTERPRET()
        do forever
                instruction ← READ(instruction_pointer)
                perform instruction in environment context
                if interrupt_signal = TRUE then
                instruction_pointer ← entry of INTERRUPT_HANDLER
                environment ← environment of INTERRUPT_HANDLER
```

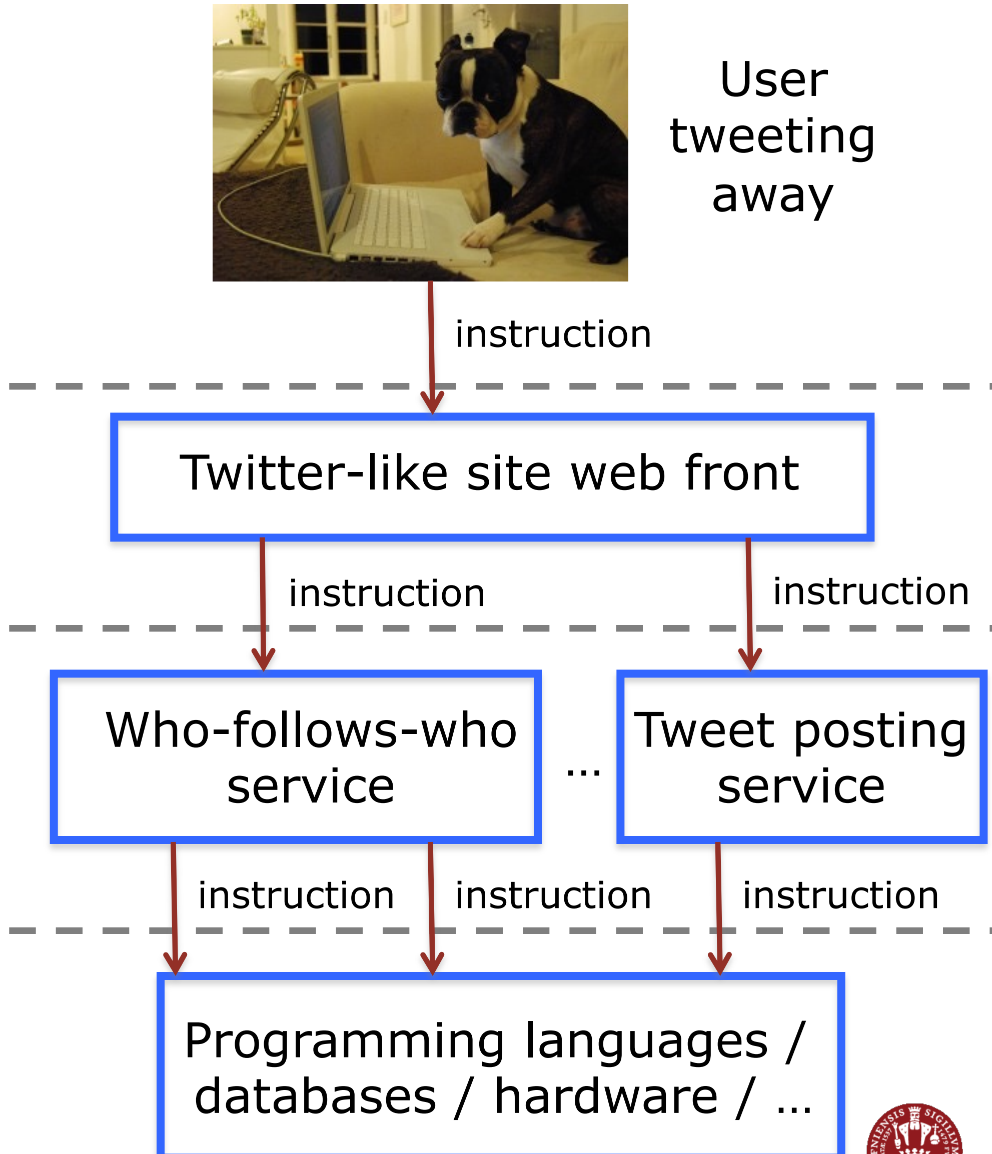
- Examples of Interpreters
  - Processors (CPU)
  - Programming language interpreters
  - Frameworks, e.g., MapReduce or Spark
  - Your own (layered) programs! (RPCs)

Source: Saltzer & Kaashoek & Morris (partial)

Layers and Modules

- Interpreters often organized in layers

- Modules
  - *Saltzer & Kaashoek glossary*: Components that can be separately designed / implemented / managed / replaced
  - "Instructions" of higher-level interpreters
  - Recursive: Can be whole interpreters themselves!



Cloud-Power @ Yahoo!

Source: Raghu Ramakrishnan, LADIS 2009 (partial)

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What happens when modules fail with (unintended) errors?

