Application Architecture

Lecture 4

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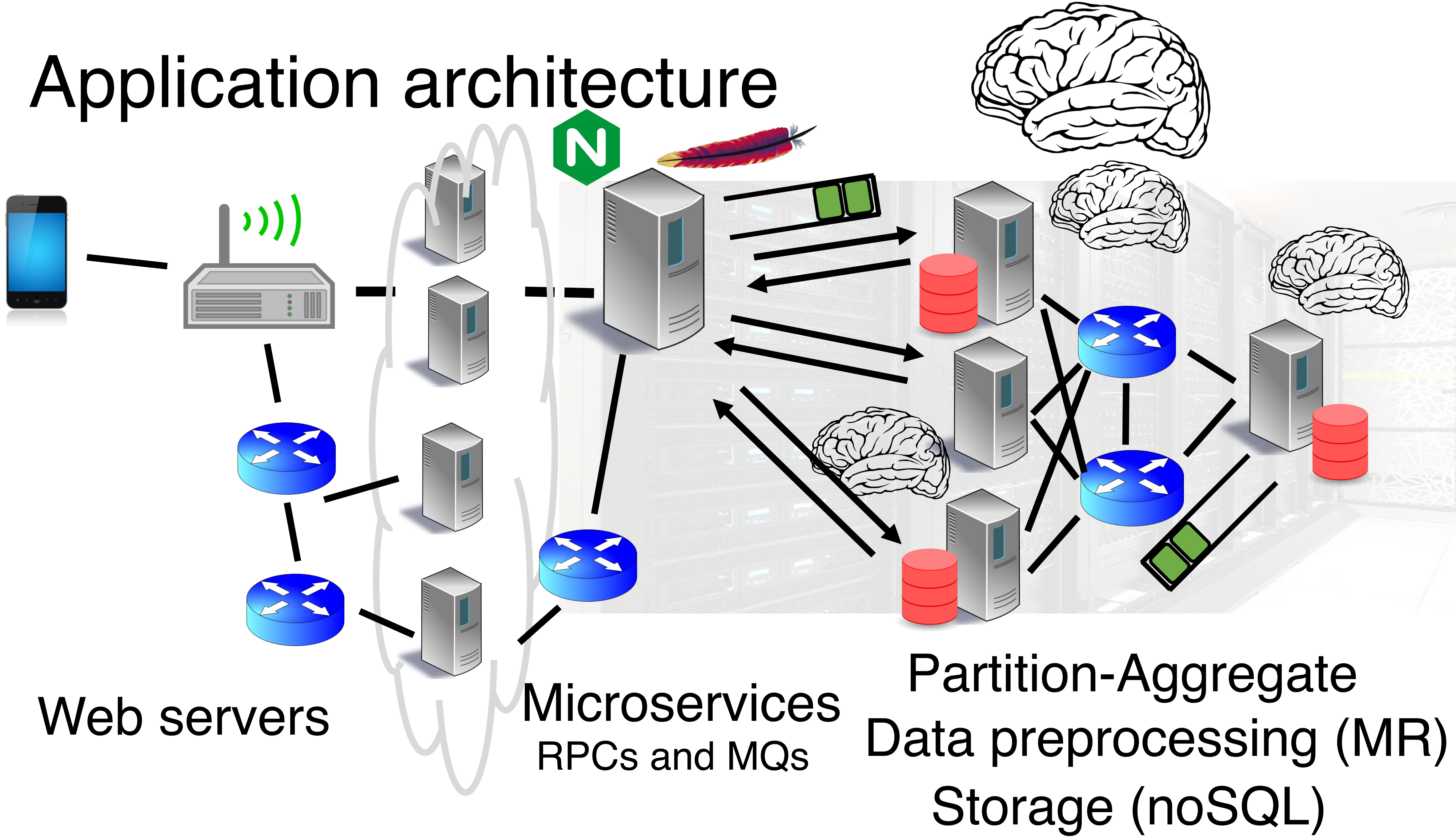
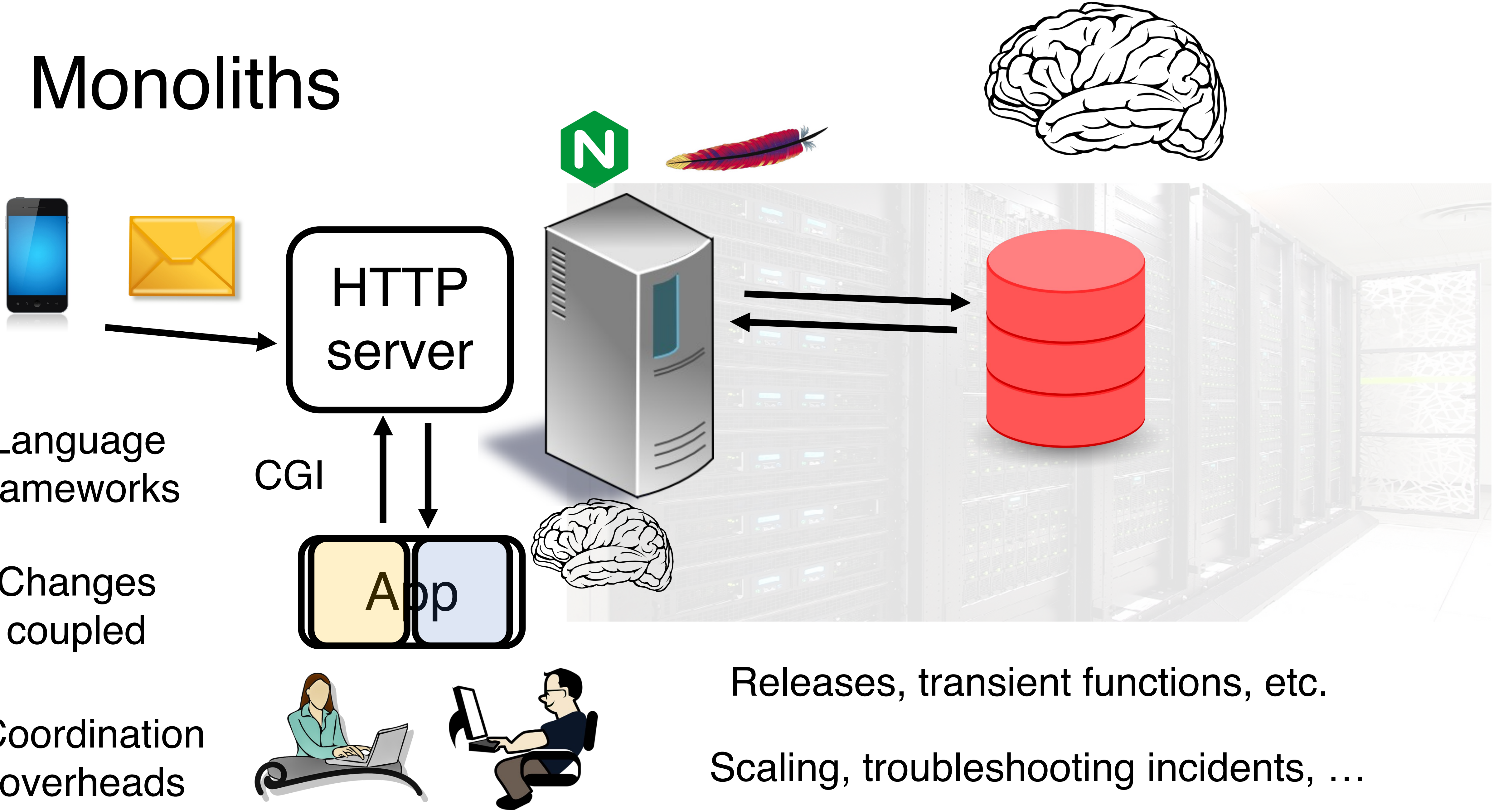
Application architecture



Monoliths



Language frameworks

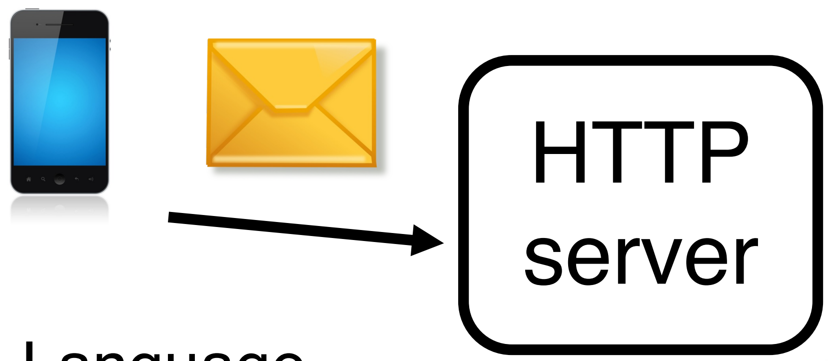
Changes coupled

Coordination overheads

Releases, transient functions, etc.

