Application Architecture

Lecture 5

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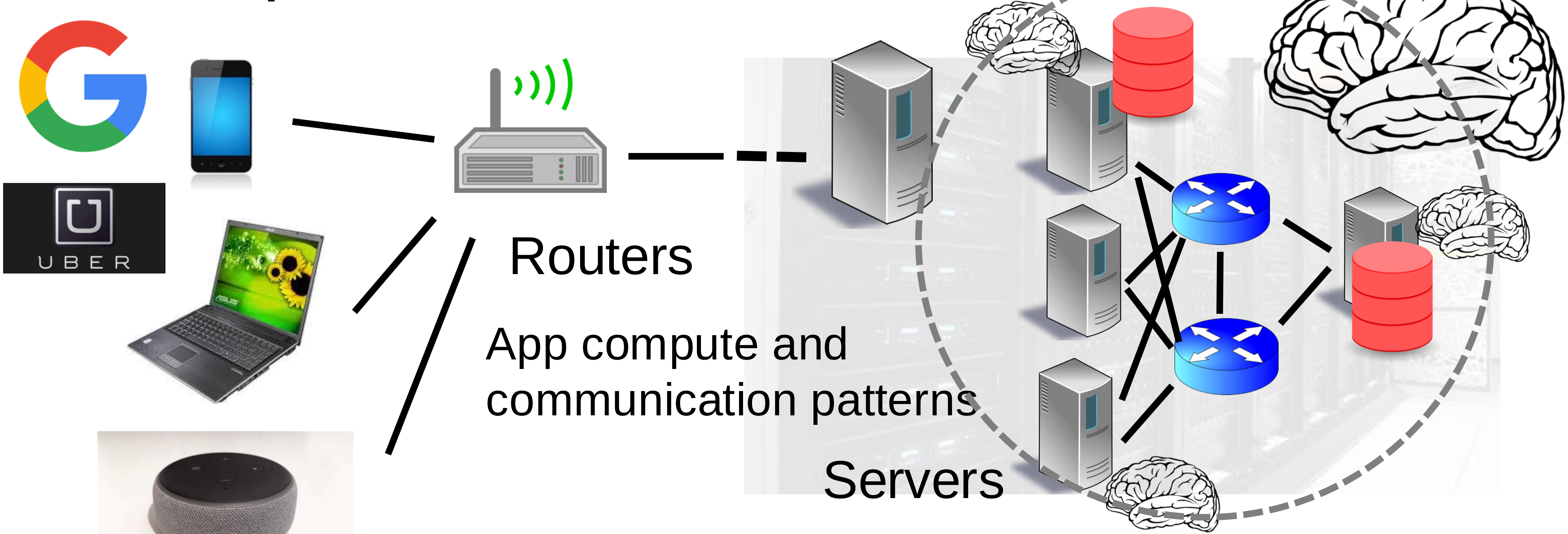
Components of an Internet Service



Modularized applications

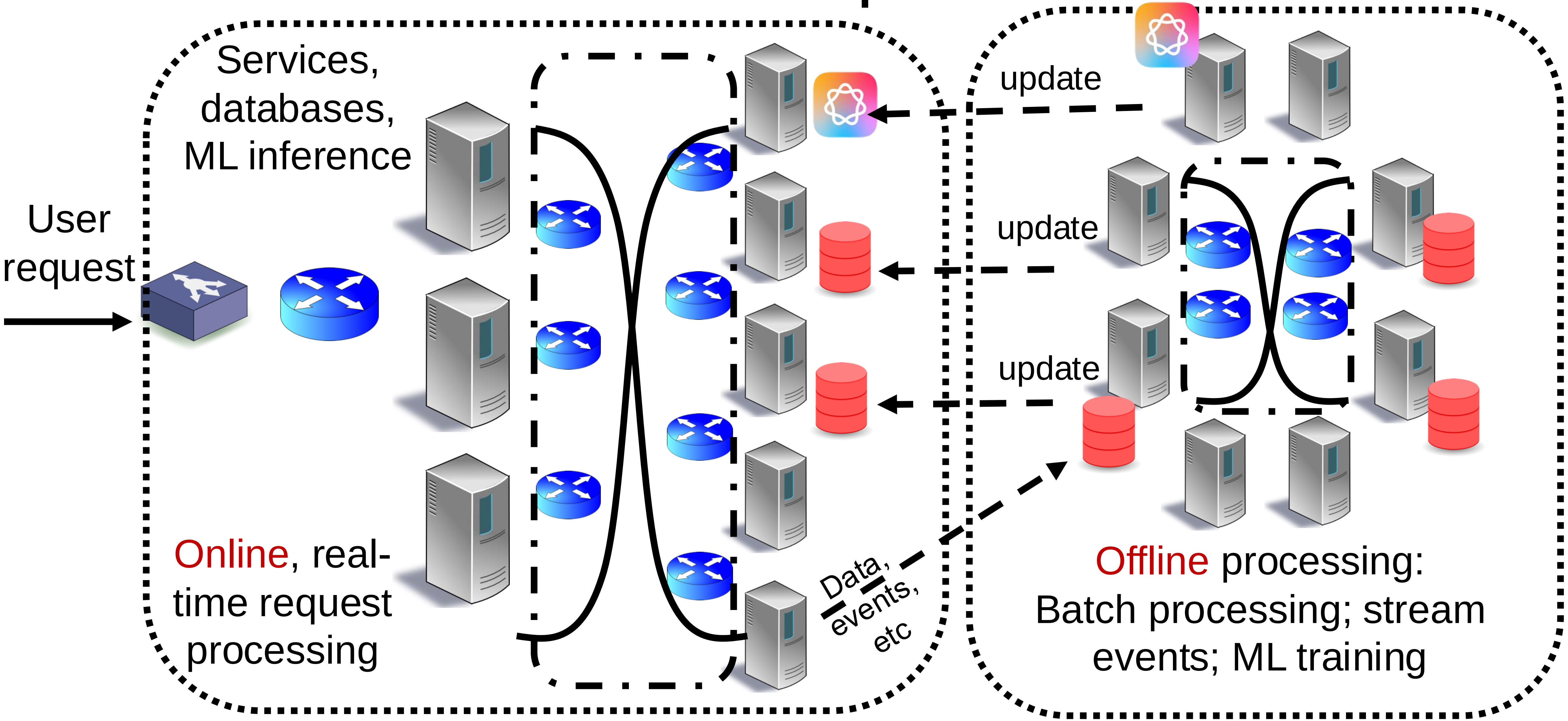
Data Center

Endpoints

Storage

Interconnect: Routers

Offline and Online components



Review: Web server design

- Process other requests while waiting for one to finish

process

socket

IP_B + $port_B$

`bind(IPaddr_B, port_B)`

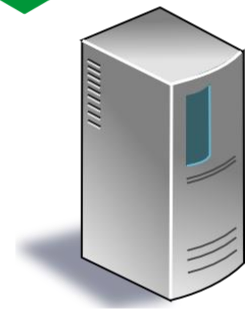
`listen()`

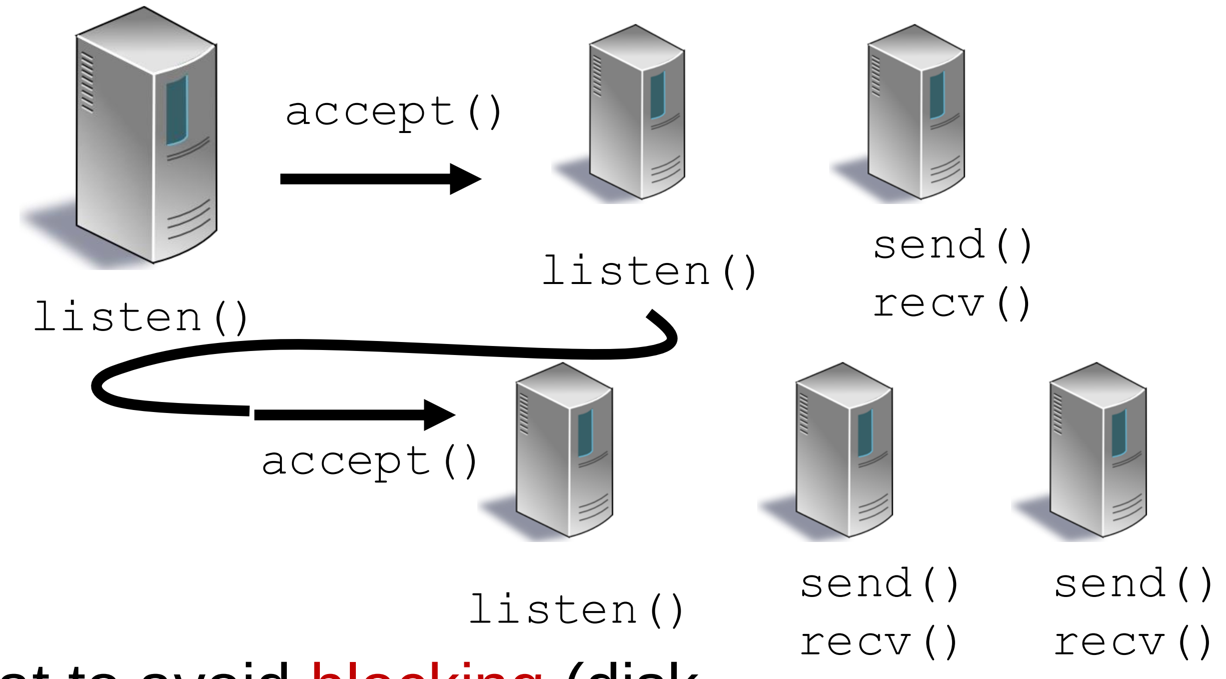
`accept()`

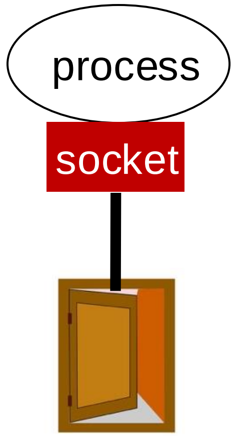
`recv()/send()/..`

Review: Parallelism

- Process requests in parallel with other requests
- One design: multiprocessing/multithreading (MP/MT)







IP_B + $port_B$

`bind(IPaddr_B, port_B)`

`listen()`

`accept()`
`fork()`
`recv()/send()/..`

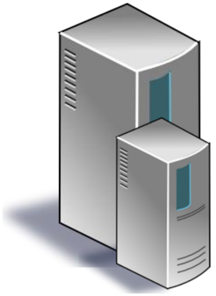
Great to avoid blocking (disk I/O, fastCGI, …)

Overhead grows with # connections
- more
- longer lived

Concurrency

State of the art designs combine parallelism (multiprocess/thread) with concurrency (event-driven)

