Communication: Message Queues & BASE End-to-End Argument (if time allows)

ACS, Marcos Vaz Salles

What should we learn today?

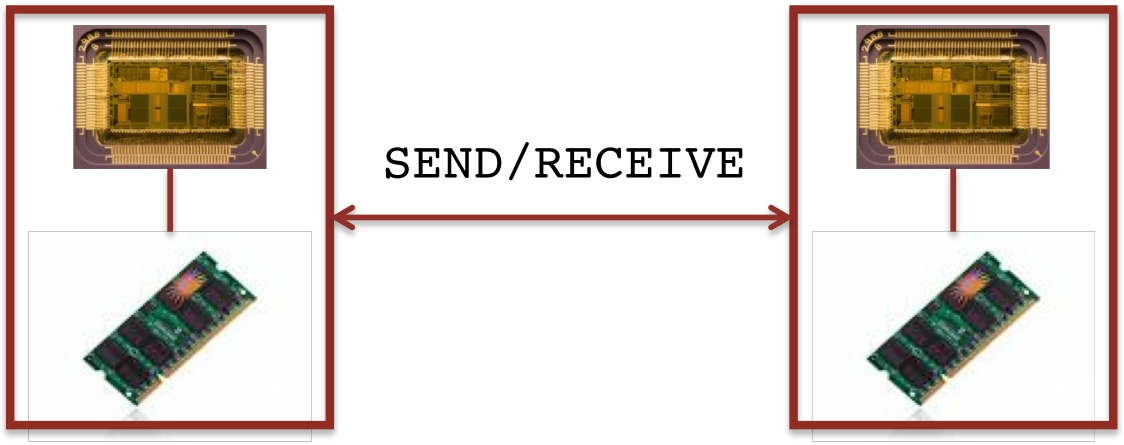
- Describe different approaches to design communication abstractions, e.g., transient vs. persistent and synchronous vs. asynchronous
- Explain the design and implementation of message-oriented middleware (MOM)
- Explain how to organize systems employing a BASE methodology
- Discuss the relationship of BASE to eventual consistency and the CAP theorem
- Identify alternative communication abstractions such as data streams and multicast / gossip
- Apply the end-to-end argument to system design situations

Availability vs. Atomicity

- Last two weeks' property: **Atomicity**
- Next two weeks: **Availability**

Towards Distribution

- Use independent services to store different data → **partitioning**
- Availability improves but now coordination may be necessary
- Employ communication abstraction



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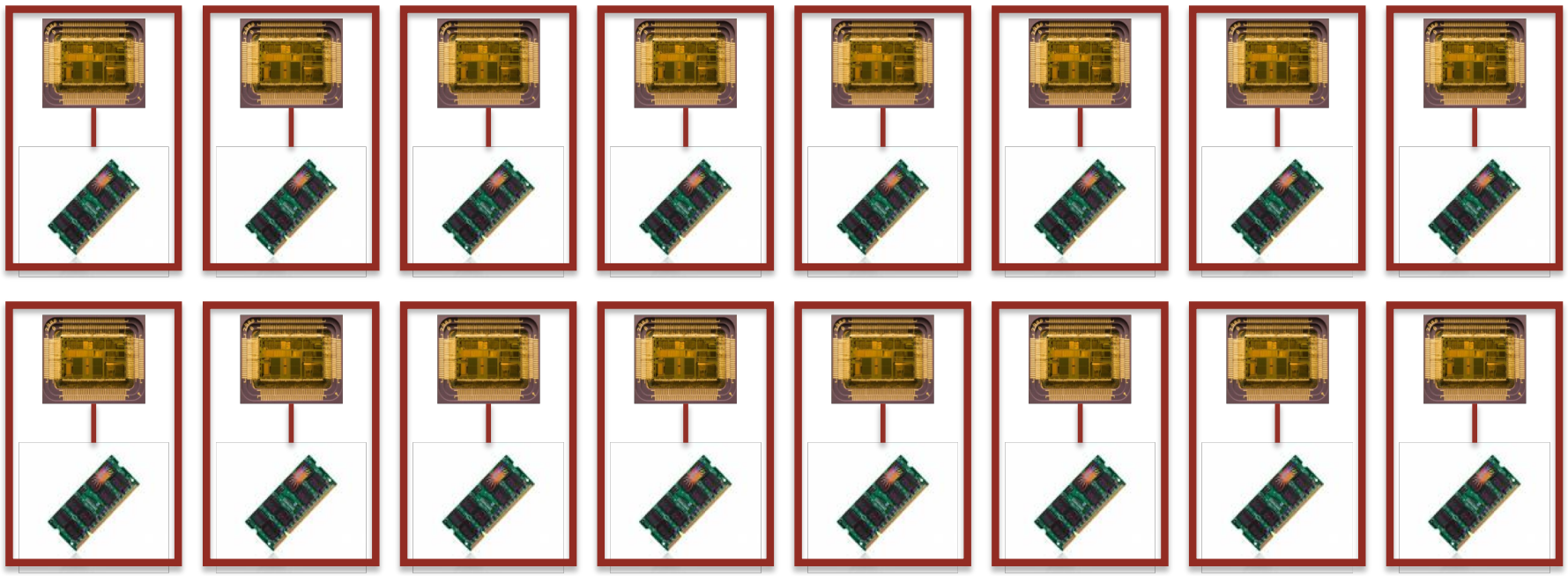