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Isolating Errors: Enforced Modularity

Clients & Services

- Restrict communication to *messages only*
- Client request / Service response (or reply)
- Conceptually client and service in different computers

OS Virtualization

- Create virtualized versions of fundamental abstractions
- Client and services remain isolated even on same computer
- VMs: Virtualize the virtualizer ☺

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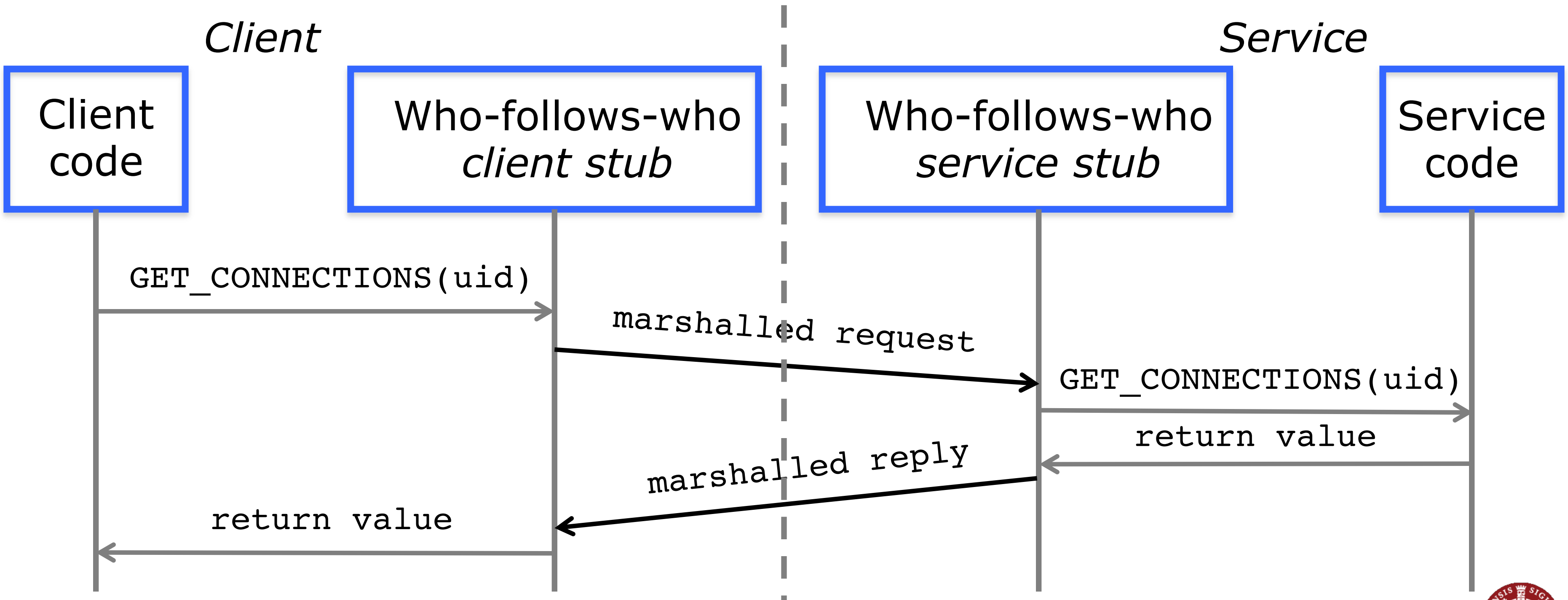
Even more techniques for fault tolerance later in the course

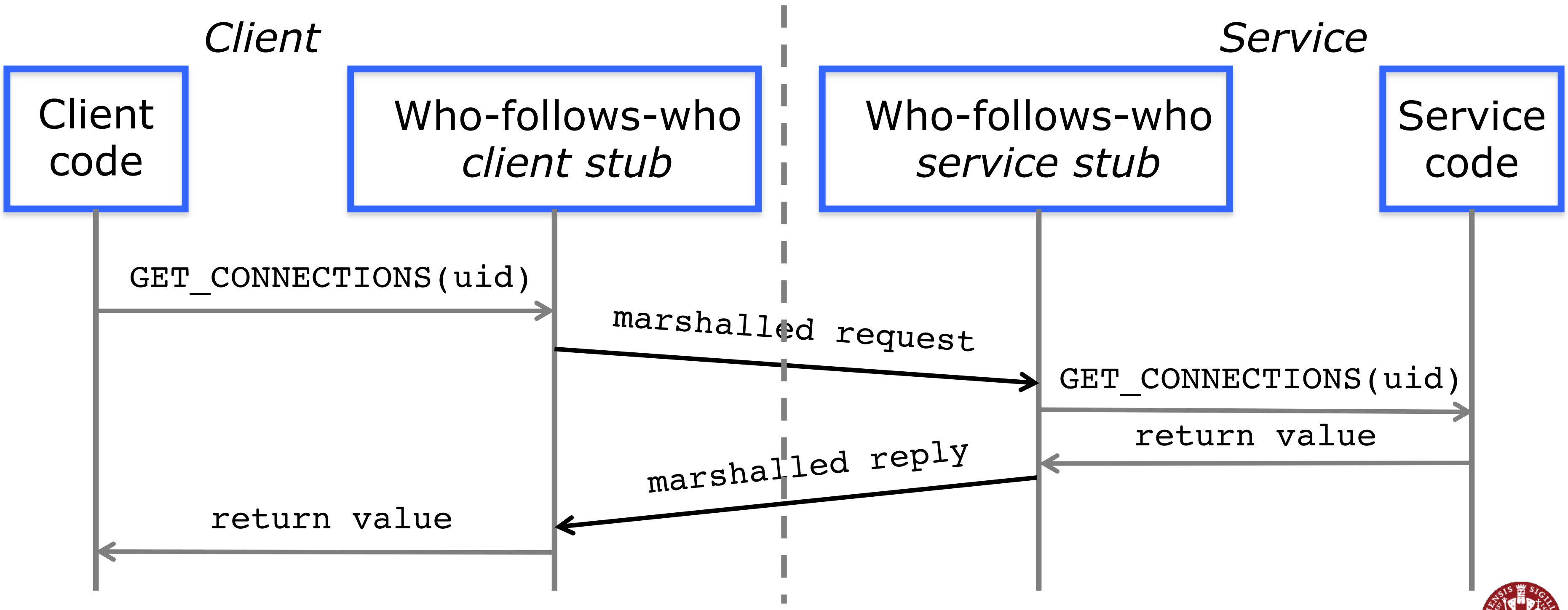
RPC: Remote Procedure Call

- Client-service request / response interactions
- Automate *marshalling* and *communication*



RPC: Remote Procedure Call

- Recall that RPC semantics differ from local procedure calls
- What can go wrong when a client crashes? What about when a server crashes?



RPC Semantics

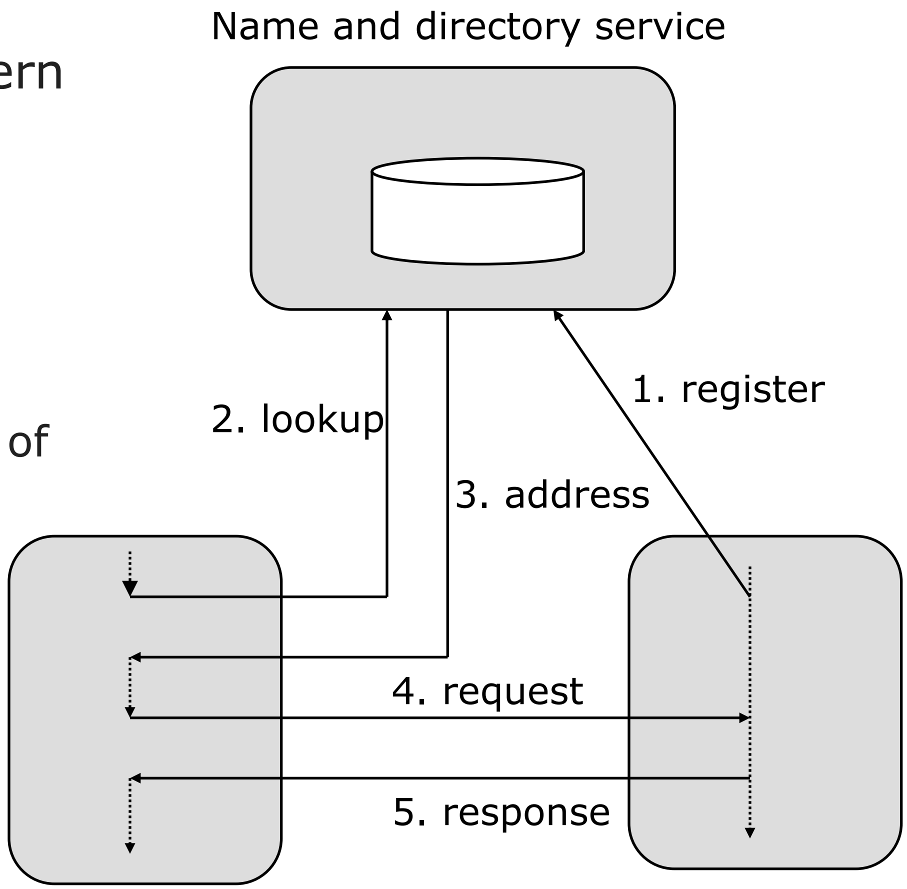
- **At-least-once**
  - Operation is *idempotent*
    - Naturally occurs if side-effect free
  - Stub just retries operation → failures can still occur!