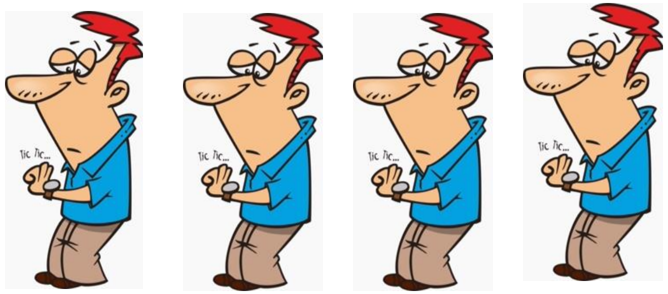
- Process other requests while waiting for one to finish
- A different design: single process event driven (SPED)



`accept()`

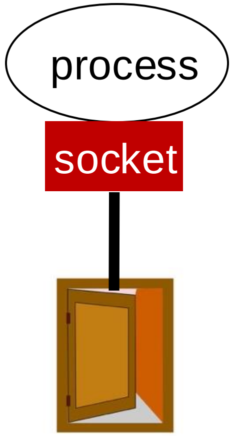
`recv()`

A queue of events



`epoll, select, kqueue, io_uring`

Lightweight



IP_B + $port_B$

`bind(IPaddr`$_B$`, port`$_B$`)`

`listen()`

`accept()`

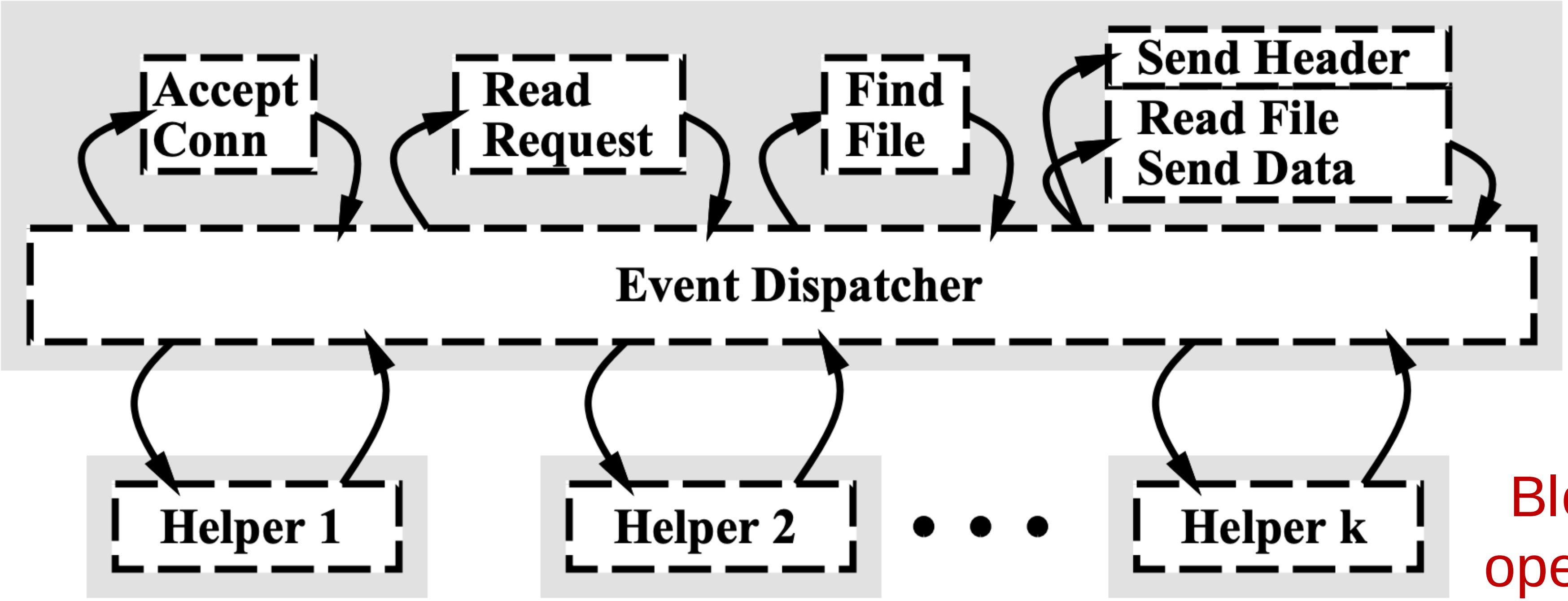
`recv()/send()/..`

Can block if any of the requests block (asynchronous IO support can be incomplete & complex)

Avoid overheads of multiple processes and threads https://aosabook.org/en/v2/nginx.html

Using parallelism + concurrency

- Asymmetric Multi-Process Event Driven (AMPED)