Scaling, troubleshooting incidents, …

Microservices

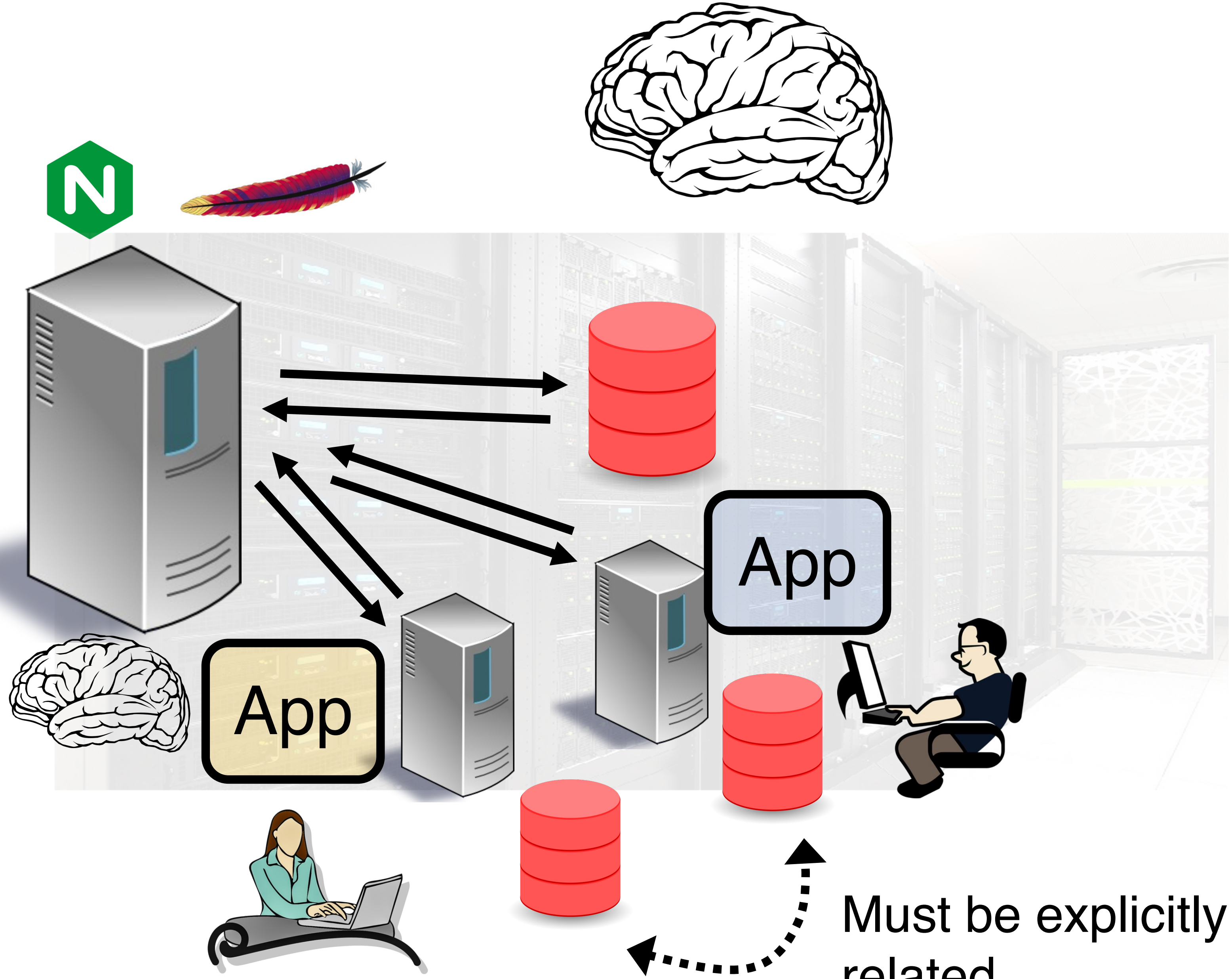


Language of choice

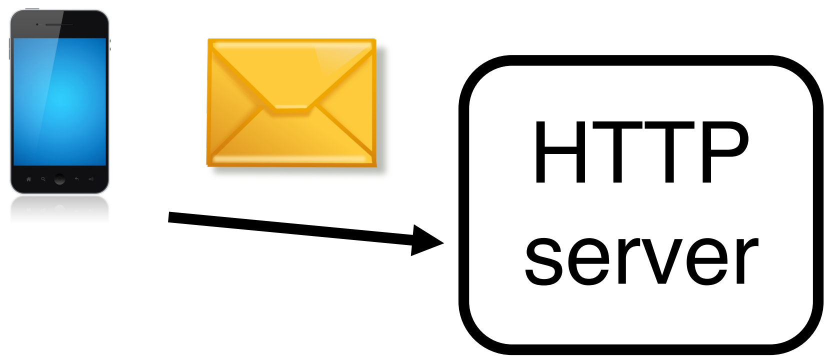
Independently upgrade and deploy

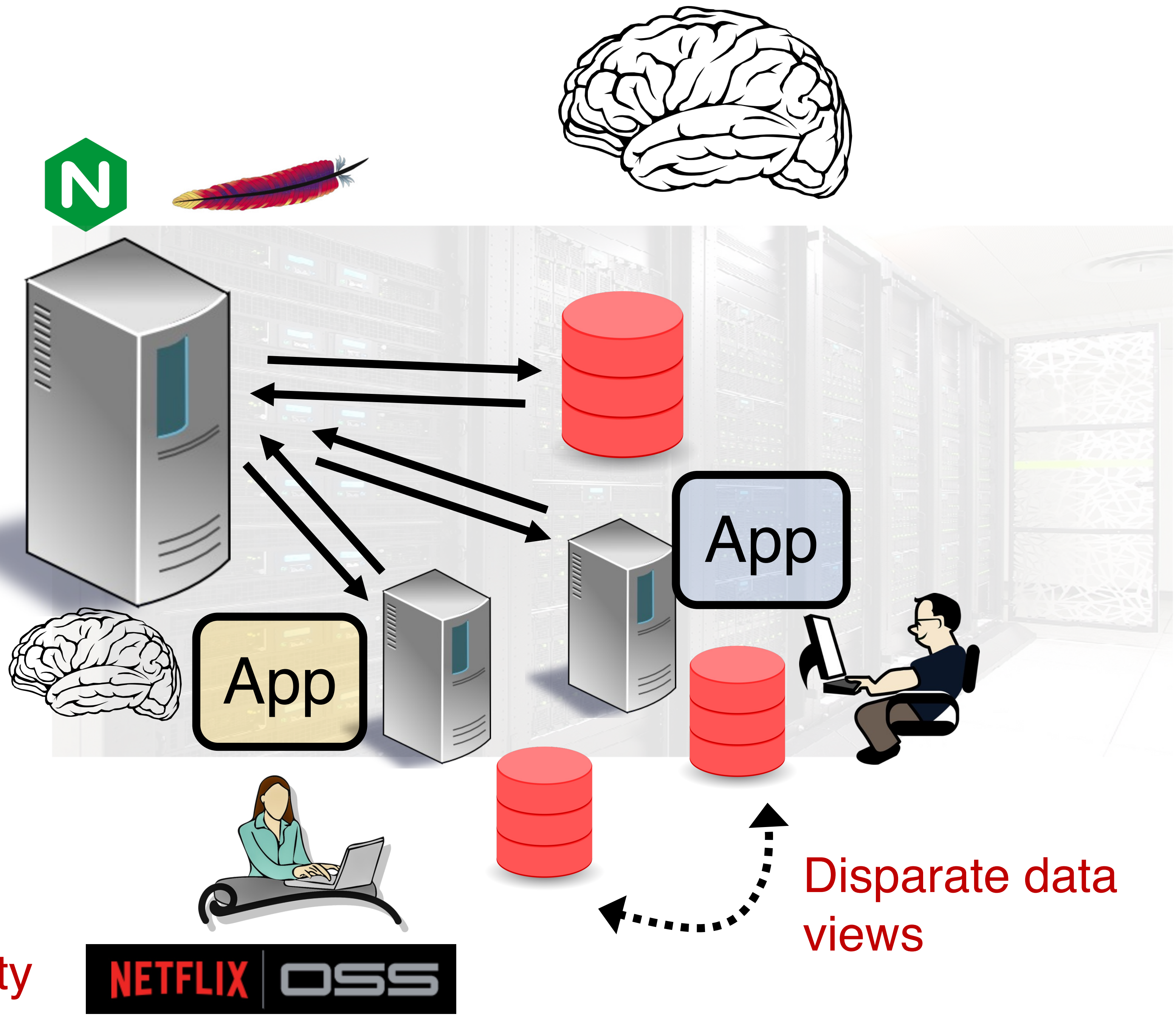
Independent data models

Distinct from a software library. Out of process.



How to split?





Business Capabilities

Churn Boundaries

Fleeting?

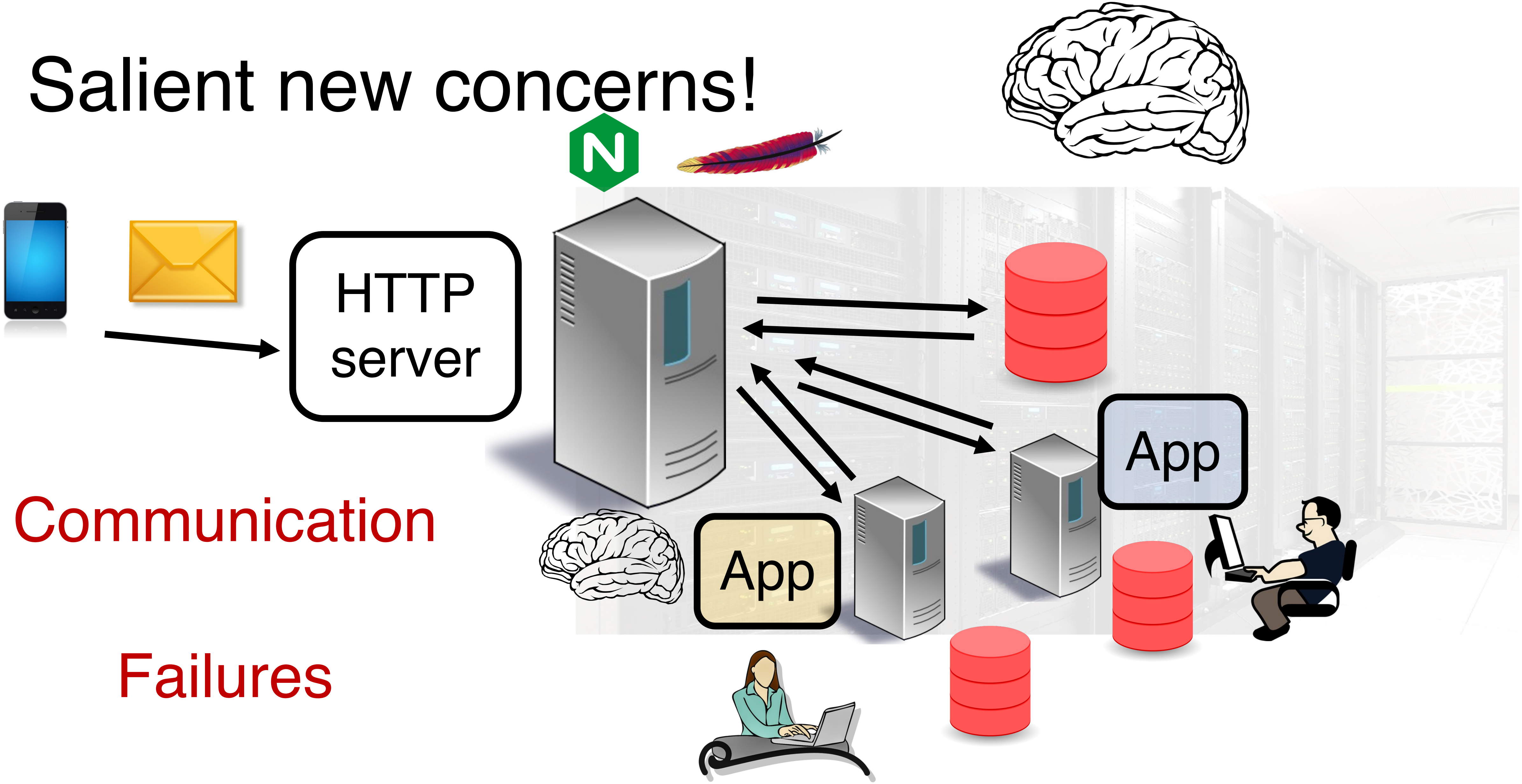
Who should know (or not)?

Changing together?

Heterogeneity in resource use

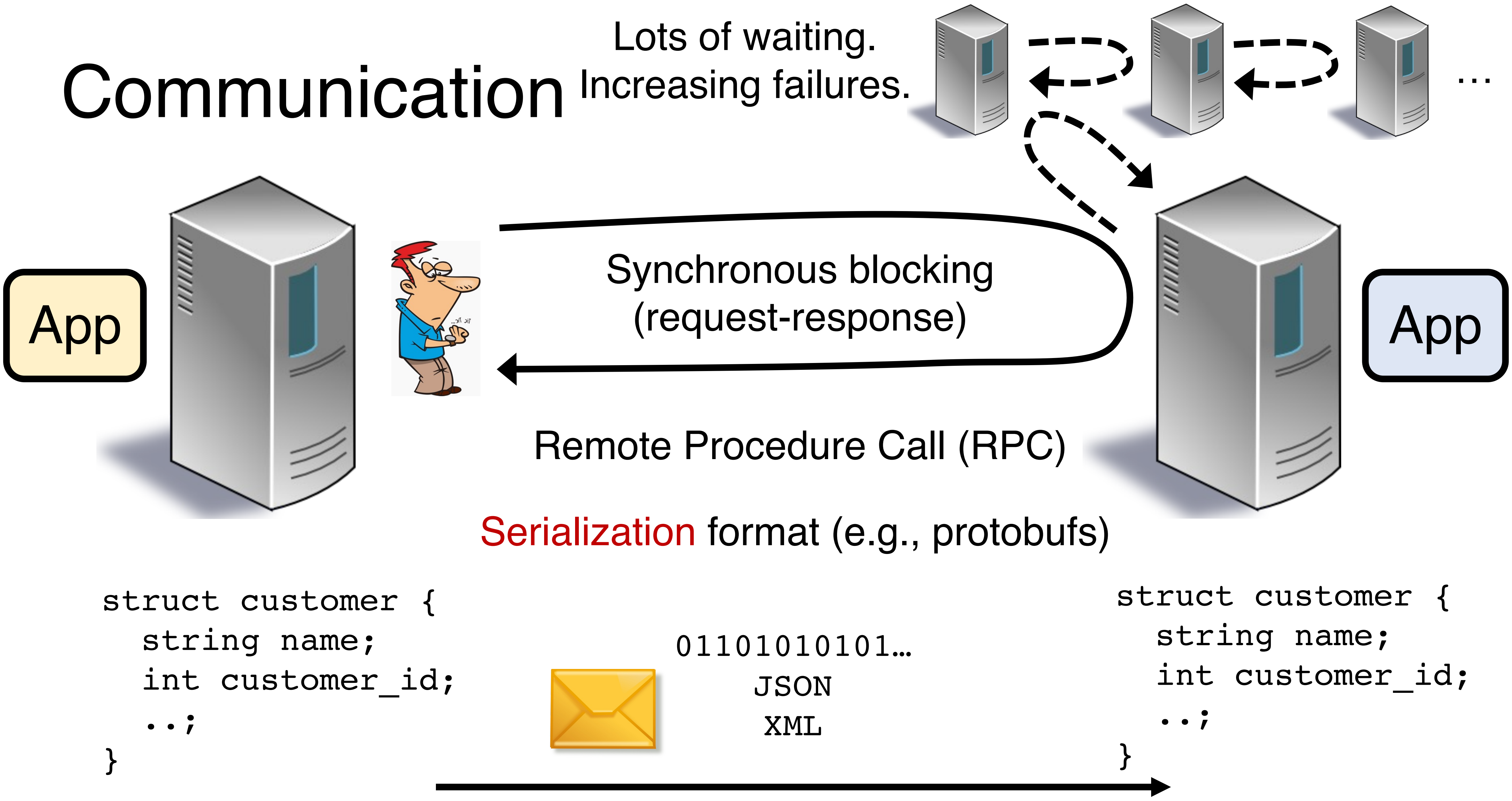
Refactoring common functionality

Salient new concerns!