  - Example: calculate SQRT
- **At-most-once**
  - Operation does have side-effects
  - Stub must ensure duplicate-free transmission
  - Example: transfer $100 from my account to yours
- **Exactly-once**
  - Possible for certain classes of failures
  - Stub & service keep track (*durably*) of requests and responses
  - Example: bank cannot develop amnesia! ☺

How to achieve RPCs?

- Special-purpose ***request-reply protocol***, e.g., as in DNS
  - Developer must design protocol and marshalling scheme
- ***Classic RPC*** protocols, e.g., DCE, Sun RPC
  - Special APIs and schemes for marshalling
- ***RMI: Remote Method Invocation***
  - RPCs for methods in OO languages
  - Compiler-generated proxies
- ***Web Services***
  - Many modes of communication possible, including RPC-style communication
  - Tools available to compile proxies, e.g., JAX-WS
  - Generic marshalling (e.g., XML, JSON, Protocol Buffers) over HTTP transport
    → ***programming-language independence***!

RPC and Naming

- Most basic extension to the synchronous interaction pattern
  - Avoid having to name the destination
  - Ask where destination is
  - Then bind to destination
- Advantages:
  - Development is independent of deployment properties (e.g., network address)
  - More flexibility:
    - Change of address
  - Can be combined with:
    - Load balancing
    - Monitoring
    - Routing
    - Advanced service search

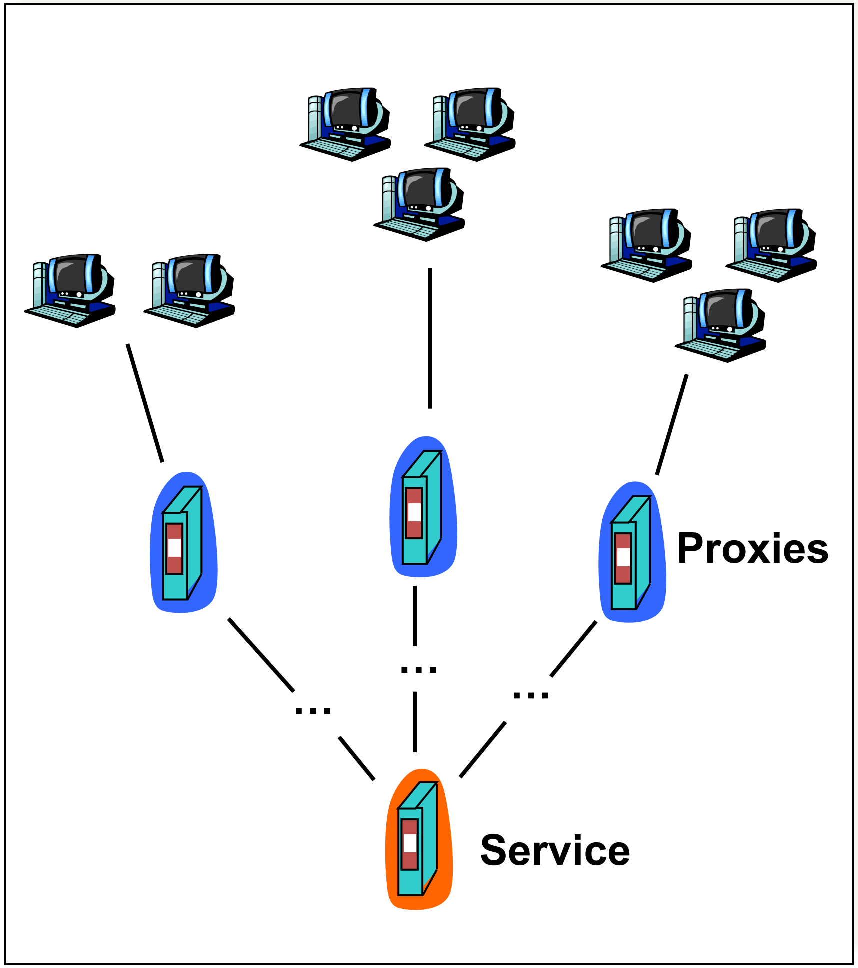


Source: Gustavo Alonso, ETH Zurich (partial)

RPCs over HTTP

- Services widely exposed on the web, accessible via HTTP

- Why is this a good idea?
- Discuss how the following features of HTTP affect service interfaces, if at all:
  - Proxies
  - Persistent connections
  - Caching



Source: Freedman (partial)

Common Issues in Designing Services

- **Consistency**
  - How to deal with *updates* from multiple clients?
- **Coherence**
  - How to refresh *caches* while respecting consistency?
- **Scalability**
  - What happens to resource usage if we increase the #clients or the #operations?
- **Fault Tolerance**
  - Under what circumstances will the service be unavailable?

Other Examples of Services

- File systems: NFS, GFS
- Object stores: Dynamo, PNUTS
- Databases: pick your favorite relational DB ☺
- Configuration: Zookeeper
- Even whole computing clouds!
  - Infrastructure-as-a-service (IaaS), e.g., Amazon EC2, Rackspace, Windows Azure
  - Platform-as-a-service (PaaS), e.g., Windows Azure, Google AppEngine
  - Software-as-a-service (SaaS), e.g., Salesforce.com, Gmail
- And many, many others
- Differences in semantics are significant!

Questions so far?

Abstractions, Implementation and Performance

- Let I_1 and I_2 be two implementations of an abstraction
- **Examples**
  - Web service with or without HTTP proxies
  - Virtual memory with or without paging
  - Transactions via concurrency or serialization

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How can we choose between I_1 and I_2?

Performance Metrics

Discussion: What do these metrics mean?