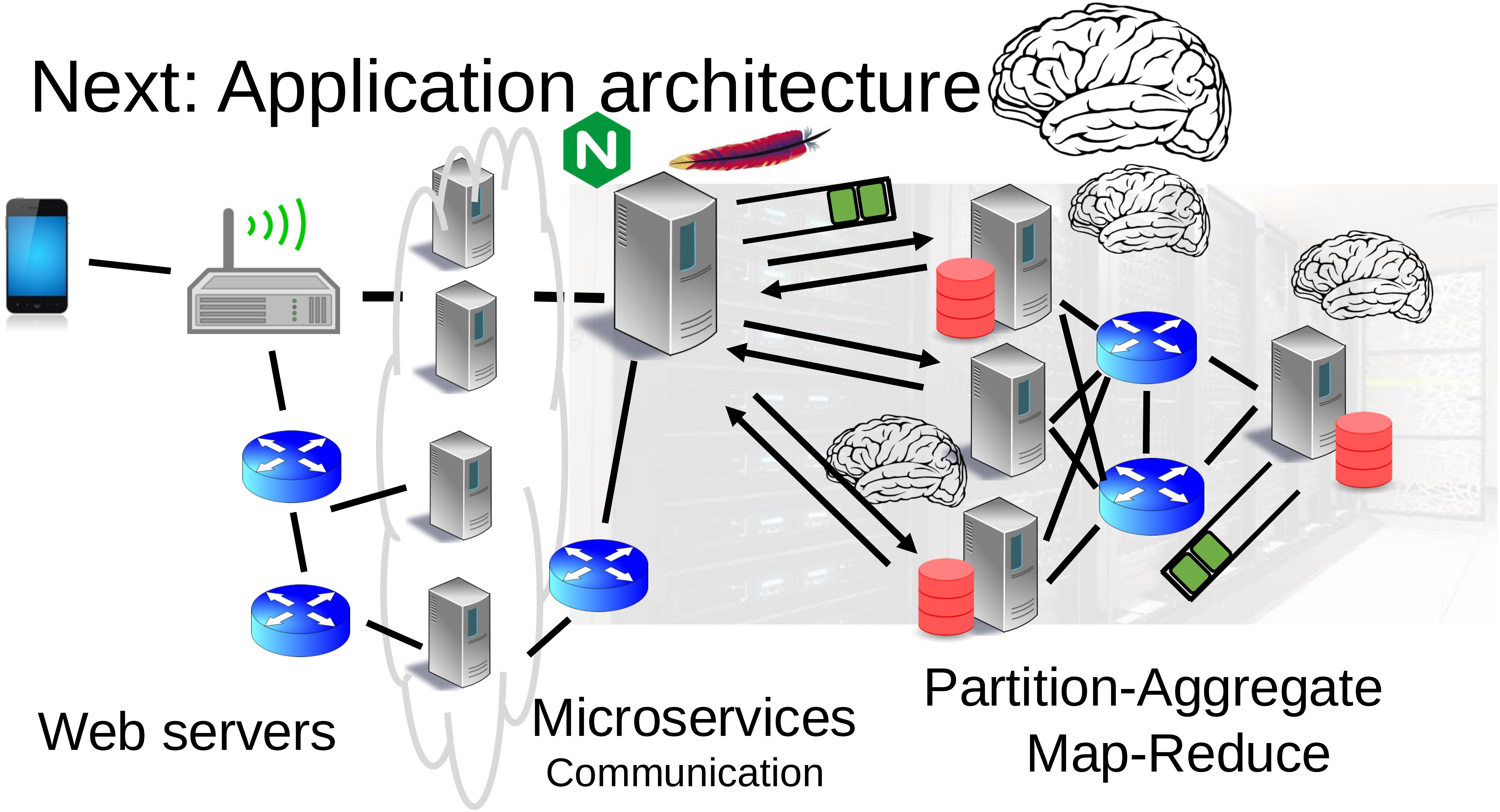


Event-driven main process

Blocking operations

Flash: An efficient and portable Web server

Next: Application architecture



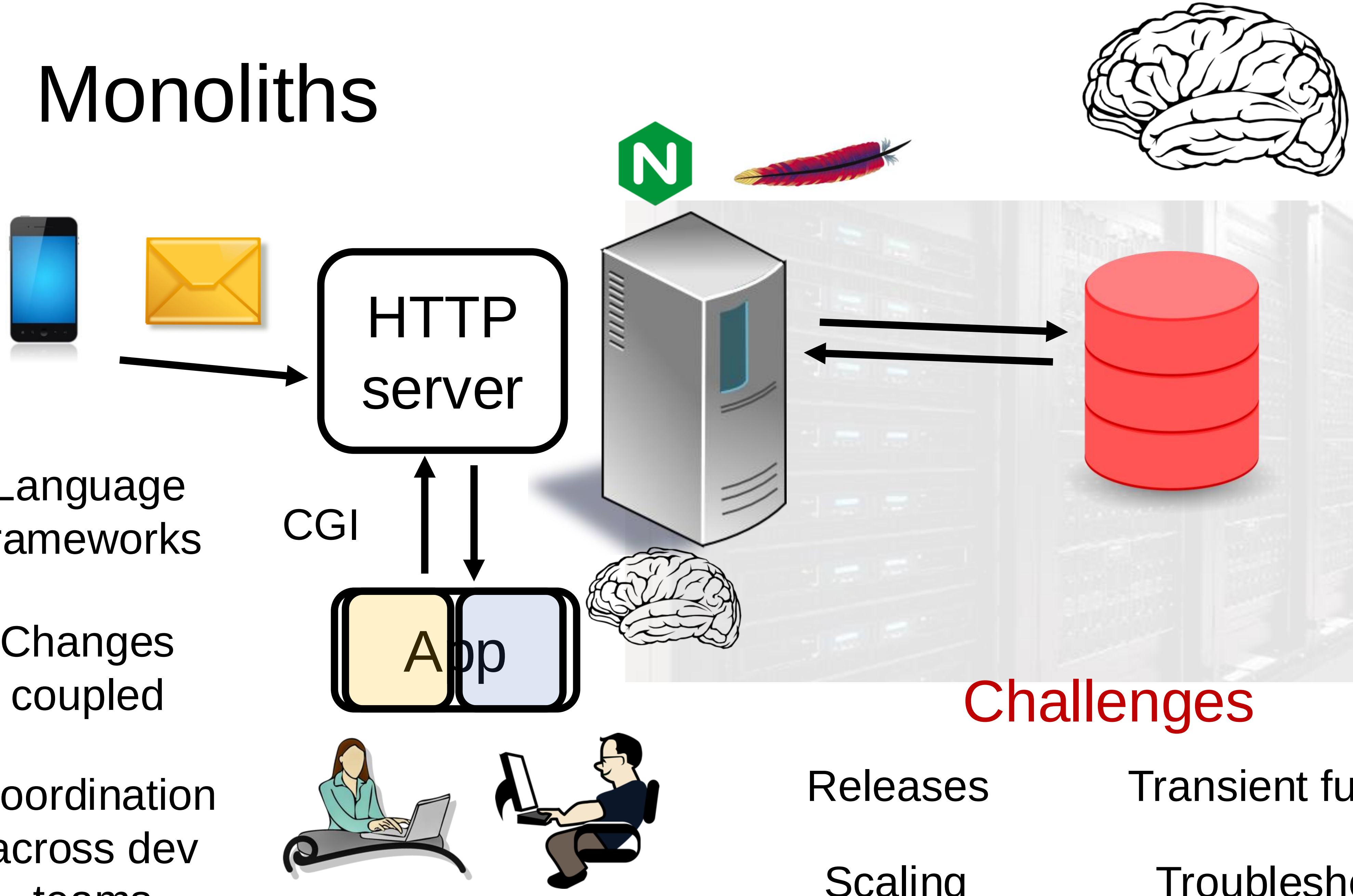
Microservice Architectural Pattern

Monoliths

Language frameworks

Changes coupled

Coordination across dev teams



Challenges

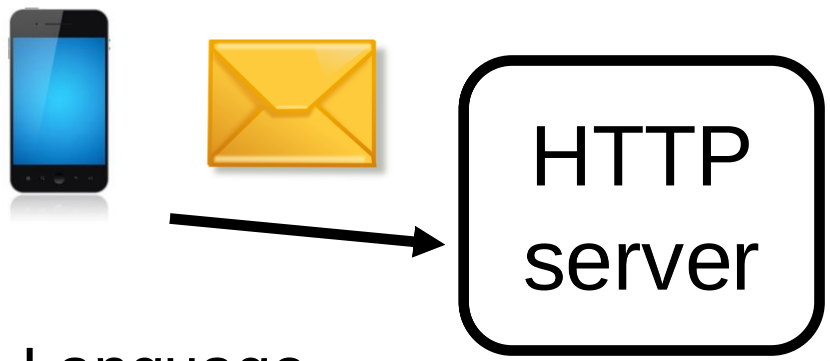
Releases

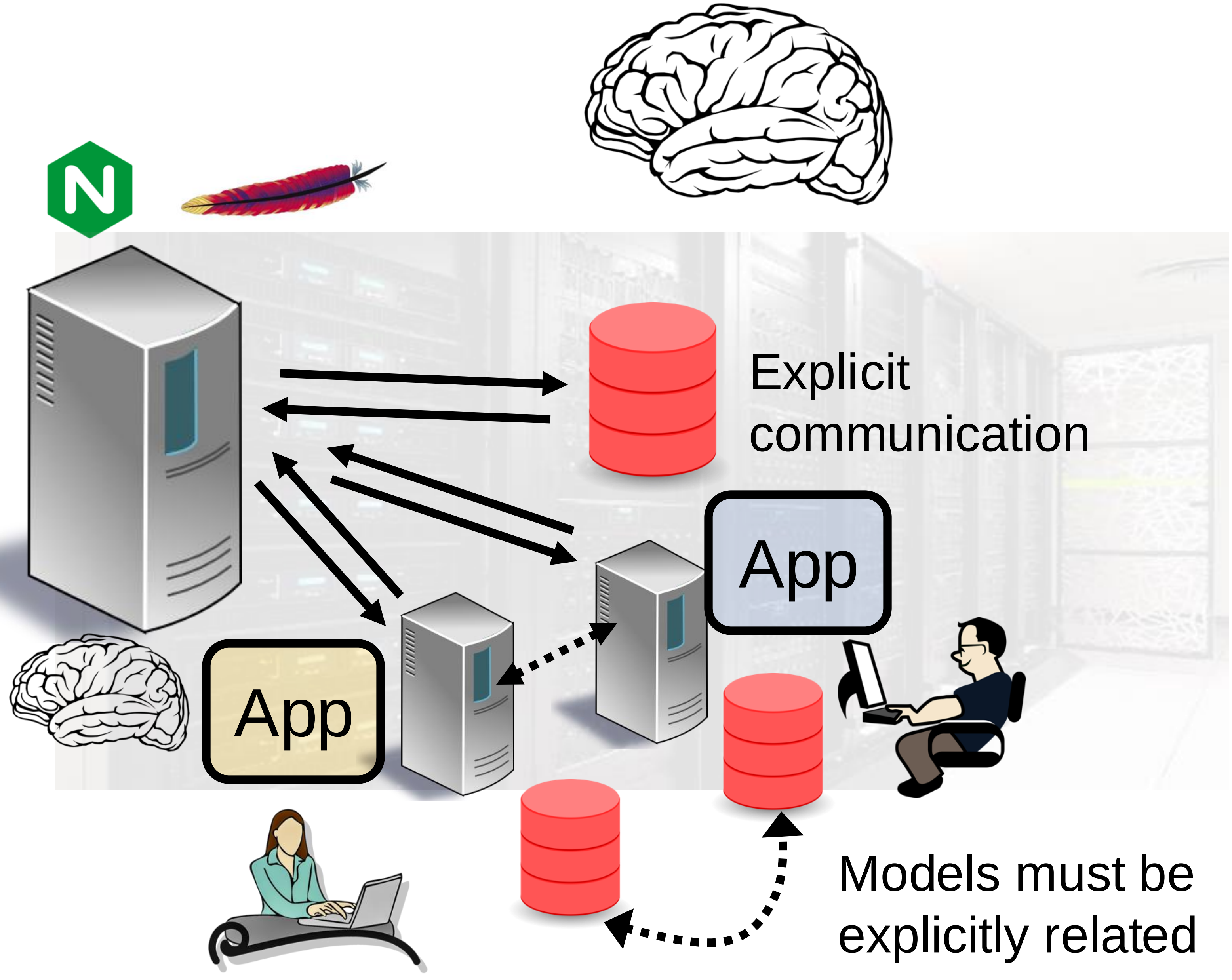
Transient functions

Scaling

Troubleshooting

Microservices





Language
of choice

Independently
upgrade and
deploy

Independent/de-
centralized data
models & storage

Distinct
from a
software
library:
Out of
process.

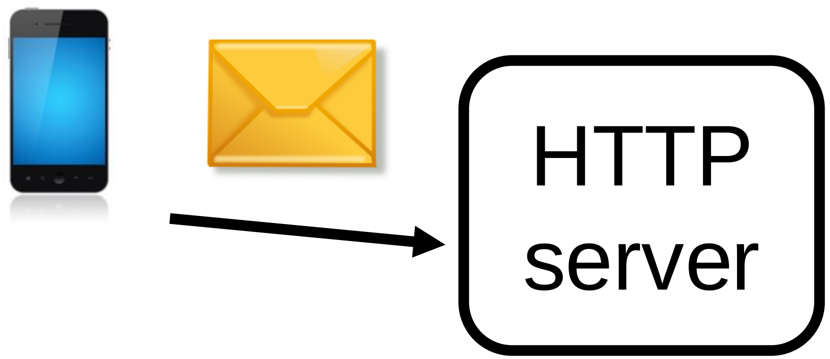
Loosely-coupled services

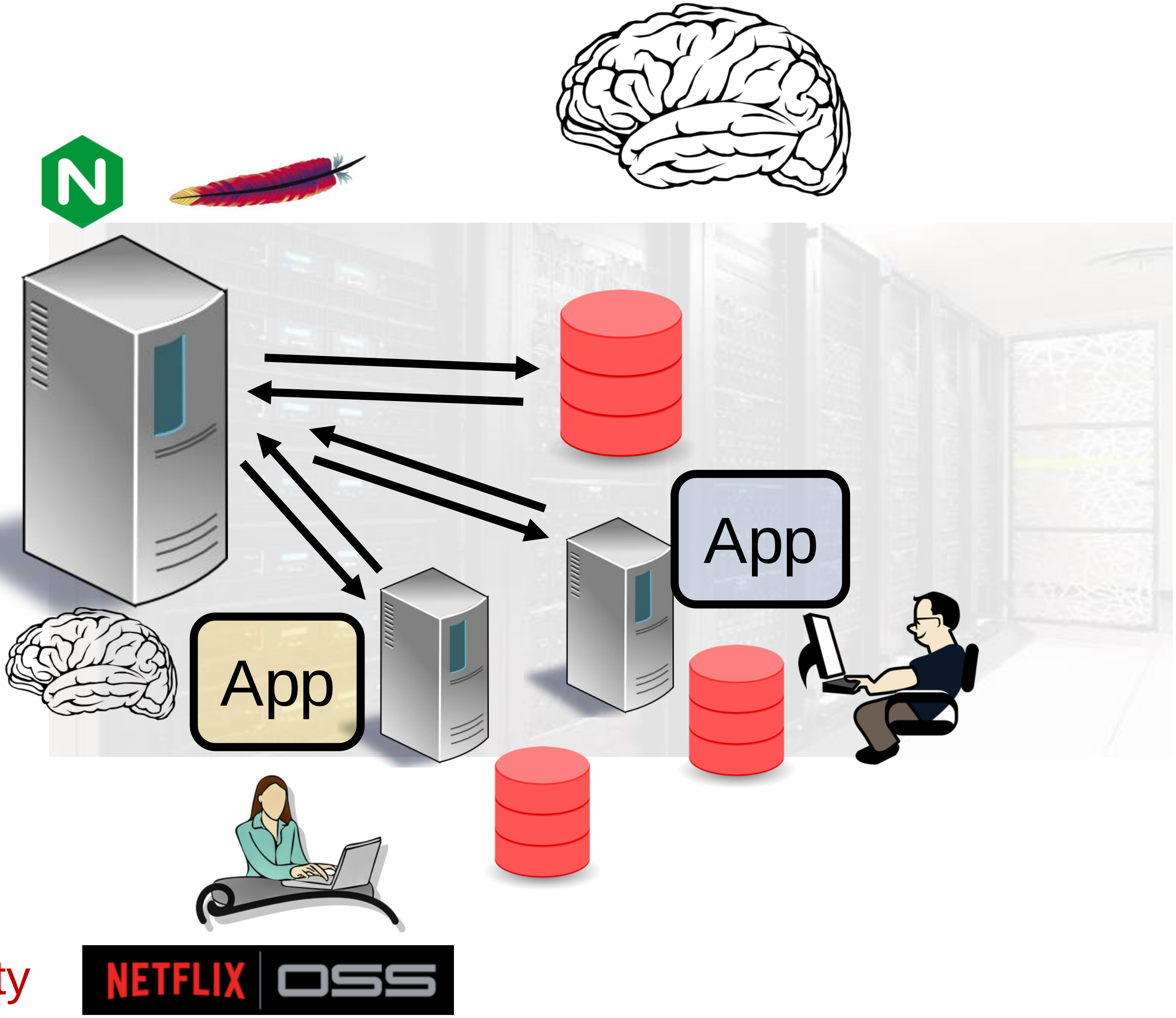
In short, the microservice architectural style is an approach to developing a single application as a **suite of small services**, each **running in its own process** and communicating with lightweight mechanisms, often an HTTP resource API. These services are **built around business capabilities** and **independently deployable** by fully automated deployment machinery. There is a **bare minimum of centralized management** of these services, which may be written in different programming languages and use different data storage technologies.