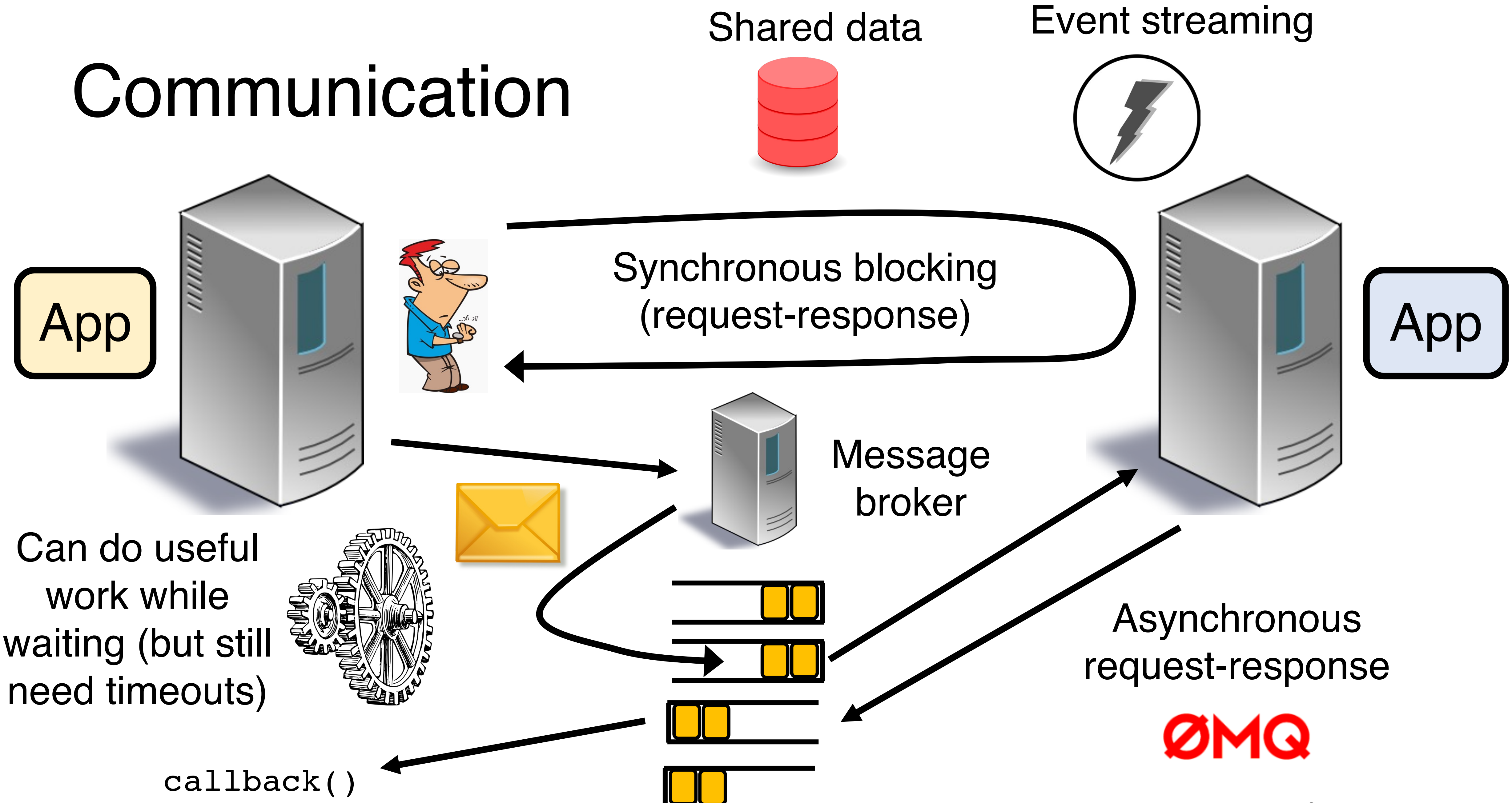


Communication

Failures


Communication
Lots of waiting.
Increasing failures.
…
App
App
Synchronous blocking
(request-response)
Remote Procedure Call (RPC)
Serialization format (e.g., protobufs)
struct customer {
string name;
int customer_id;
..;
}
01101010101…
JSON
XML
struct customer {
string name;
int customer_id;
..;
}

Communication



“Building microservices”, Sam Newman

Cost of communication: Performance

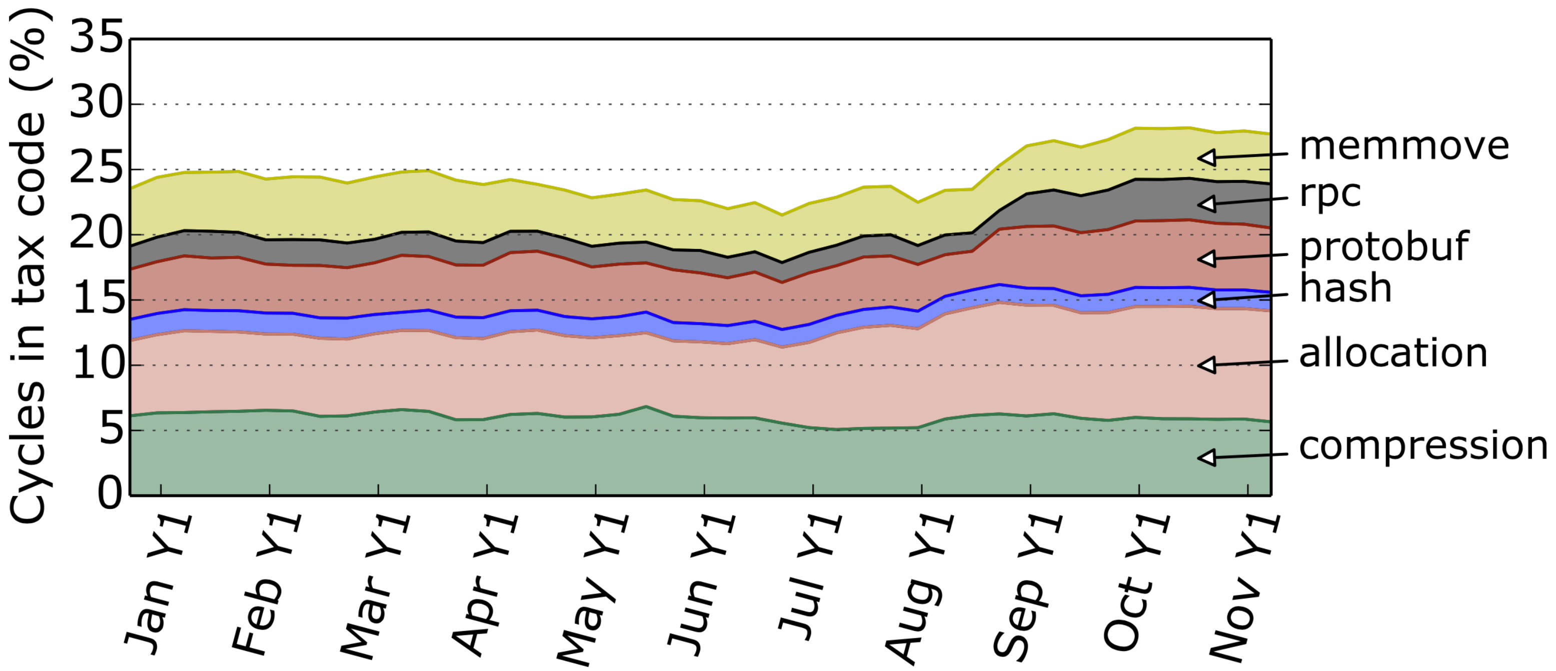
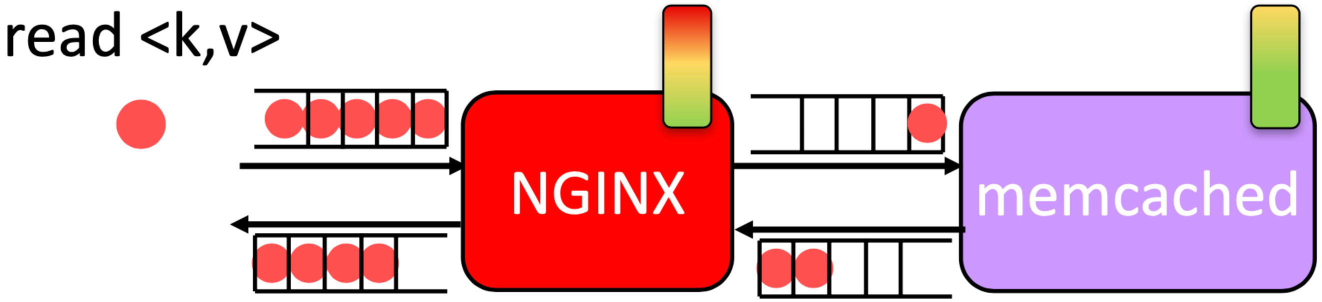


Figure 4: 22–27% of WSC cycles are spent in different components of "datacenter tax".

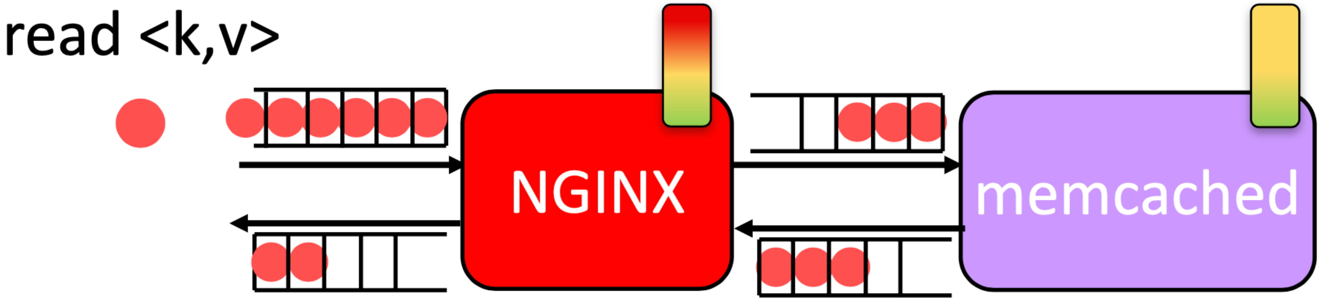
Profiling a warehouse-scale computer (Google). ISCA'15.