Common Issues with Performance Metrics

- Properties of ***resources*** and/or ***services***
  - Utilization, capacity
  - Overhead, throughput, latency
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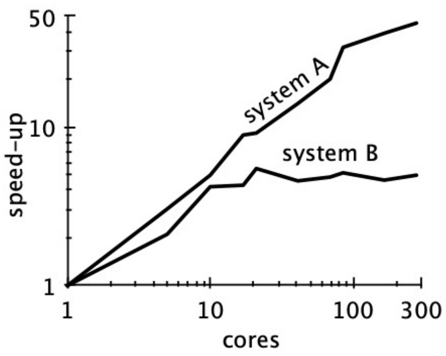

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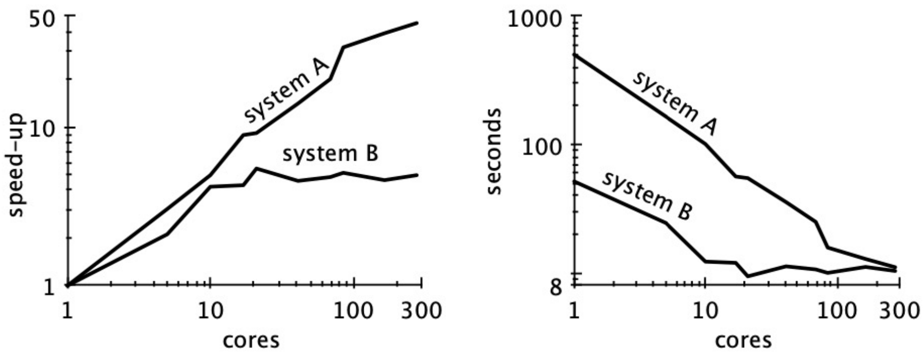

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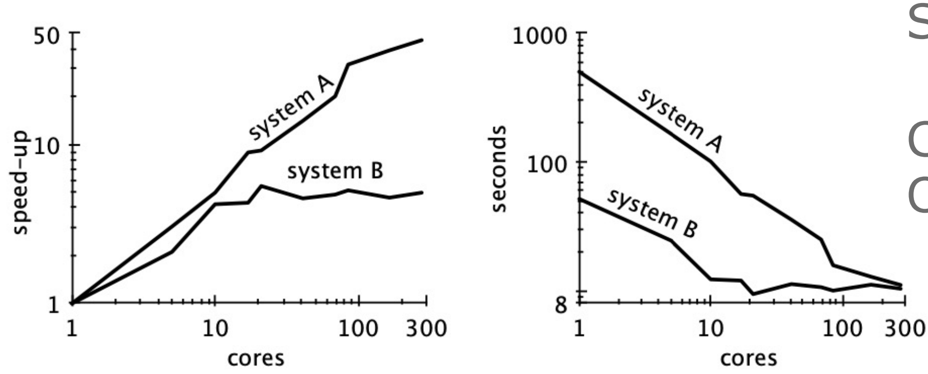

McSherry, Isard, Murray
Scalability! But at what COST?

COST = Configuration that Outperforms a Single Thread

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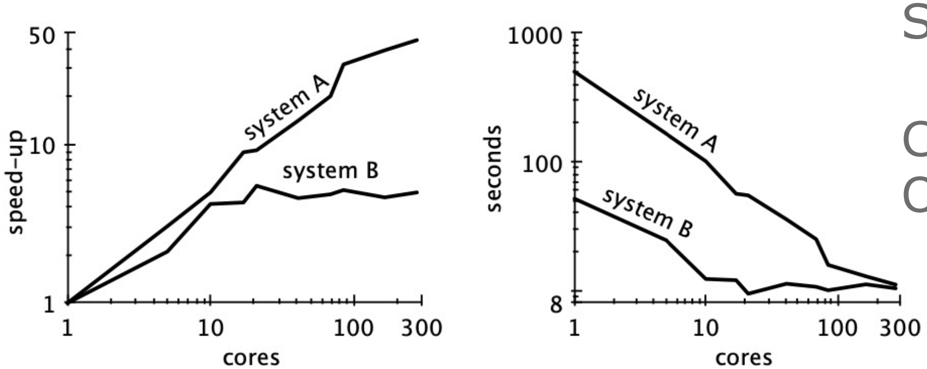

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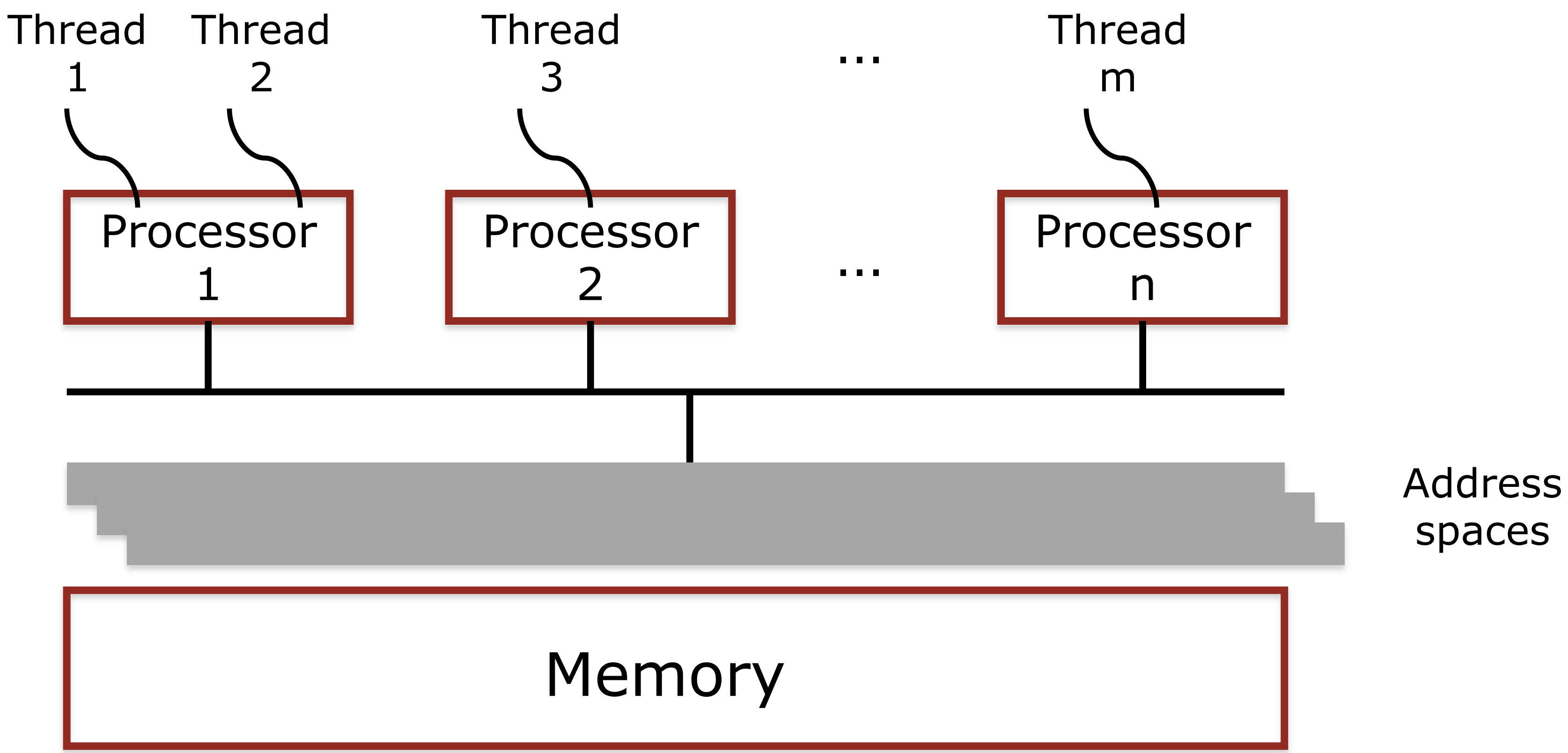
Scalability! But at what COST?