-- James Lewis and Martin Fowler (2014)

https://martinfowler.com/articles/microservices.html https://martinfowler.com/microservices/

How to split?





Business Capabilities

Boundaries of change

Lifetime of the service?

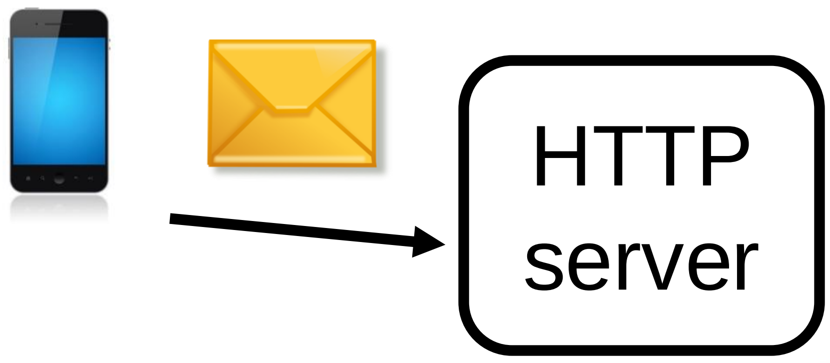
Who should know (or not)?

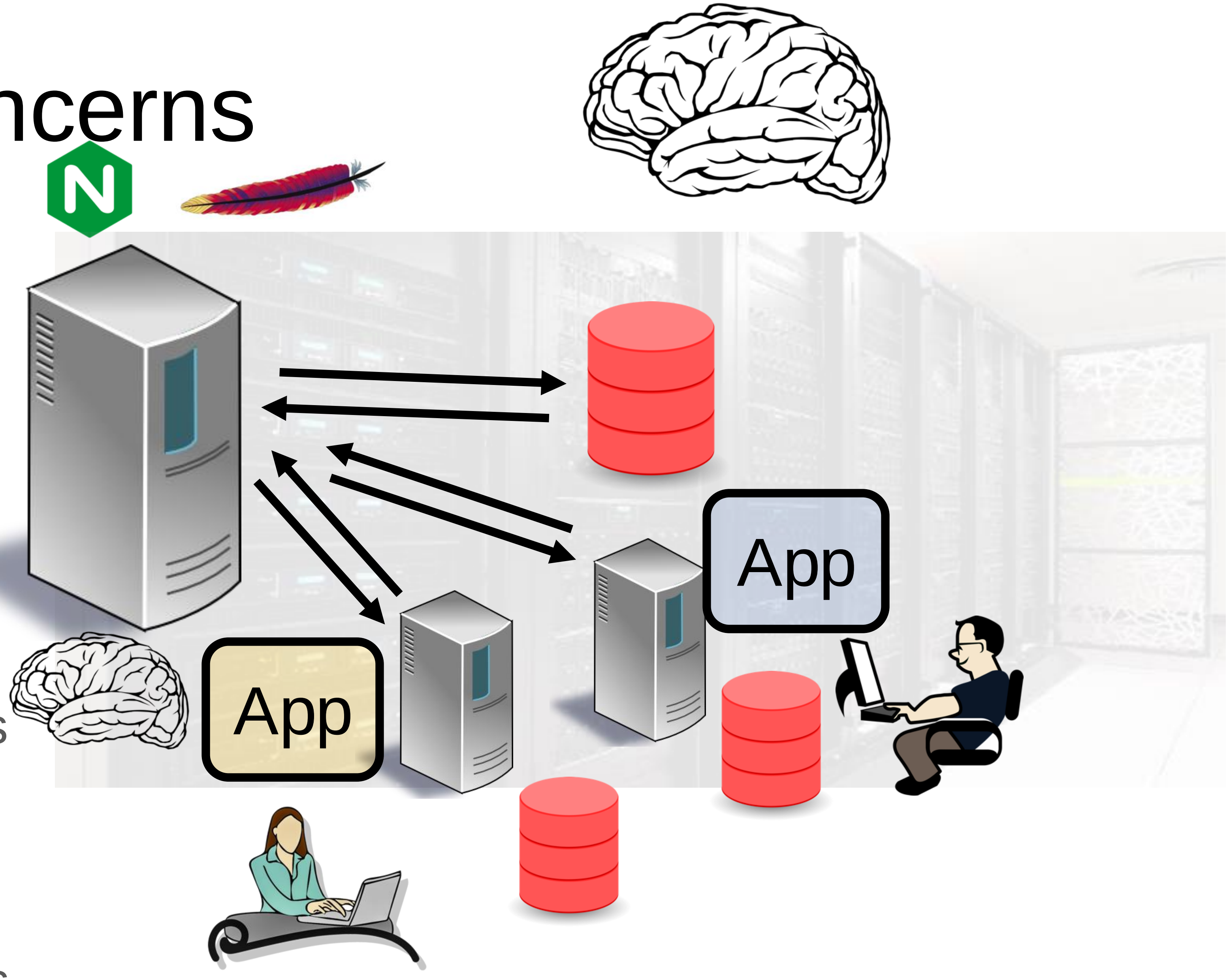
Changing together vs separately?