Cost of comm: Hotspot spreading

A. NGINX Saturation

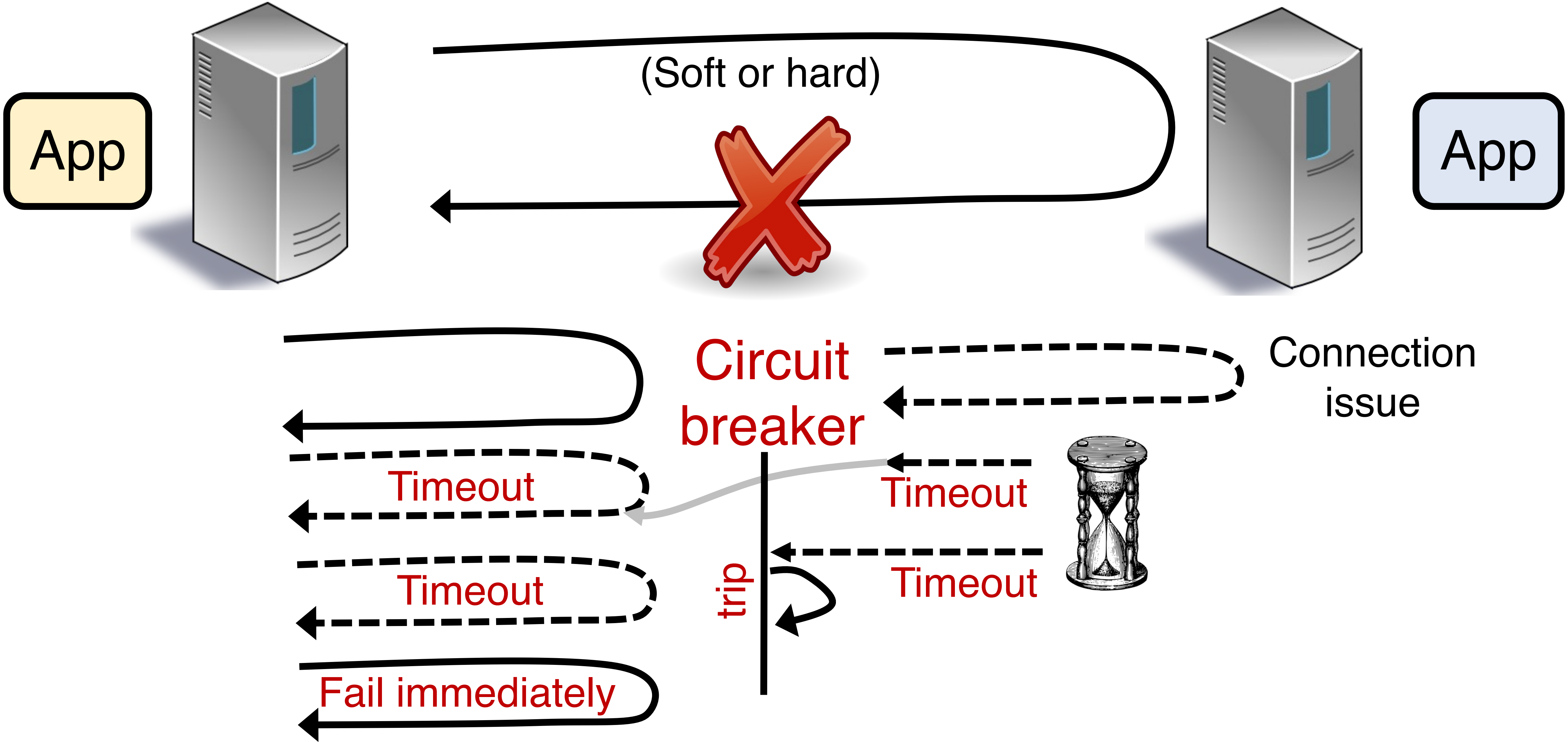


B. Memcached Backpressuring NGINX



Deathstarbench. ASPLOS’19.

Cost of comm: high level failure handling



Microservices aren’t always good

- Just a technology. Look at problems first
- Observability
- Deployment automation
- Integration: refactoring service boundaries is hard
- How significant are dev coordination overheads?
- Complexity

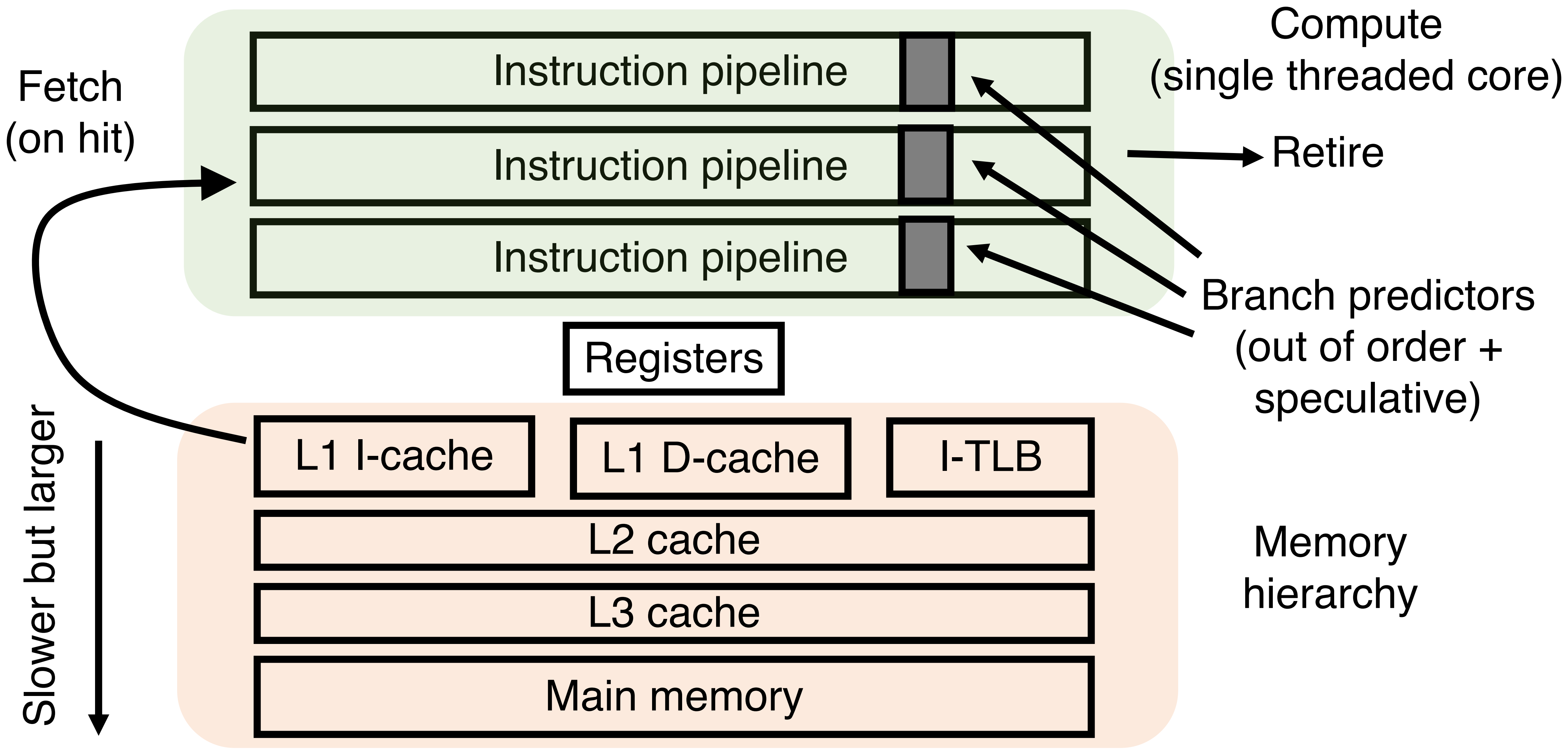
Partition-Aggregate

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
- Cannot process on a single machine within acceptable time

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

Use parallelism

- Can't drive high single threaded performance

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.

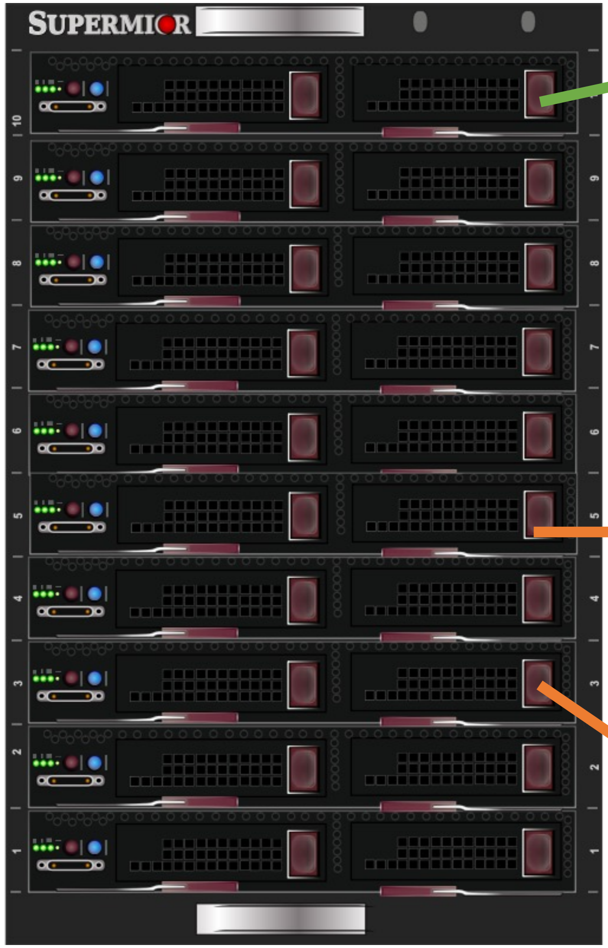
Web search for a planet, MICRO'03.

How to use parallelism?

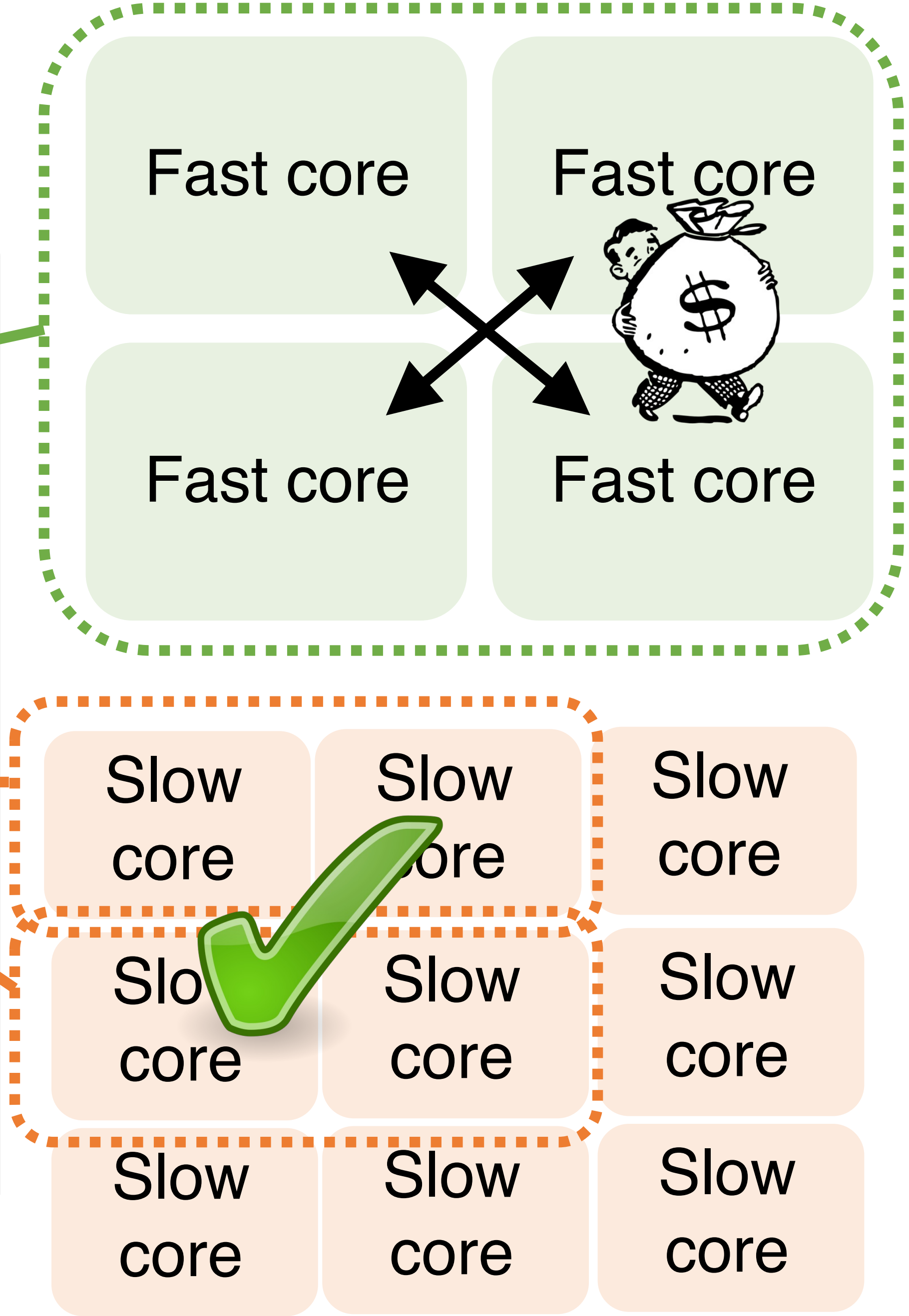
- Few fast cores with high-speed interconnect
- Or more slow cores?