COST = Configuration that Outperforms a Single Thread

- Relationship between ***latency*** and ***throughput***
  - In serial case: latency = 1 / throughput
  - Not true when there is concurrency!

Performance and Hardware Trends

- OS-provided illusion of a computer:



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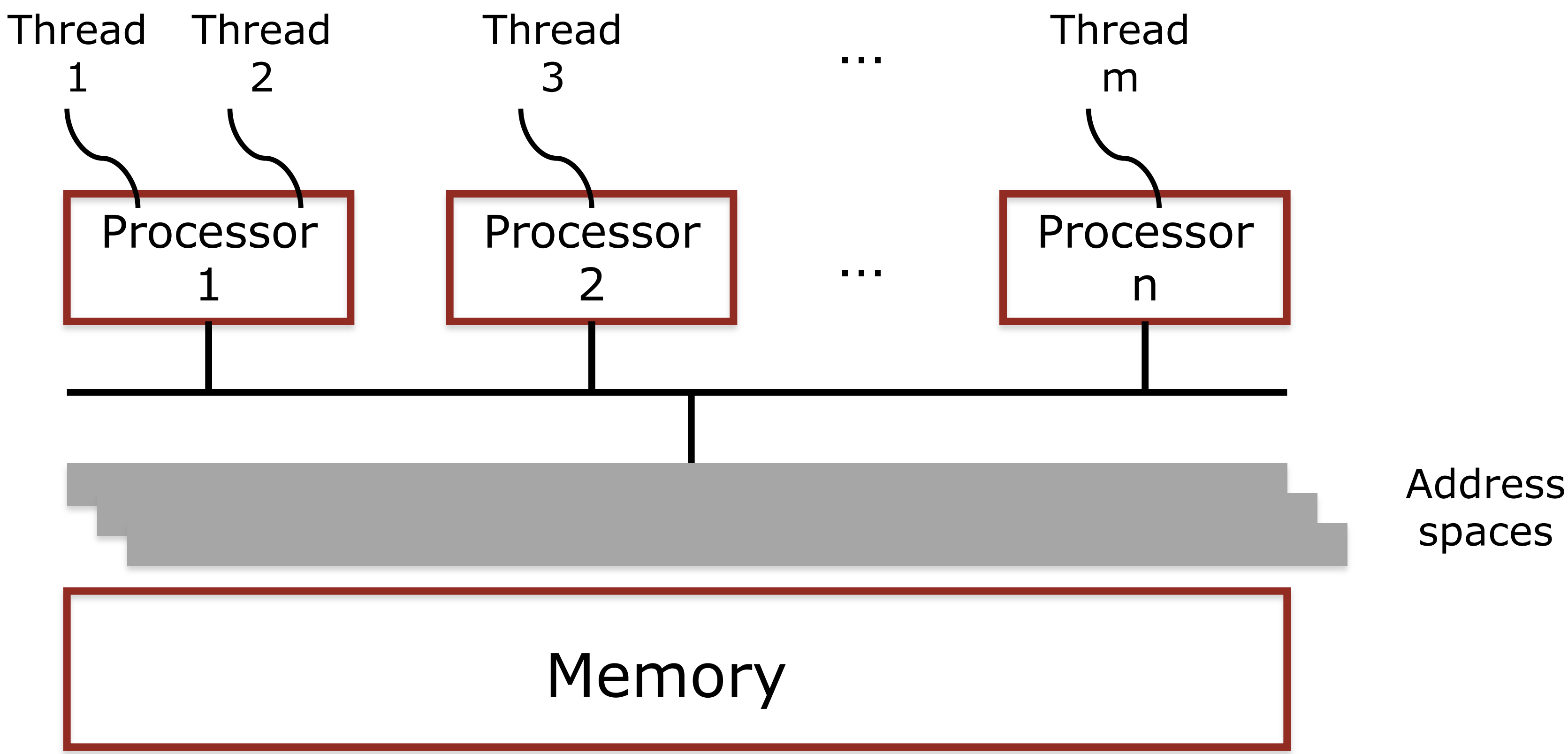
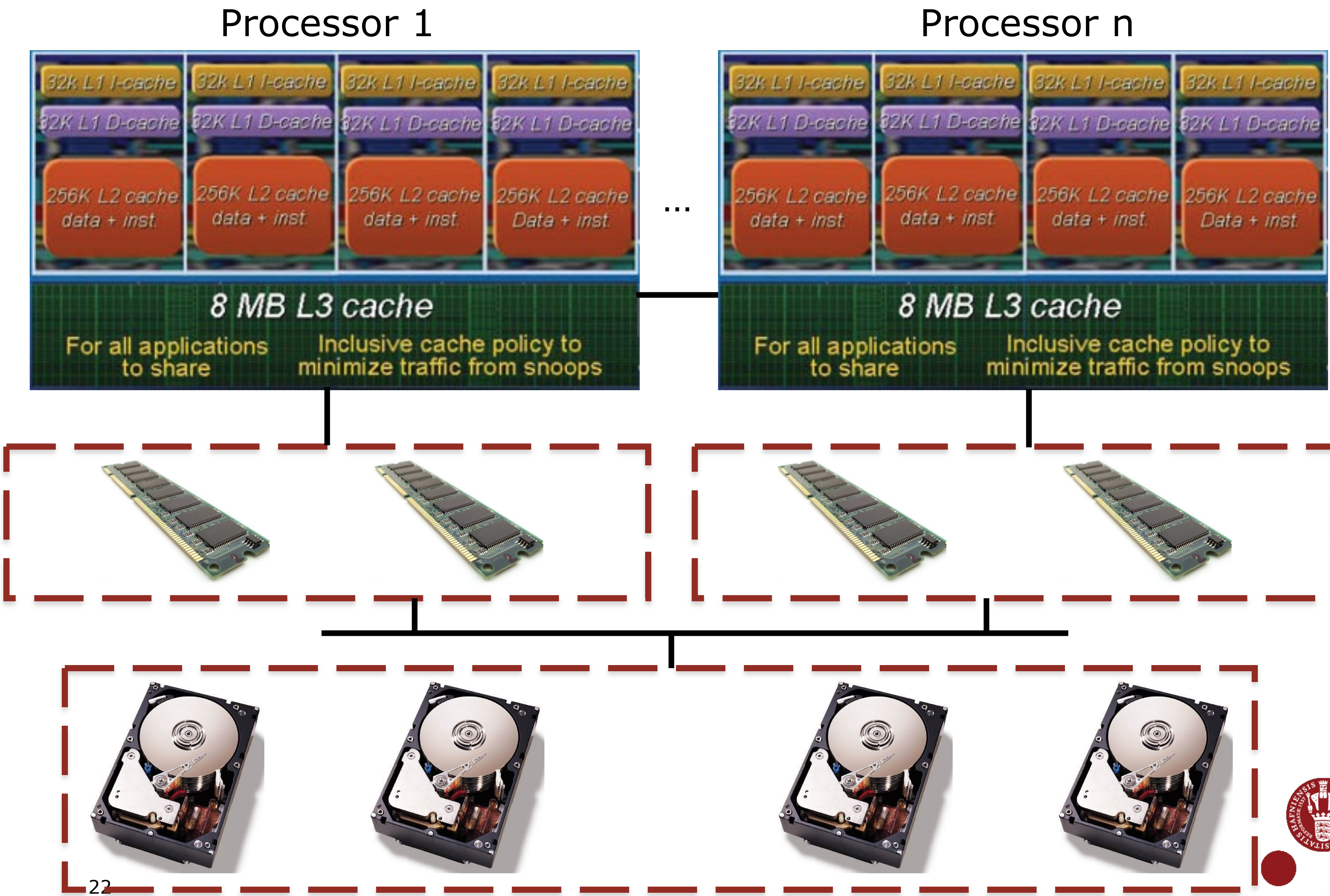