Heterogeneity in resource use

Refactoring common functionality

Salient new concerns





Communication

No longer a function call

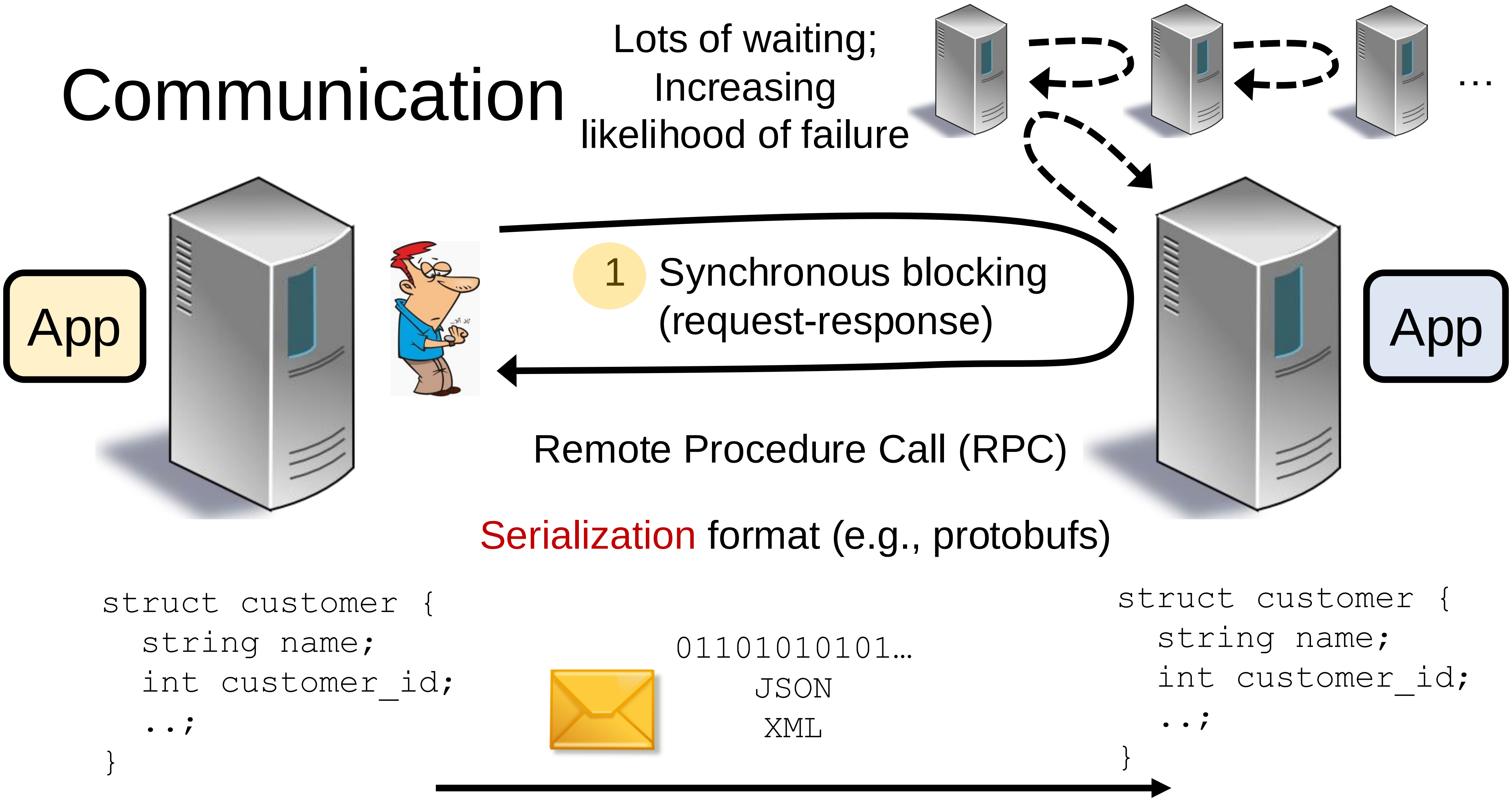
Design good module boundaries

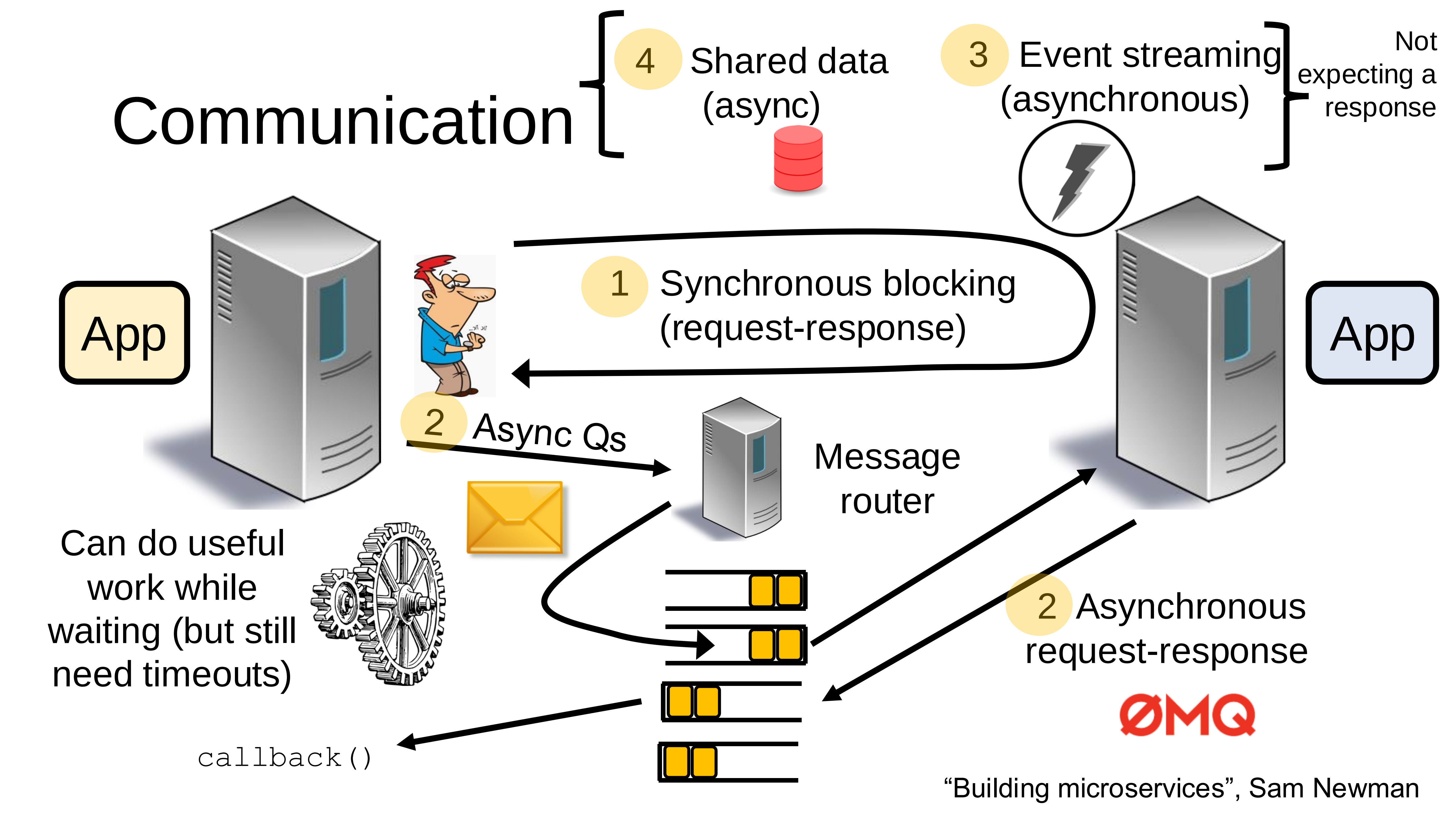
Failures

Networks & components fail

No longer in the same process

Communication




Communication
4 Shared data (async)
3 Event streaming (asynchronous)
Not expecting a response
App
1 Synchronous blocking (request-response)
App
2 Async Qs
Message router
Can do useful work while waiting (but still need timeouts)
2 Asynchronous request-response
ØMQ
callback()
“Building microservices”, Sam Newman

Cost of communication: Performance

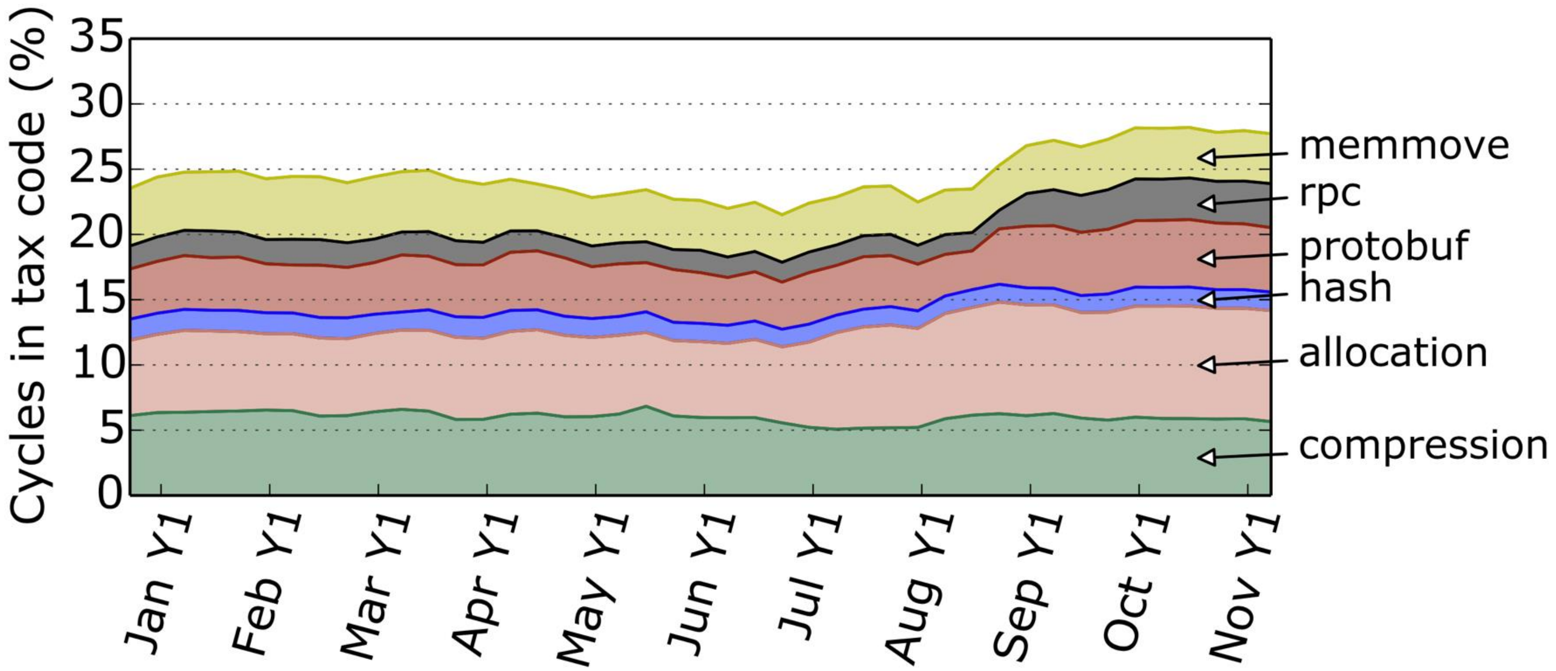
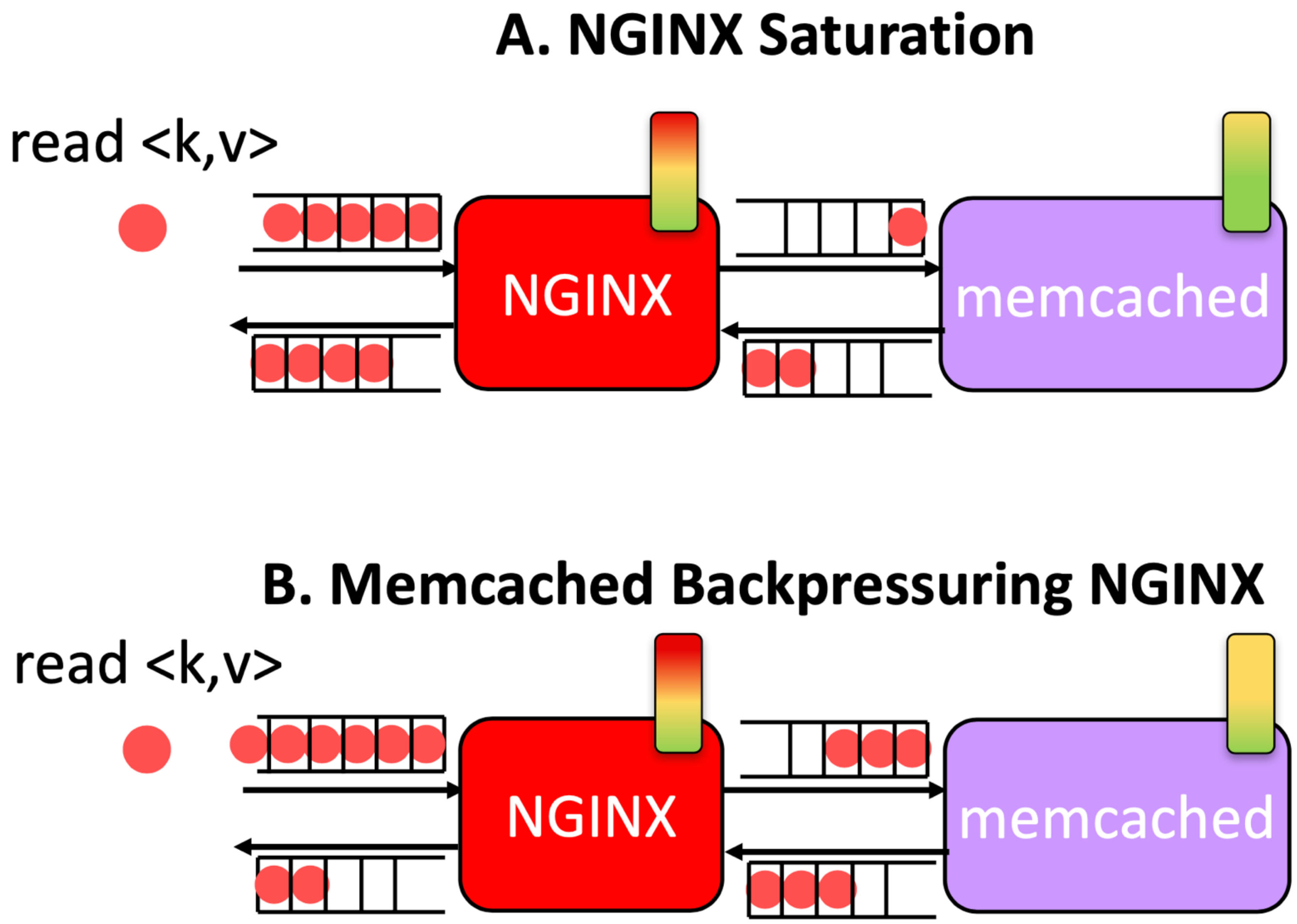


Figure 4: 22-27% of WSC cycles are spent in different components of "datacenter tax".