- Cost per query processed?
- Power efficiency?

(hyperthreaded or on-chip multicore)

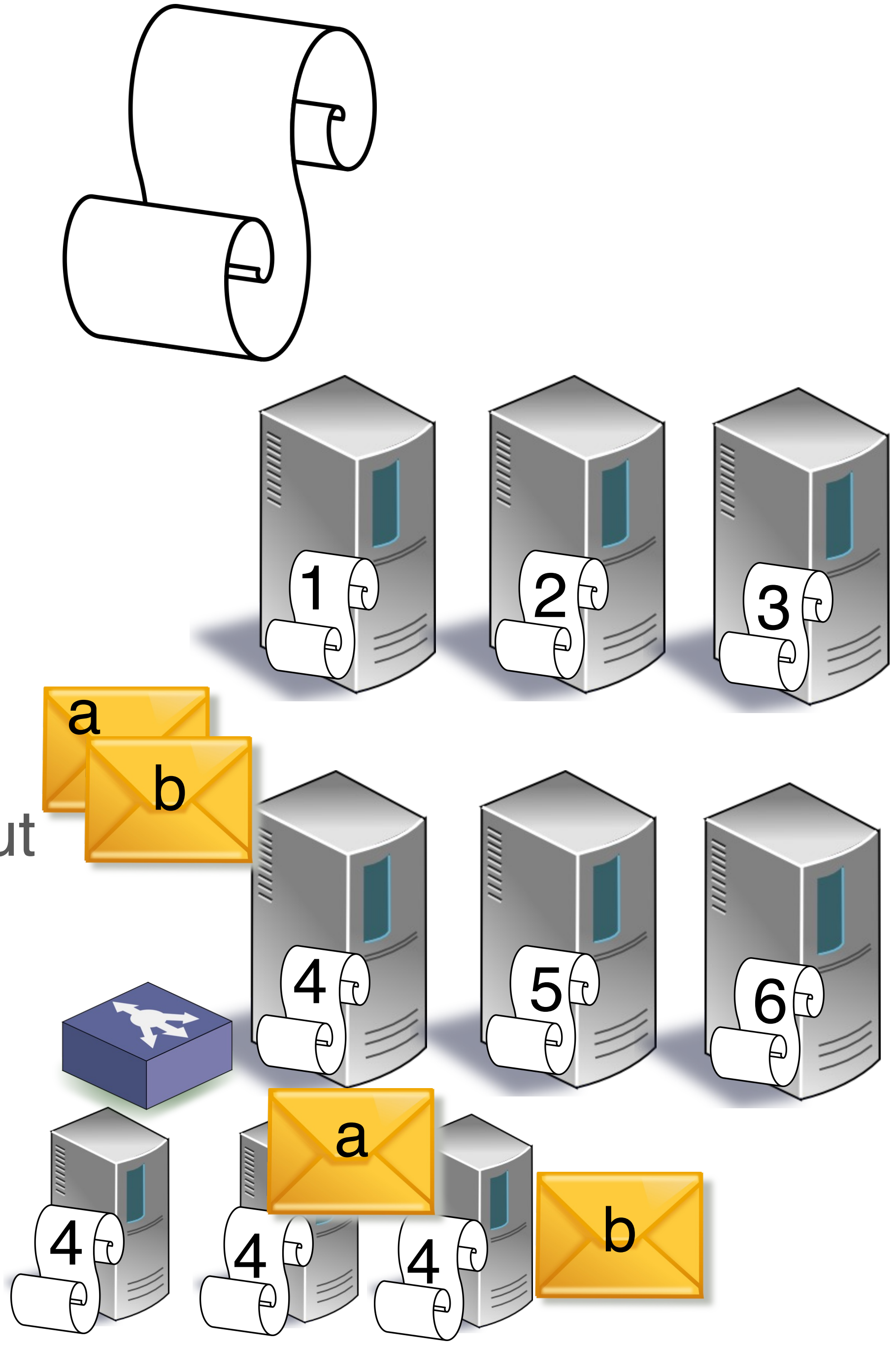


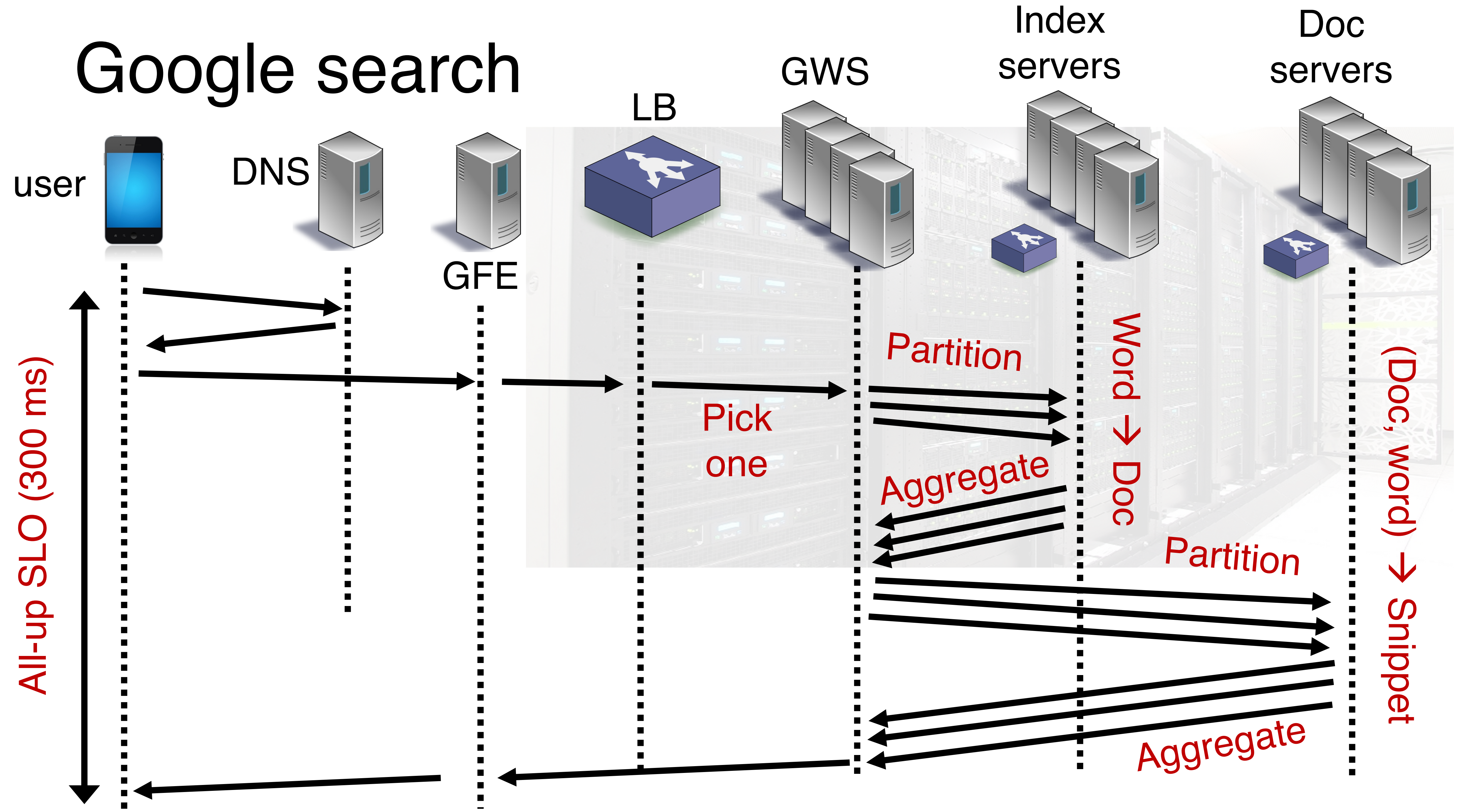
Server rack



Data parallelism

- Significant parts of computation are independent over shards of data
  - Fast interconnects not as critical
  - Stateless, no coordination within a request
- Different requests are independent
  - Use parallelism across 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
user
DNS
GFE
LB
GWS
Index servers
Doc servers
All-up SLO (300 ms)
Pick one
Partition
Aggregate
Word → Doc
Partition
Aggregate
(Doc, word) → Snippet

Internet architecture: Review

Routing

Software/hardware organization at hosts

- Application: useful user-level functions
- Transport: provide guarantees to apps
- Network: best-effort global pkt delivery
- Link: best-effort local pkt delivery

Communication functions broken up and “stacked”

Each layer depends on the one below it.

Each layer supports the one above it.

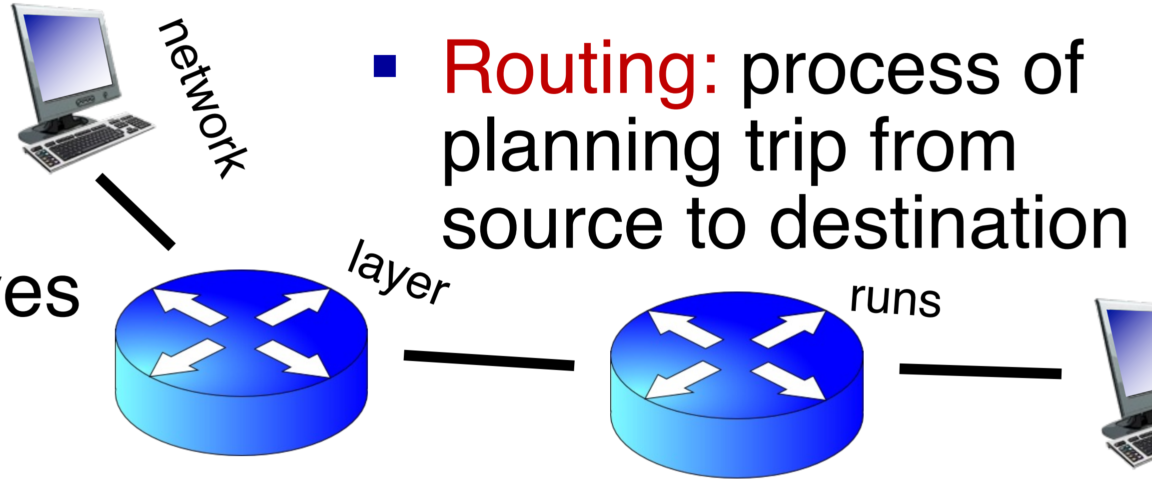
The interfaces between layers are well-defined and standardized.