Does this picture look like a real computer?

How about this one?



But the picture is not to scale!

Size of
last-level cache

But the picture is not to scale!

Size of
last-level cache

Size of
memory

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Size of
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Size of
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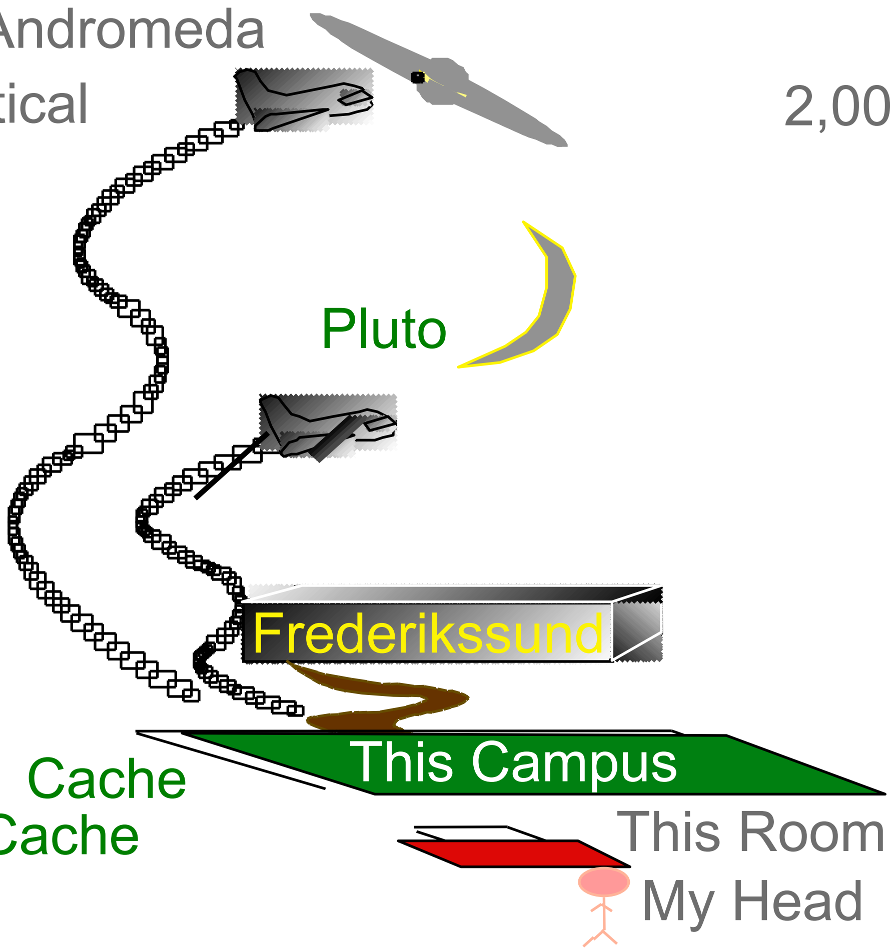
What about the size of disk?