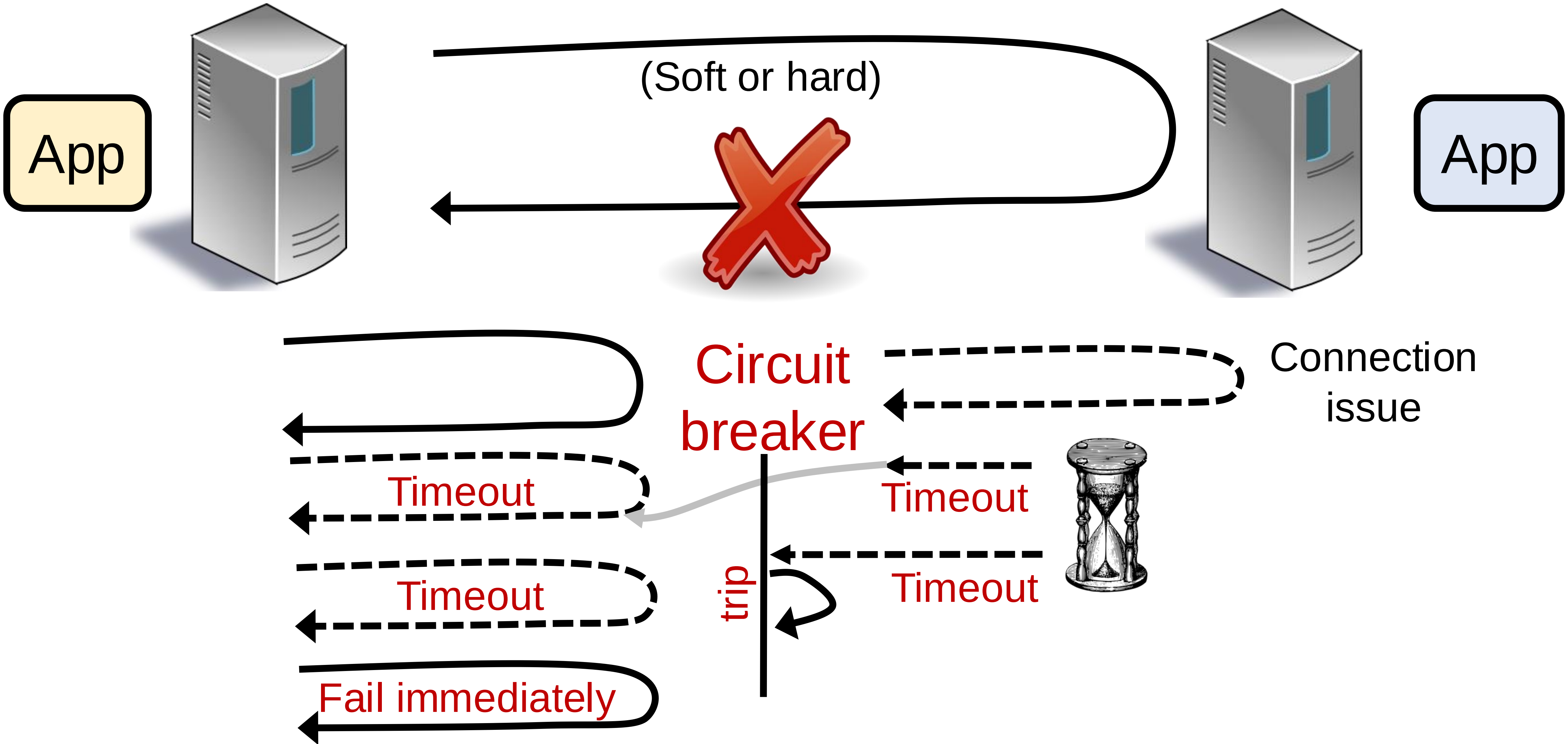
Profiling a warehouse-scale computer (Google). ISCA'15.

Cost of comm: Hotspot spreading



Deathstarbench. ASPLOS'19.

Cost of comm: high level failure handling



Are microservices always ideal?

- Just an architectural style. Look at solving problems first
- How to evolve the splitting of components?
  - Refactoring microservice interfaces later isn't easy
  - Interface changes need buy-in from multiple dev teams
  - Components should compose cleanly in the first place
- How to design apps?
  - Monolith first, or microservices from the beginning?
- Testing, Observability, Deploy automation
- How significant are dev coordination overheads?
- Complexity

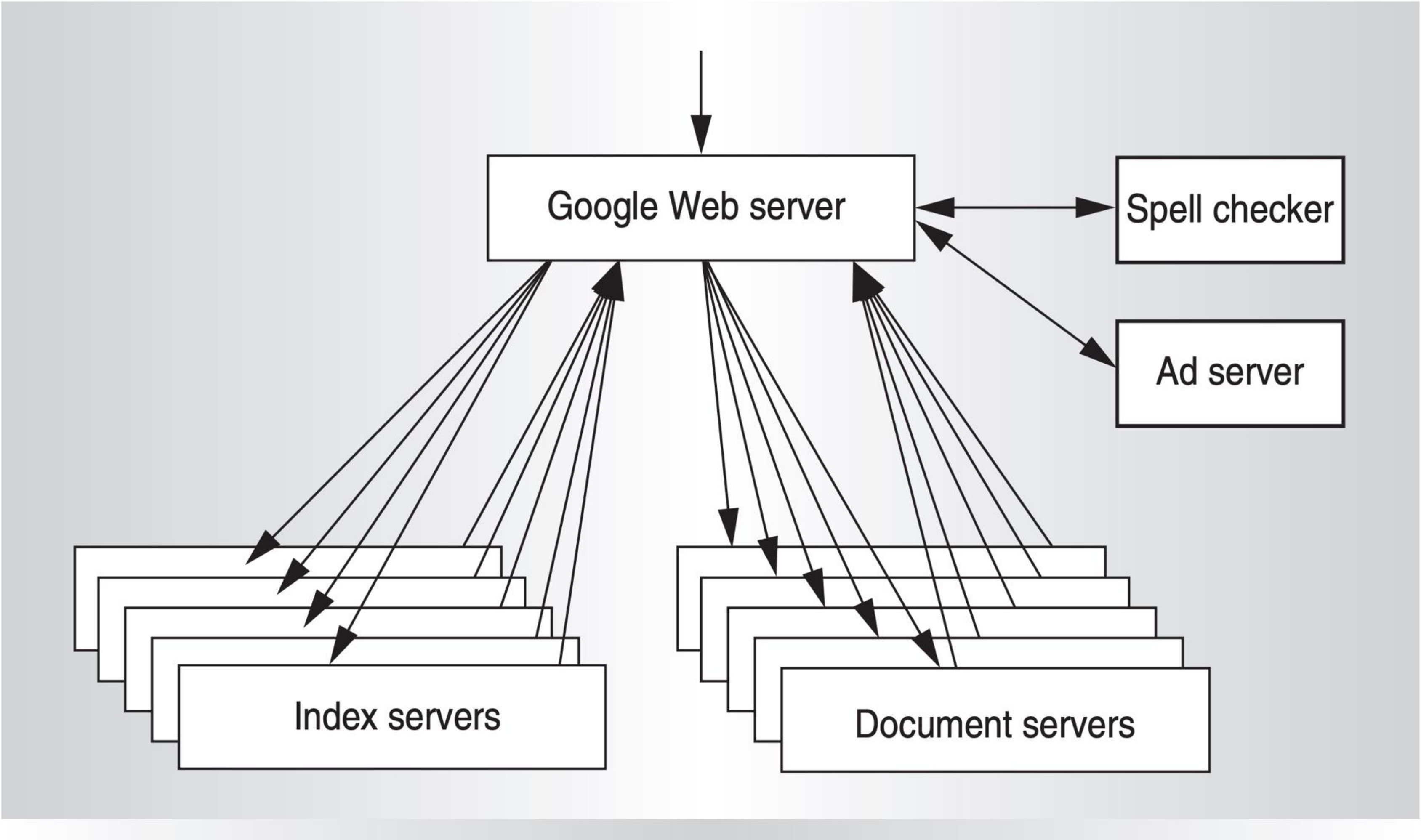
Partition-Aggregate

Processing interactive search queries

Web search: some numbers (circa 2003)

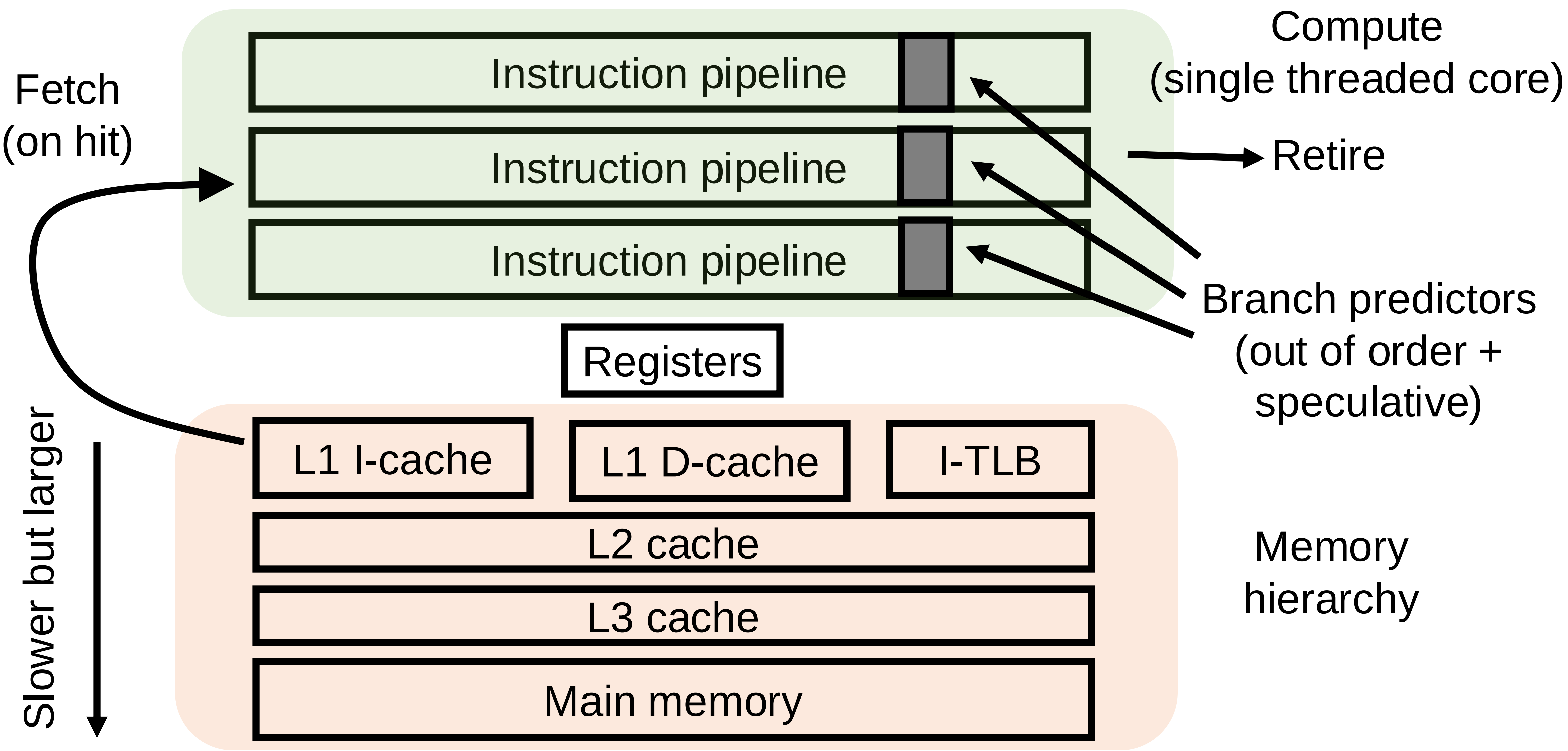
- 10s of terabytes of web corpus data
  - Read 100s of megabytes per query
- 10s of billions of CPU instructions per query
- Data accessed depends on the query; hard to predict
- All results to be returned to users within (say) 300 milliseconds
- Cannot process on a single machine within acceptable time