Routing


Norwegian Sea
Iceland
Sweden
Finland
Norway
Russia
Denmark
Ireland
Poland
Belarus
Ukraine
Kazakhstan
Austria
Romania
Spain
Portugal
Turkey
Turkmenistan
Syria
Iraq
Iran
Afghanistan
Pakistan
Tunisia
Morocco
Algeria
Libya
Egypt
Saudi Arabia
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Oman
Burkina Faso
Guinea
Nigeria
Ghana
South Sudan
Ethiopia
Gulf of Guinea
Somalia
Kenya
Gabon
DR Congo
Tanzania
Gulf of Aden
Arabian Sea
Laccadive Sea
India
Nepal
Bay of Bengal
China
Myanmar (Burma)
Philippines
Indonesia
Banda Sea
Arafura Sea
Papua New Guinea
Sea of Japan
Sea of Okhotsk

Two key network-layer functions

- **Forwarding:** move packets from router's input to appropriate router output
- **Routing:** determine route taken by packets from source to destination
  - routing algorithms
- The network layer solves the routing problem.



Analogy: taking a road trip

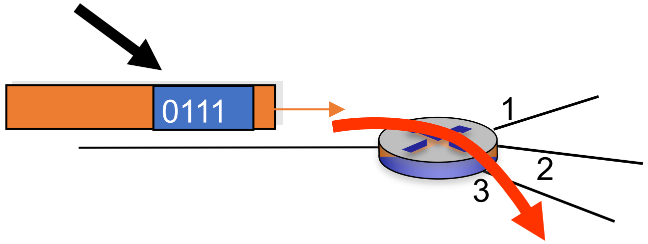
- **Forwarding:** process of getting through single exit
- **Routing:** process of planning trip from source to destination

Control/Data Planes

Data plane = Forwarding

- local, per-router function
- determines how datagram arriving on router input port is forwarded to router output port

values in arriving packet header



Control plane = Routing

- network-wide logic
- determines how datagram is routed along end-to-end path from source to destination endpoint
- two control-plane approaches:
  - Distributed routing algorithm running on each router
  - Centralized routing algorithm running on a (logically) centralized machine

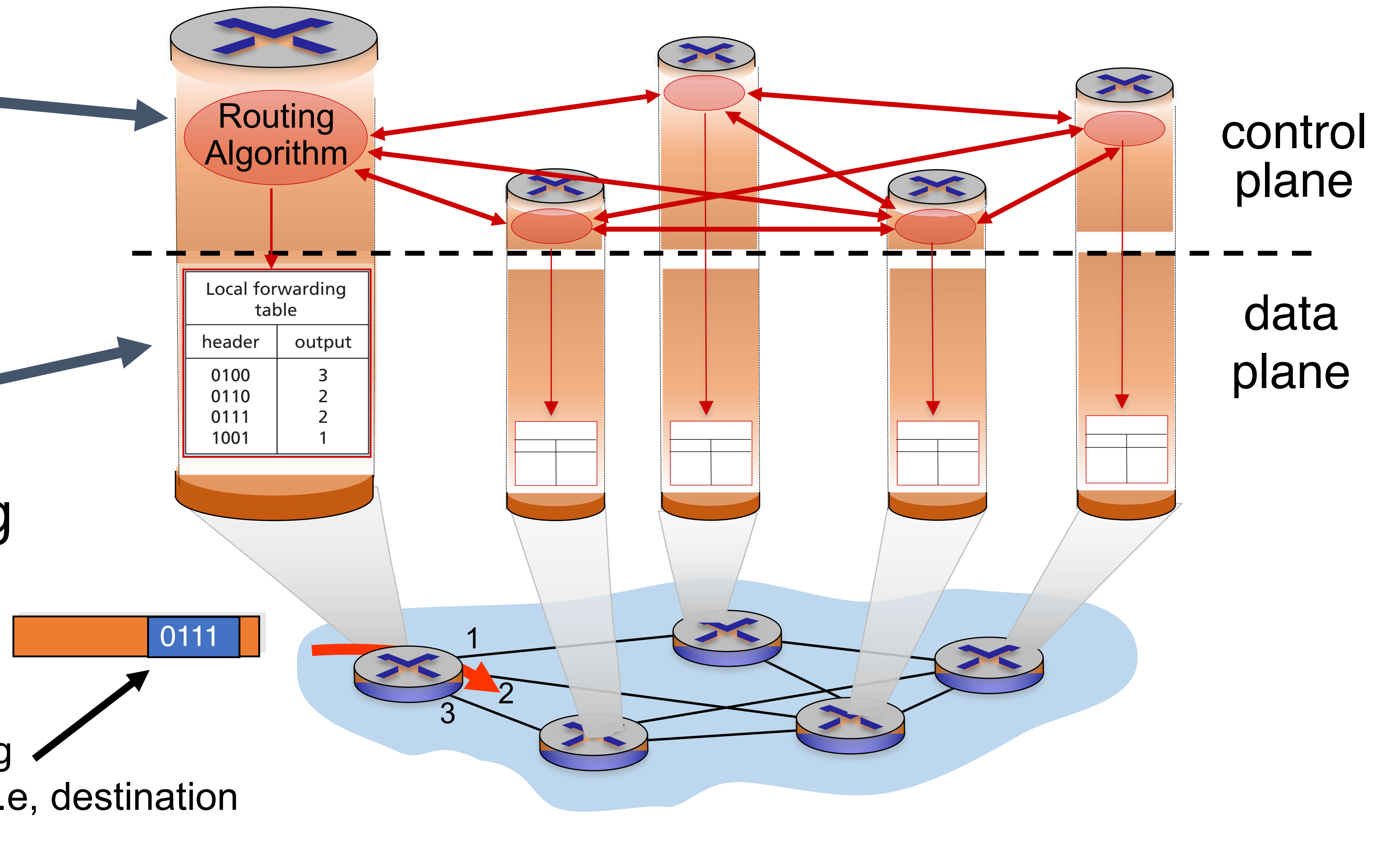
Distributed routing

Control plane

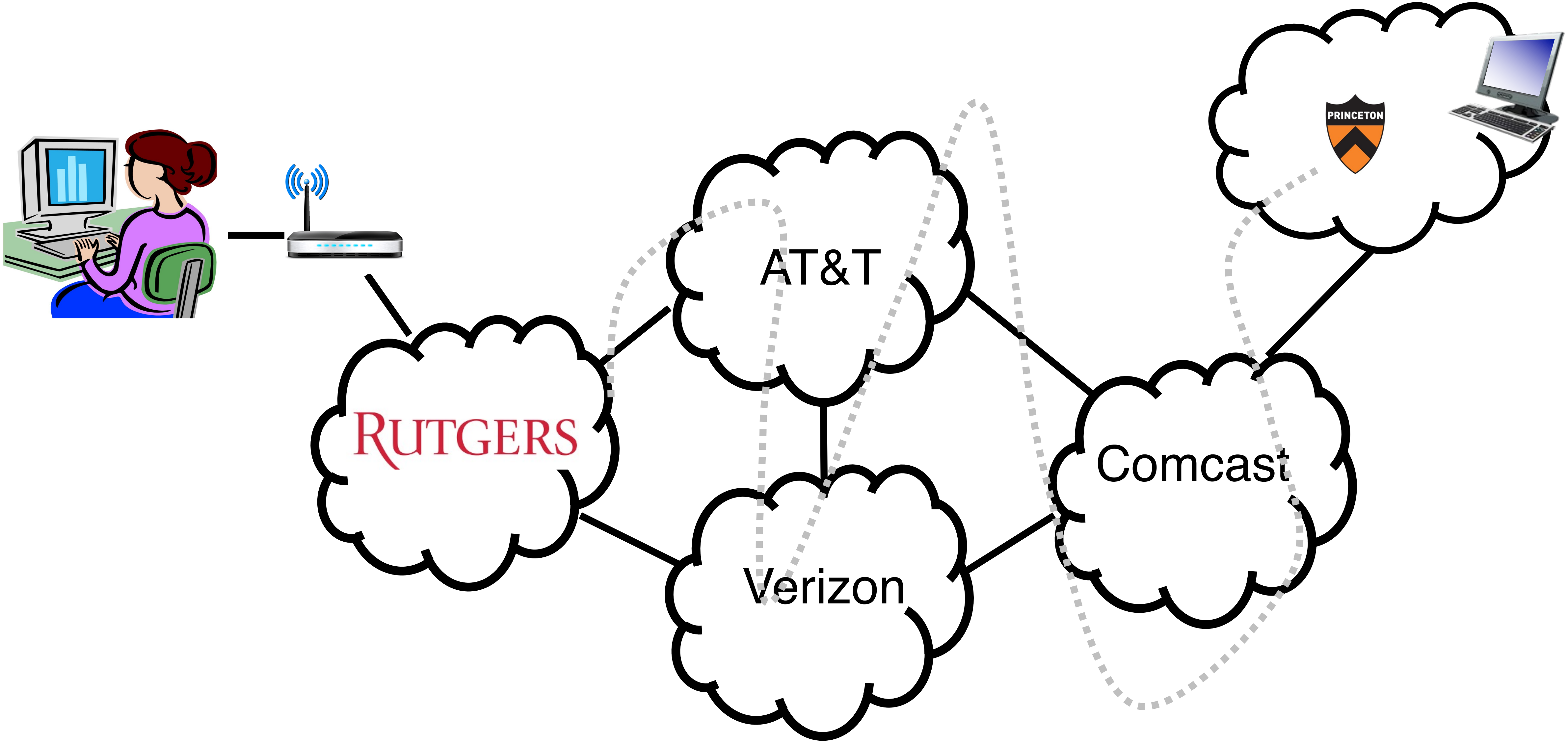
Traditional routing protocols: per route-change processing (~ a few tens of seconds)

Data plane

per-packet processing (~ tens of nanoseconds)



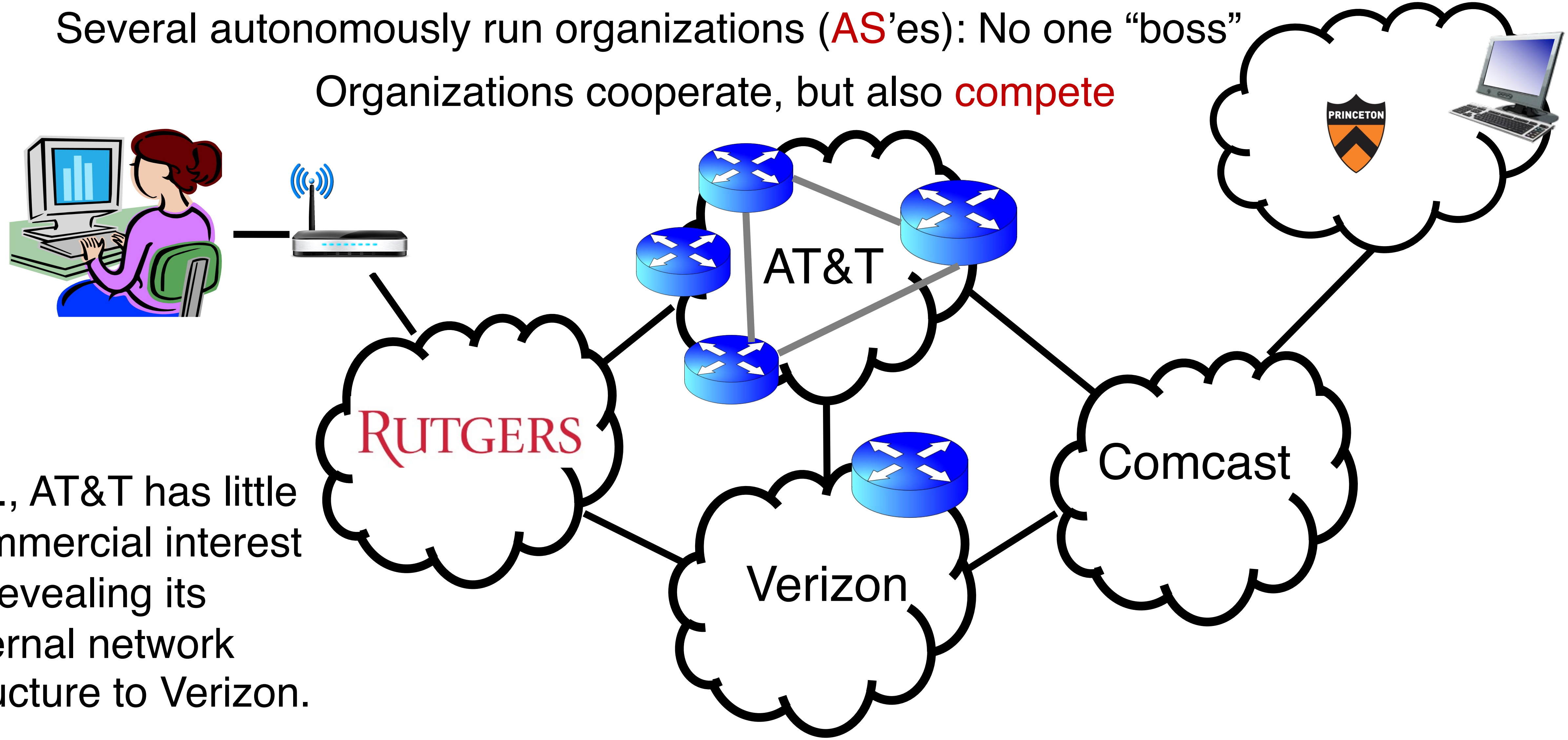
The Internet is a large federated network