Storage Hierarchy

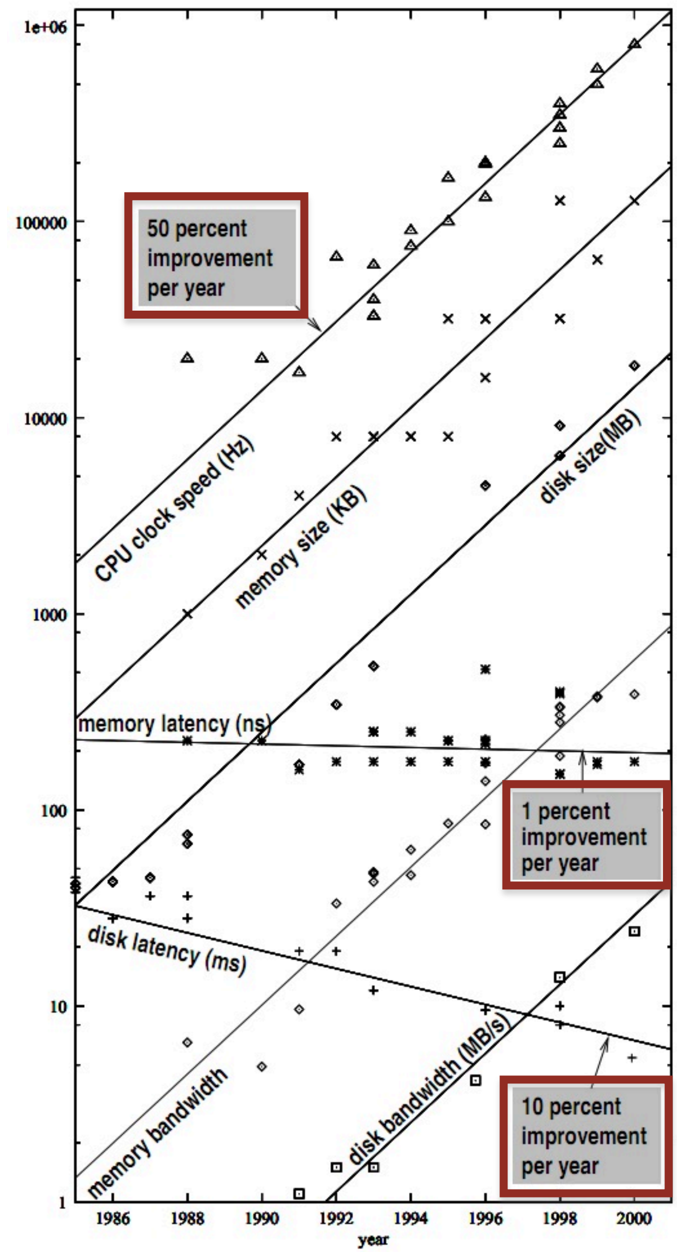
10^9	Tape /Optical Robot	2,000 Years
10^6	Disk	2 Years
100	Memory	1.5 hr
10	On Board Cache	10 min
2	On Chip Cache	
1	Registers	1 min



Source: Gray (partial)

And only getting worse…

- Riding Moore's Law
  - CPU clock speed. (not anymore ☺)
  - Memory size
  - Memory bandwidth
  - Disk size
  - Disk bandwidth
- Going way slower
  - Memory latency
  - Disk latency
- What does that do to random accesses?



Source: Boncz (partial)

RAM = NQSRAM?!

- What we call

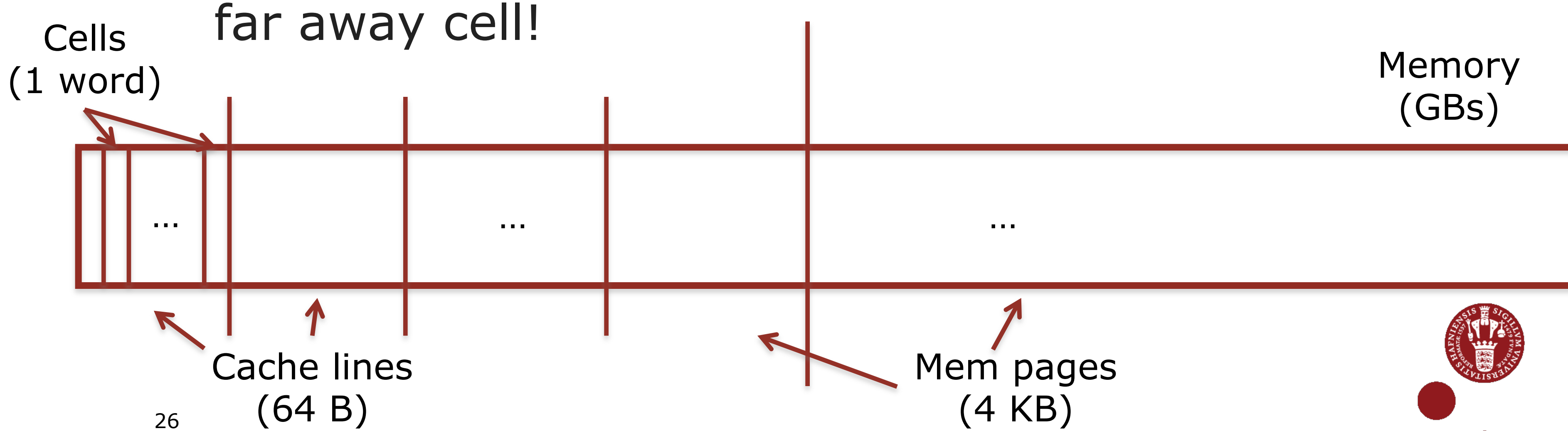
  Random **A**ccess **M**emory

  actually behaves as

  Not-**Q**uite-**S**o-**R**andom **A**ccess **M**emory

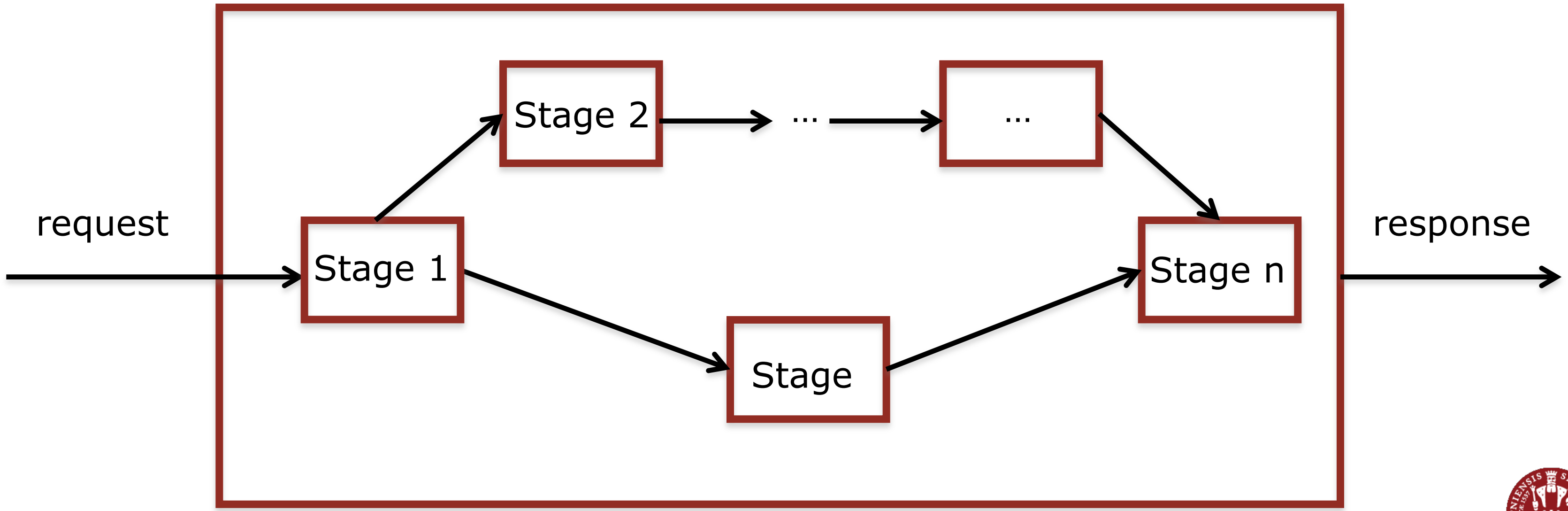
  because of the memory hierarchy

- Access to nearby cell **much faster** than to a far away cell!