Example: Google search architecture



Web search for a planet, MICRO'03

Quick Review: Compute & Memory Org



Measurements from one (index) server

- Not too fast single-threaded
  - Data dependencies
  - Branches often mispredicted
- Small instruction memory footprint
- Data locality within a block, but not across blocks
- Numbers not much better on a newer architecture
- Can’t drive high single-threaded performance

Use parallelism

Characteristic	Value
Cycles per instruction	1.1
Ratios (percentage)	
Branch mispredict	5.0
Level 1 instruction miss*	0.4
Level 1 data miss*	0.7
Level 2 miss*	0.3
Instruction TLB miss*	0.04
Data TLB miss*	0.7

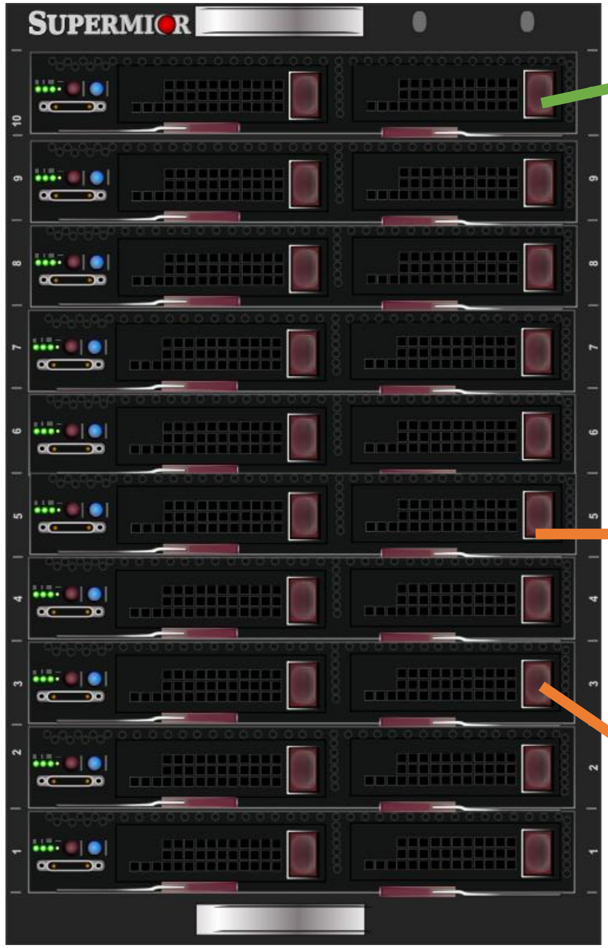
* Cache and TLB ratios are per instructions retired.

Web search for a planet, MICRO’03.

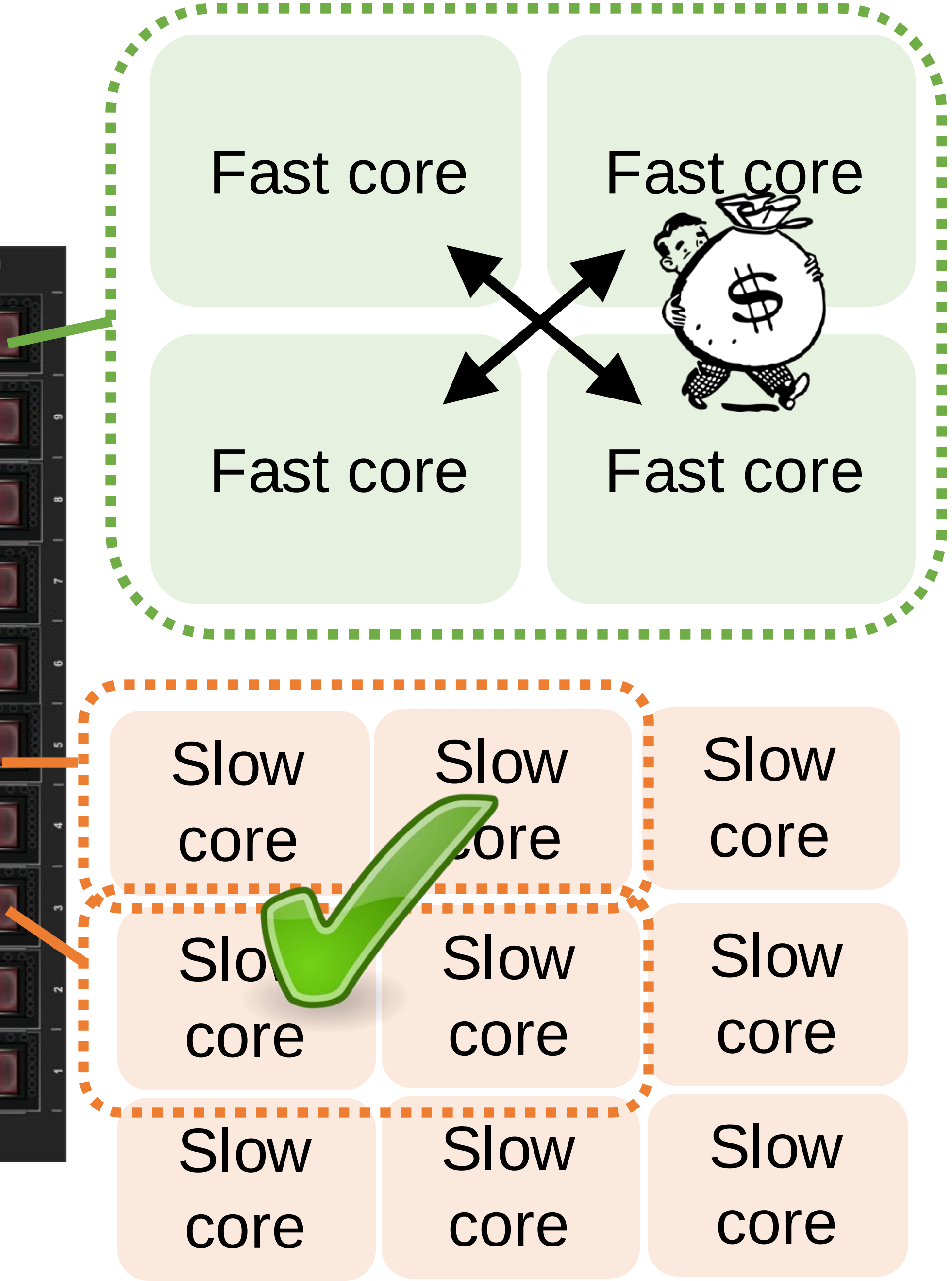
How to use parallelism?

- Few fast cores with high-speed interconnect
- Or more slow cores?
- Cost per query processed?
  - Dominated by capital server costs
- Power efficiency?

(hyperthreaded or on-chip multicore)