The Internet is a large federated network

Several autonomously run organizations (AS'es): No one "boss"

Organizations cooperate, but also compete

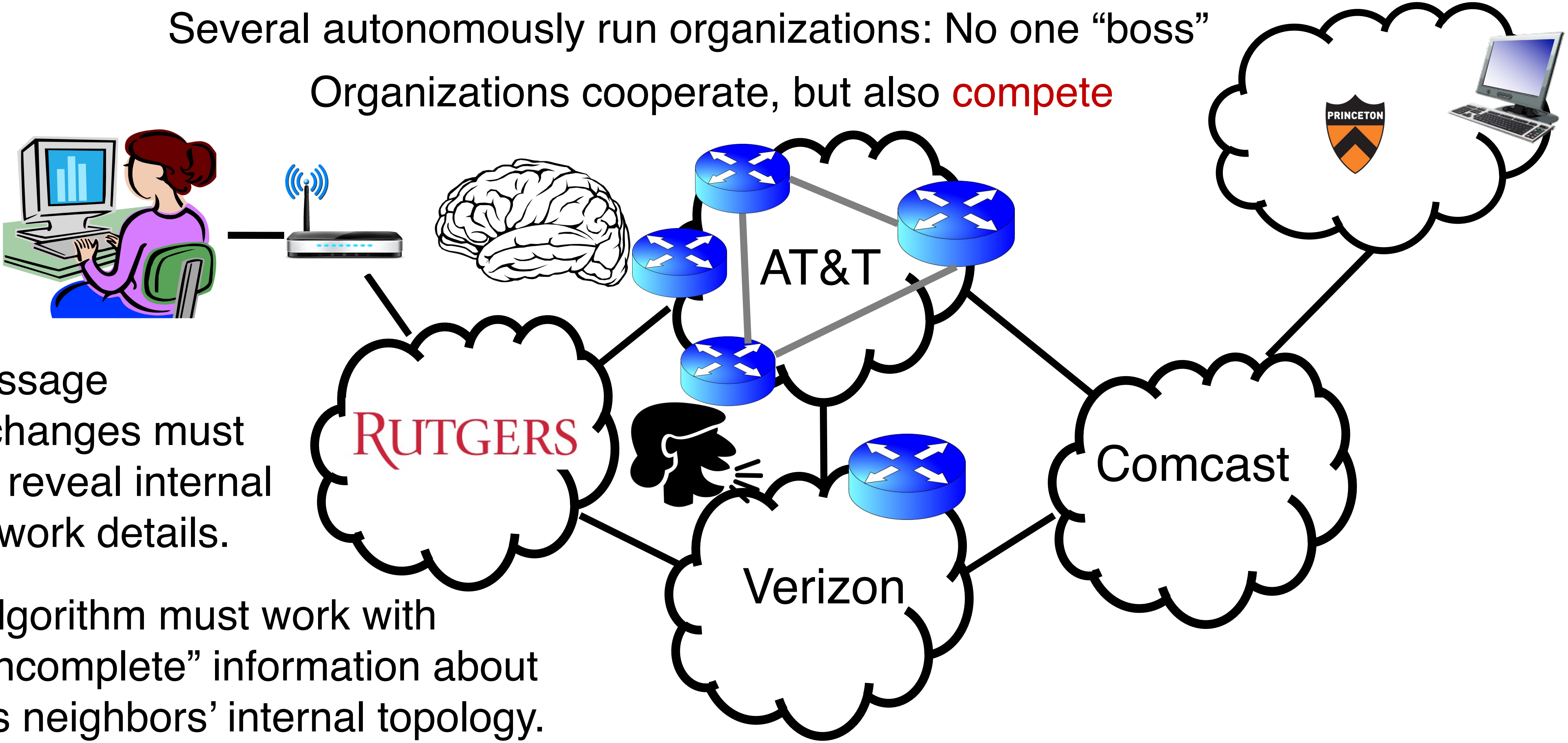


e.g., AT&T has little commercial interest in revealing its internal network structure to Verizon.

The Internet is a large federated network

Several autonomously run organizations: No one “boss”

Organizations cooperate, but also compete



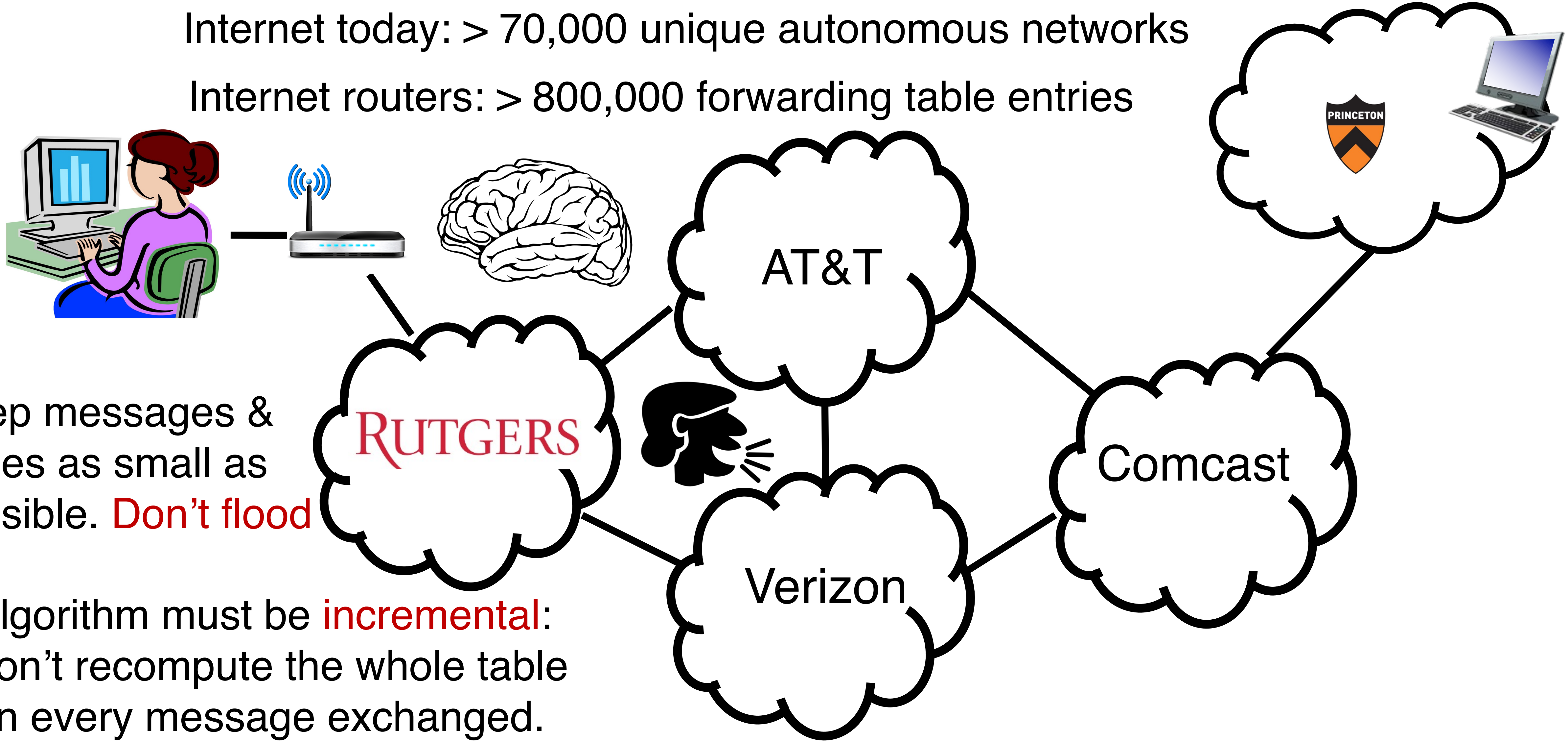
Message exchanges must not reveal internal network details.

Algorithm must work with “incomplete” information about its neighbors’ internal topology.

The Internet is a large federated network

Internet today: > 70,000 unique autonomous networks

Internet routers: > 800,000 forwarding table entries

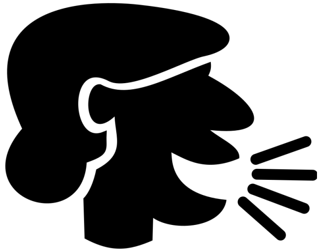


Keep messages & tables as small as possible. Don’t flood

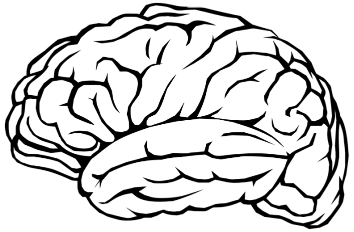
Algorithm must be incremental: don’t recompute the whole table on every message exchanged.

Inter-domain Routing

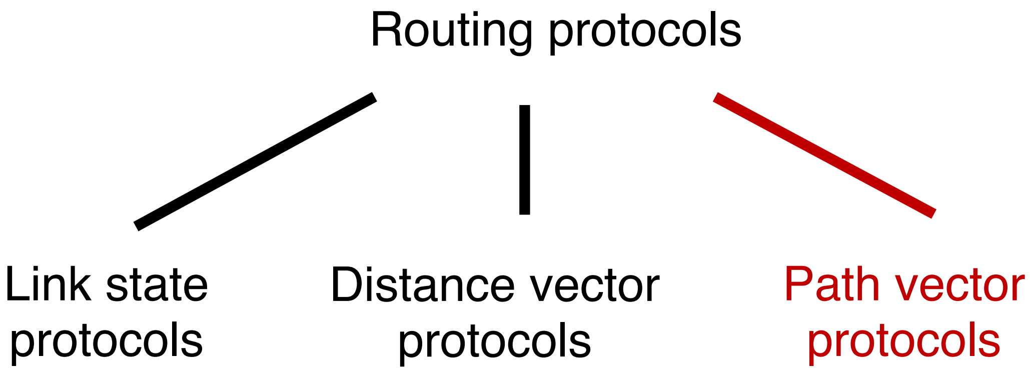
- The Internet uses Border Gateway Protocol (BGP)
- All AS'es speak BGP. It is the glue that holds the Internet together
- BGP is a path vector protocol



Messages?

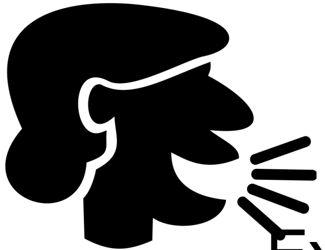


Algorithm?