How can we improve performance?

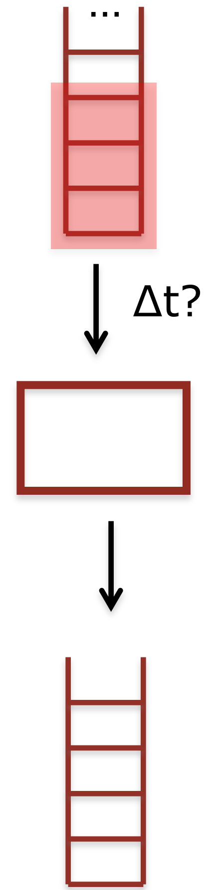
- Fast-path coding
  - Split processing into two code paths
  - One optimized path for common requests → fast path
  - One slow but comprehensive path for all other requests → slow path
  - Caching is an example of fast-path coding



Source: Saltzer & Kaashoek & Morris (partial)

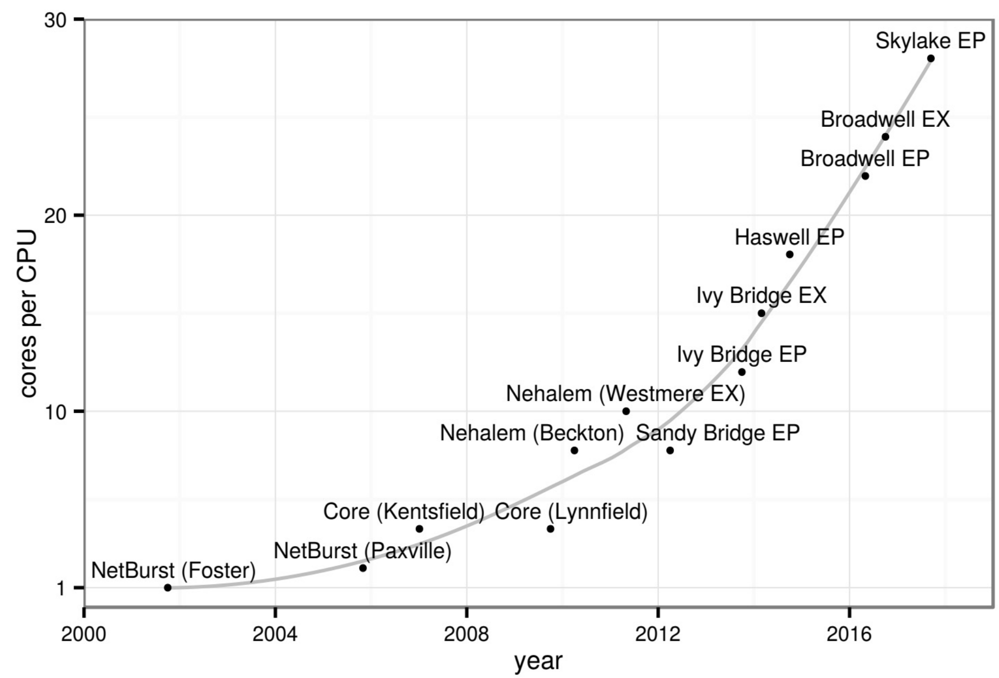
How can we improve performance?

- Batching
  - Run multiple requests at once
  - Example: batch I/Os and use elevator algorithm
  - May improve latency **and** throughput
- Dallying
  - Wait until you accumulate some requests and then run them
  - Example: group commit
  - May improve throughput when used together with batching, but typically incurs a latency penalty



Parallelism is only increasing

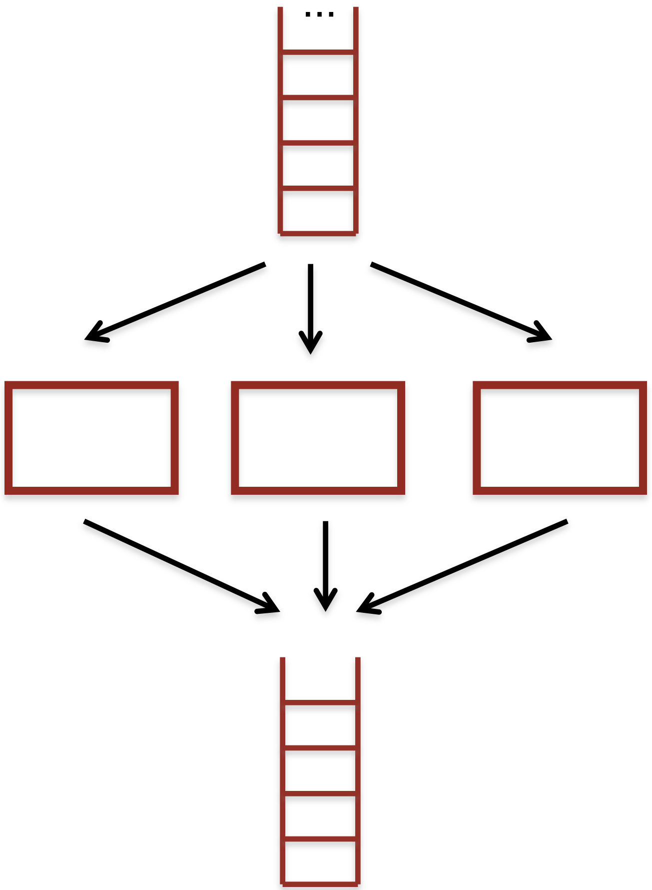
- Moore’s Law demise is in the horizon
  - CPU clock speed not anymore improving
- But number of cores still increasing in general-purpose CPUs
  - Also, specialized hardware gaining traction (check out the PMPH elective)
- How can we leverage multiple cores?



Source: Leis (partial)

How can we improve performance?

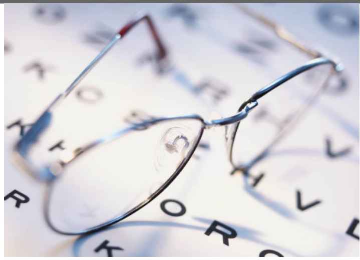
- Concurrency
  - Run multiple requests in different threads
  - Example: different web requests run in different threads or even servers
  - May improve both throughput **and** latency, but must be careful with locking, correctness
  - Can be hidden under abstractions, e.g., MapReduce and transactions



Remember RPC?

How can we improve performance?

- Speculation, i.e., predict the future ☺
  - Guess the next requests and run them in advance
  - Example: prefetching
  - May overlap expensive operations, instead of waiting for their completion



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