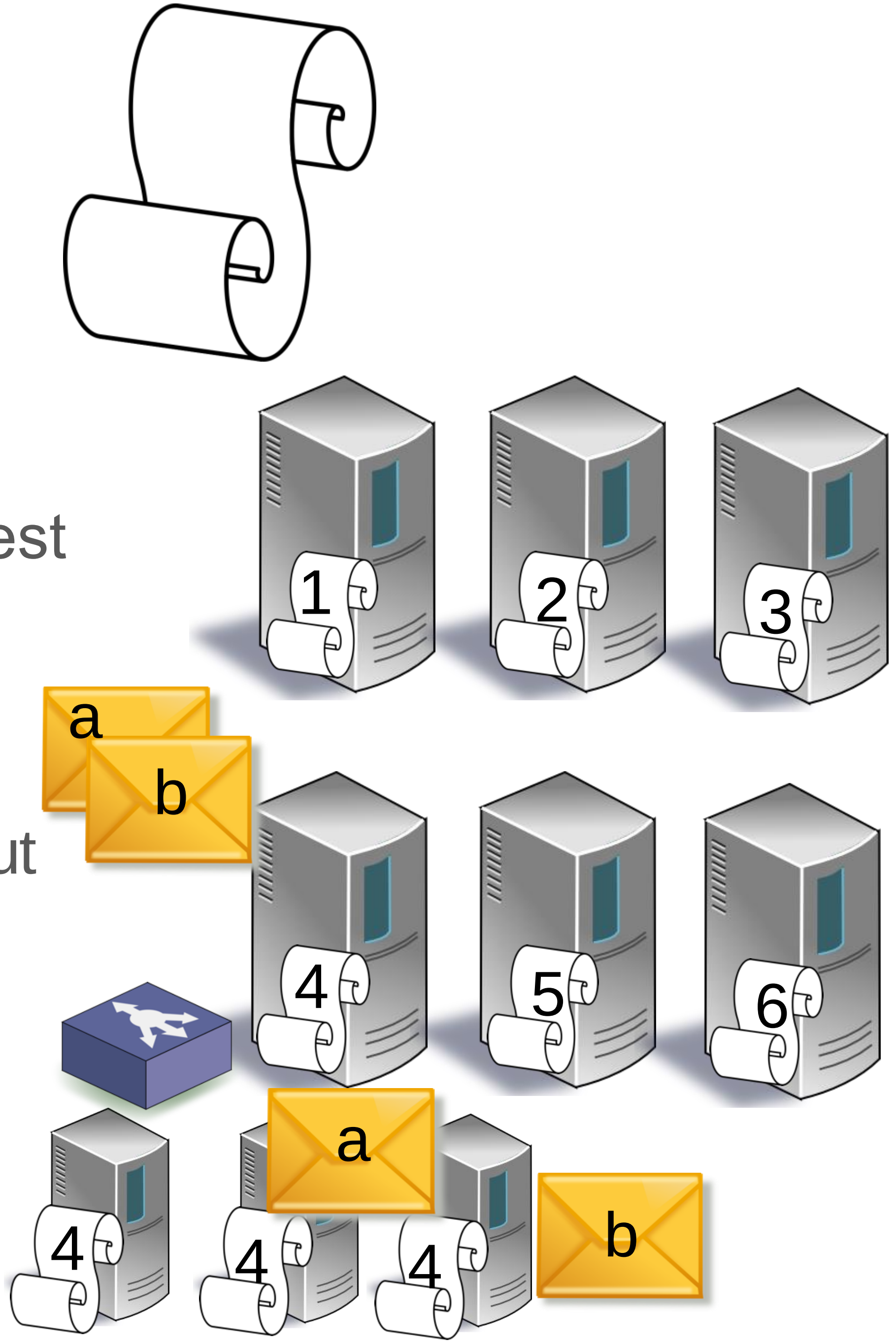


Server rack

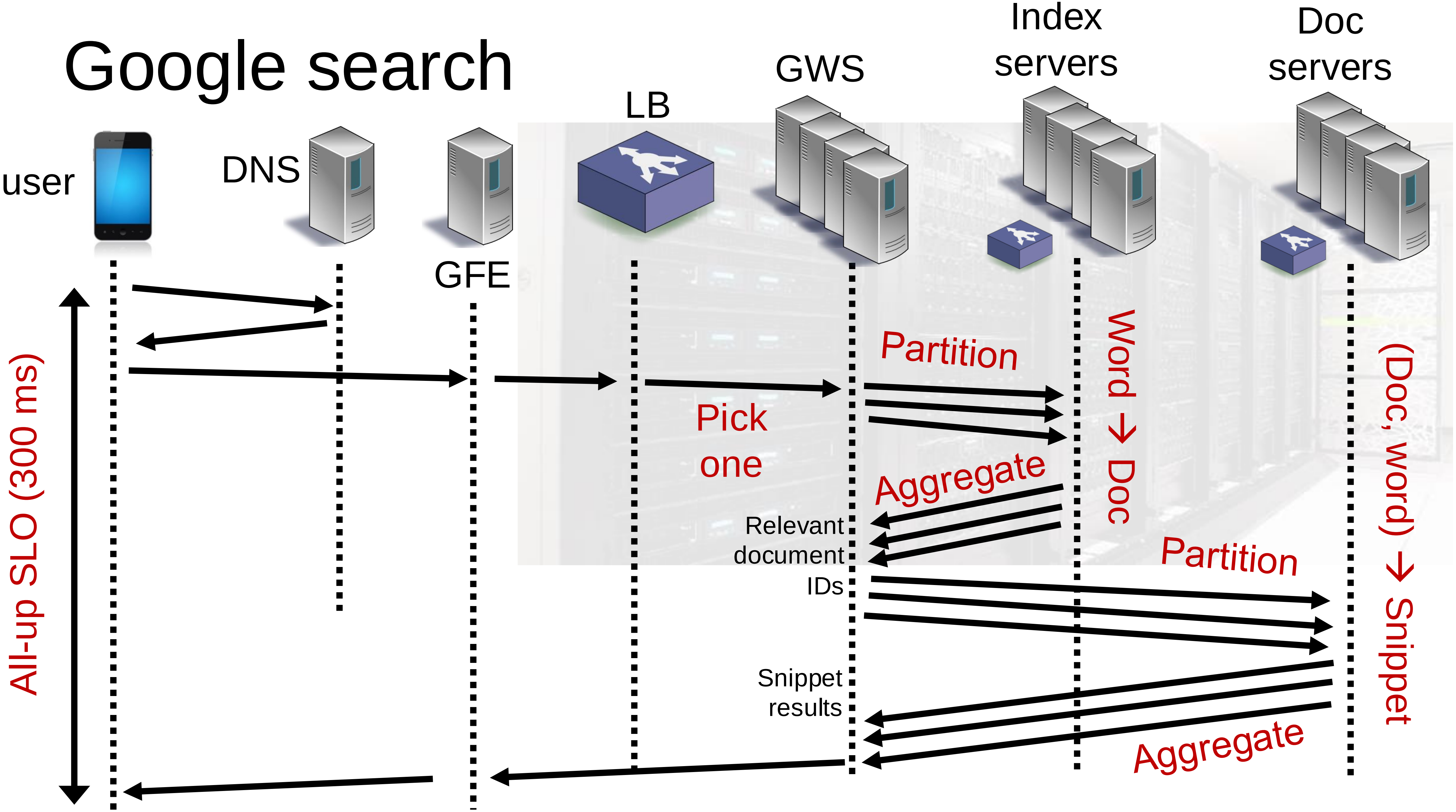


Two kinds of parallelism

- Data parallelism: independent compute over shards of data
  - Fast interconnects not as critical
  - “Stateless” little coordination within a request
- Request parallelism: independent compute across requests
  - More machines for more requests
  - Shard itself can be replicated for throughput
- Need lower latency?
- Compensate slow cores with smaller shard (add more shards)
- Turn throughput into latency advantage



Google search



Many apps can use partition-aggregate

- Need low latency, but single-threaded low latency is hard
- Data parallelism
  - Little coordination across shards
  - Inexpensive merges across partial results from shards
- Query parallelism
  - More replicas/machines for more requests
- Use commodity (not fancy) hardware
- Turn high throughput into a latency advantage
- Focus on price per unit performance
- Significant problems: cooling for many compute servers

Map Reduce

Bulk parallel data processing with simple abstractions

Simple computations over big datasets

- Some examples:
  - Distributed “grep”
  - Counting words, links in the web corpus
  - Distributed sort
- Simple computations, but over large data sets:
  - Partitioning computing across machines
  - Replication of data and compute
  - Failures of machines; data loss
- Algorithm developers == distributed system experts?

Abstraction borrowed from functional programming

Many different implementations exist

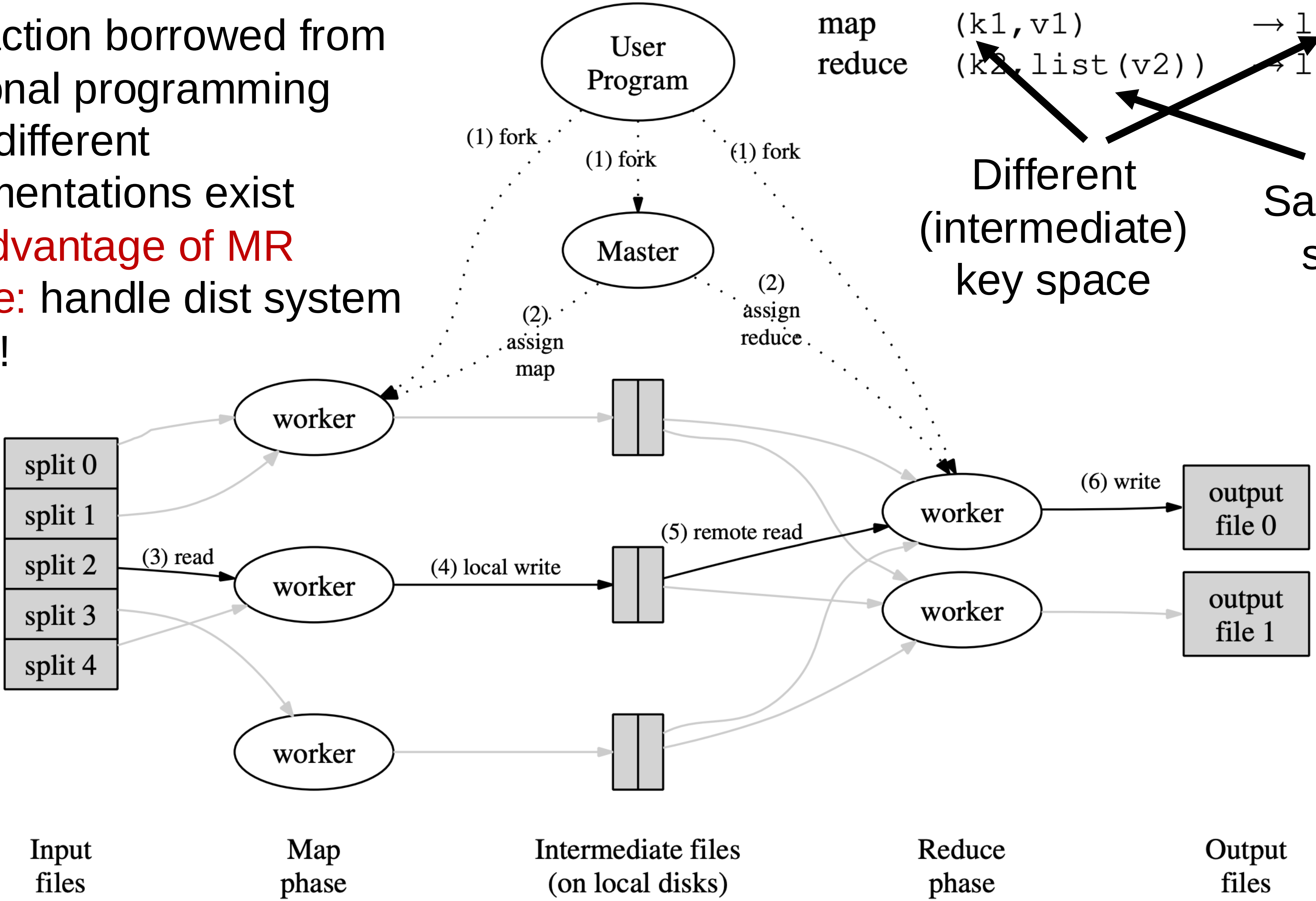
Key advantage of MR Google: handle dist system issues!

map $(k1,v1) \rightarrow list(k2,v2)$

reduce $(k2,list(v2)) \rightarrow list(v2)$

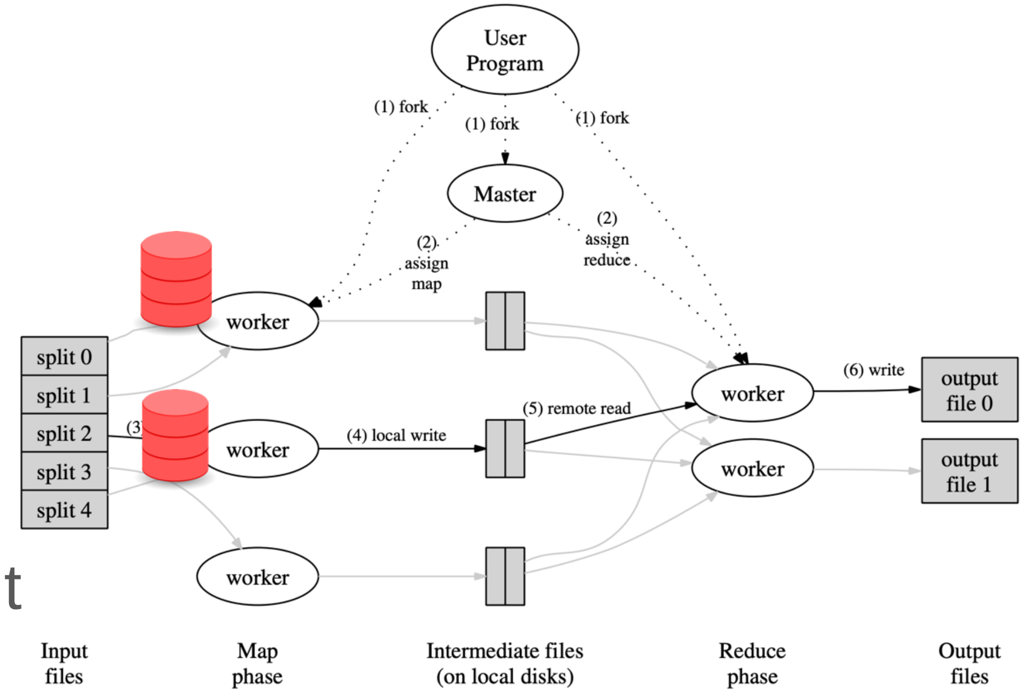
Different (intermediate) key space

Same key space



Some key ideas

- Locality:
  - Co-locate compute with data
  - Reduce network BW use
  - Local persistence of intermediate output



- Handle failures through restarts
  - Software fault tolerance, use commodity (not fancy) hardware
  - Catch and skip shards with deterministic faults

- Straggler handling through eager replication of compute
  - Contention for resources, configuration bugs