Applicable within a single AS

(1) BGP Messages

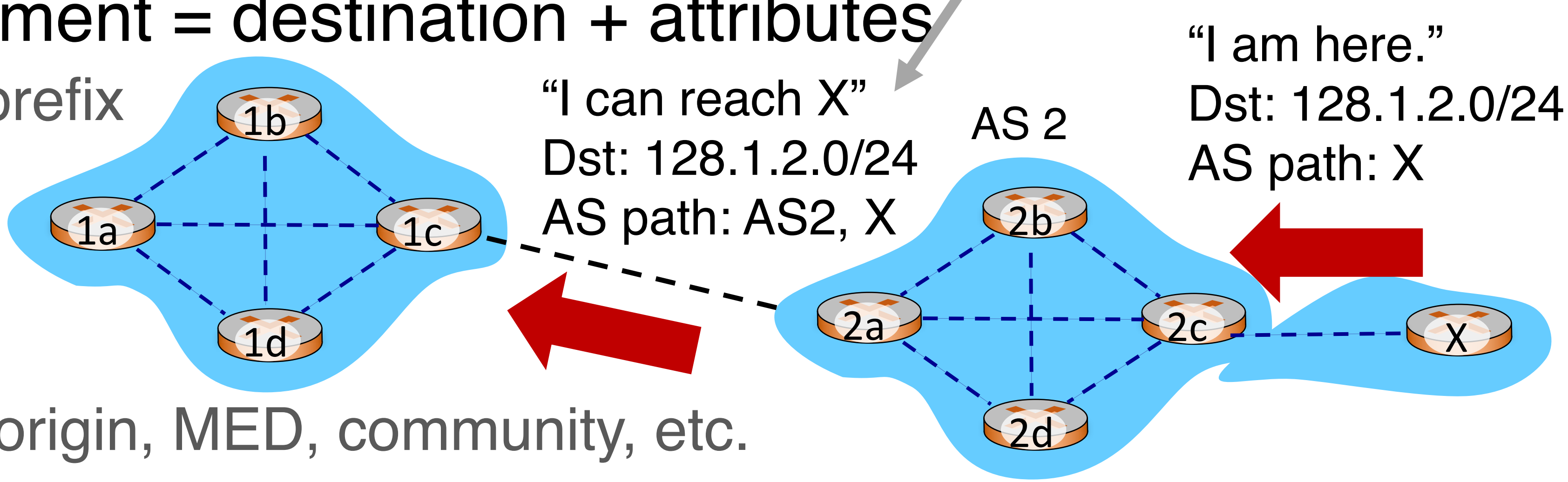


Loop detection is easy
(no “count to infinity”)

Exchange paths: path vector

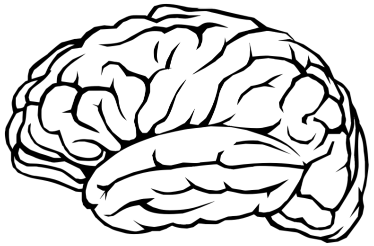
No link metrics, distances!

- Routing Announcements or Advertisements
  - “I am here” or “I can reach here”
  - Occur over a TCP connection (BGP session) between routers
- Route announcement = destination + attributes
  - Destination: IP prefix
- Route Attributes:
  - AS-level path
  - Next hop
  - Several others: origin, MED, community, etc.



- An AS promises to use advertised path to reach destination
- Only route changes are advertised after BGP session established

(2) BGP algorithm



- A BGP router does *not* consider every routing advertisement it receives by default to make routing decisions!
  - An import policy determines whether a route is even considered a candidate
- Once imported, the router performs route selection
- A BGP router does *not* propagate its chosen path to a destination to all other AS'es by default!
  - An export policy determines whether a (chosen) path can be advertised to other AS'es and routers

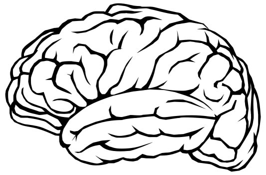
Programmed by network operator

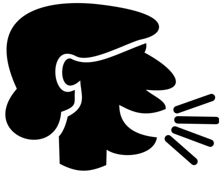
Business policy considerations drive BGP.
NOT efficiency considerations.

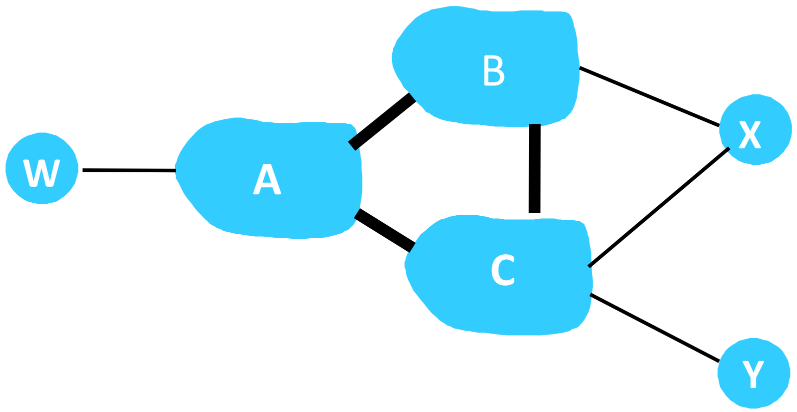
Policy arises from business relationships

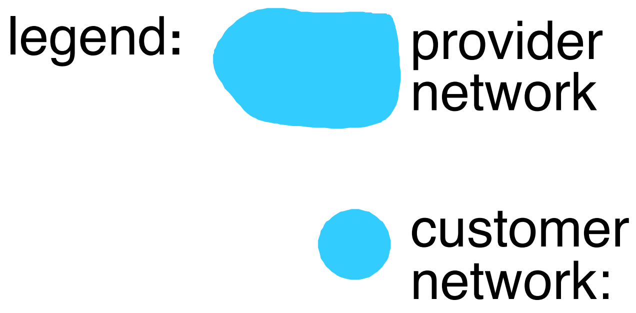
- Customer-provider relationships:
  - E.g., Rutgers is a customer of AT&T
- Peer-peer relationships:
  - E.g., Verizon is a peer of AT&T
- Business relationships depend on where connectivity occurs
  - “Where”, also called a “point of presence” (PoP)
  - e.g., customers at one PoP but peers at another
  - Internet-eXchange Points (IXPs) are large PoPs where ISPs come together to connect with each other (often for free)

BGP Export Policy





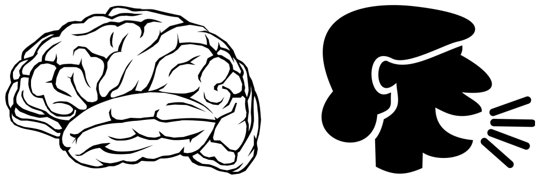


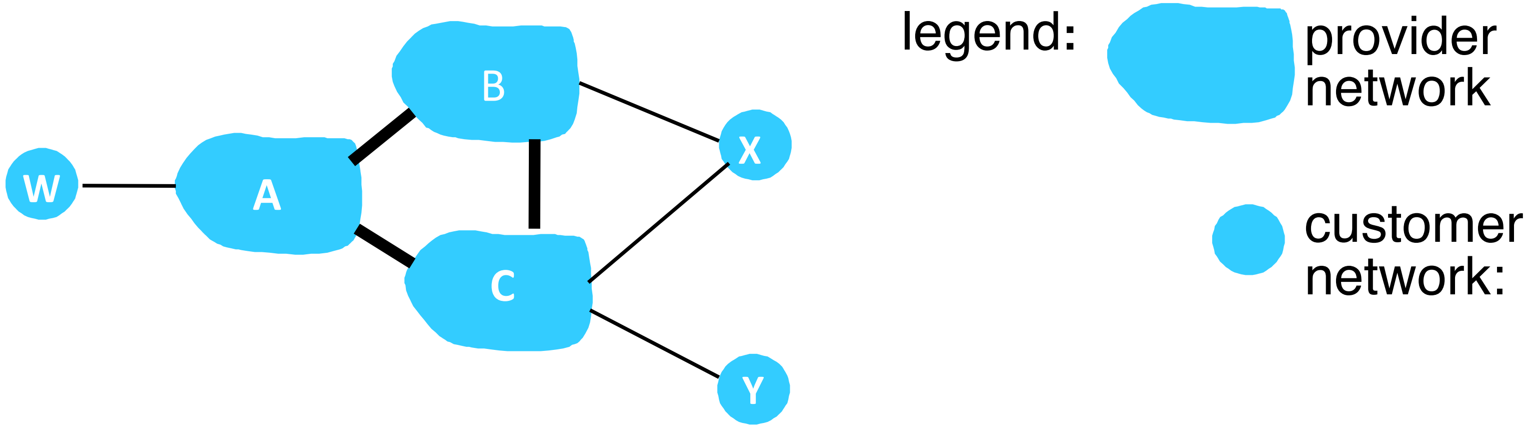


Suppose an ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs)

- A,B,C are provider networks
- X,W,Y are customers (of provider networks)
- X is dual-homed: attached to two networks
- policy to enforce: X does not want to route from B to C via X
  - So, X will not announce to B a route to C

BGP Export Policy

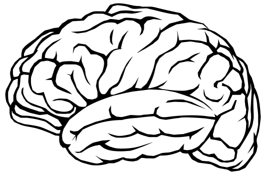


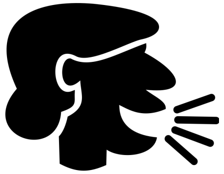


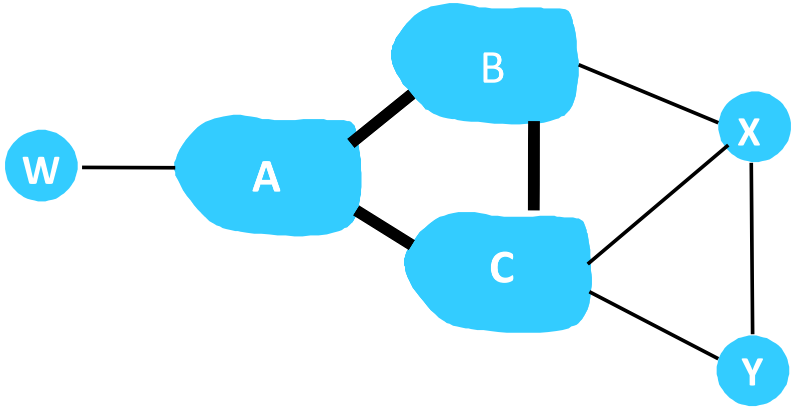
Suppose an ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs)

- A announces path Aw to B and to C
- B will not announce BAw to C:
  - B gets no "revenue" for routing CBAw, since none of C, A, w are B's customers
- C will route CAw (not using B) to get to w

BGP Import Policy







legend:

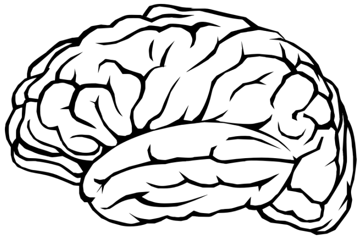
provider network

customer network:

Suppose an ISP wants to minimize costs by avoiding routing through its providers when possible.

- Suppose C announces path Cy to x
- Further, y announces a direct path ("y") to x
- Then x may choose not to import the path Cy to y since it has a peer path ("y") towards y

Q2. BGP Route Selection



- When a router imports more than one route to a destination IP prefix, it selects route based on:
  1. local preference value attribute (import policy decision -- set by network admin)
  2. shortest AS-PATH
  3. closest NEXT-HOP router
  4. Several additional criteria: You can read up on the full, complex, list of criteria, e.g., at https://www.cisco.com/c/en/us/support/docs/ip/border-gateway-protocol-bgp/13753-25.html

Problems with BGP

Approaches to bring flexibility:
Flexible control logic for path selection (Google, Facebook)
Detour/overlay routing (Akamai)

- Not designed for efficiency

    1. local preference value attribute (import policy decision -- set by network admin)
    2. shortest AS-PATH
    3. closest NEXT-HOP router

  Nothing to do with path length, delay, or available capacity.

- Only a single path per destination
- Slow to converge after a change
- Vulnerable to bugs & malice