Types of Communication Abstractions

- **Message-Oriented**
  - `SEND/RECEIVE` of point-to-point messages
  - Synchronous vs. Asynchronous
  - Transient vs. Persistent
- **Stream-Oriented**
  - Continuous vs. discrete
  - Asynchronous vs. Synchronous vs. Isochronous
  - Simple vs. complex
- **Multicast**
  - `SEND/RECEIVE` over groups
  - Application-level multicast vs. gossip

What about Remote-Procedure Call (RPC)?

Source: Saltzer & Kaashoek & Morris (partial), Tanenbaum & Steen (partial)

Source: Tanenbaum & Van Steen

Message-Oriented Communication

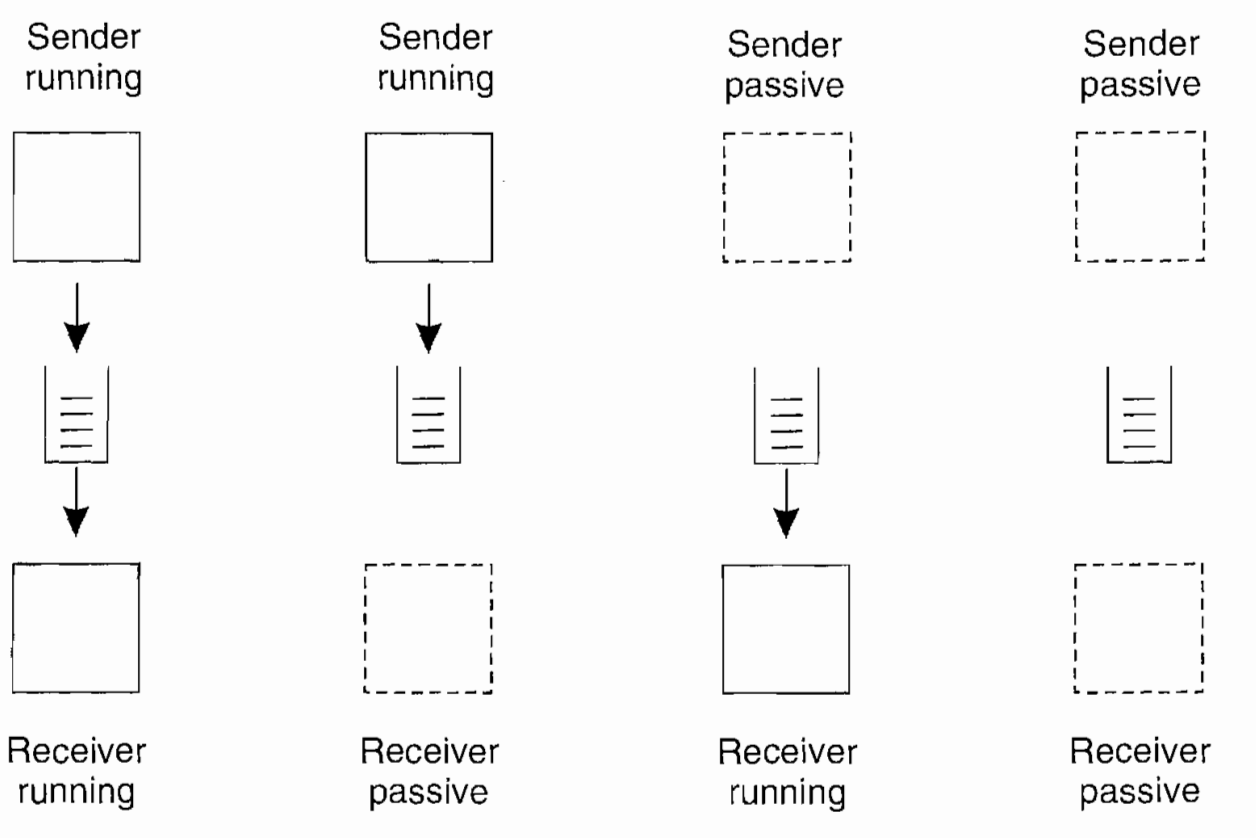
- Middleware for different types of communication
  - Synchronous vs. Asynchronous
    - Synchronize at request submission (1)
    - Synchronize at request delivery (2)
    - Synchronize after processing by server (3)
  - Transient vs. Persistent

Examples?

	Persistent	Transient
Asynchronous	E-mail	Erlang
Synchronous	Google chat (1)+(2)	RPC (3)

Message-Oriented Persistent Communication

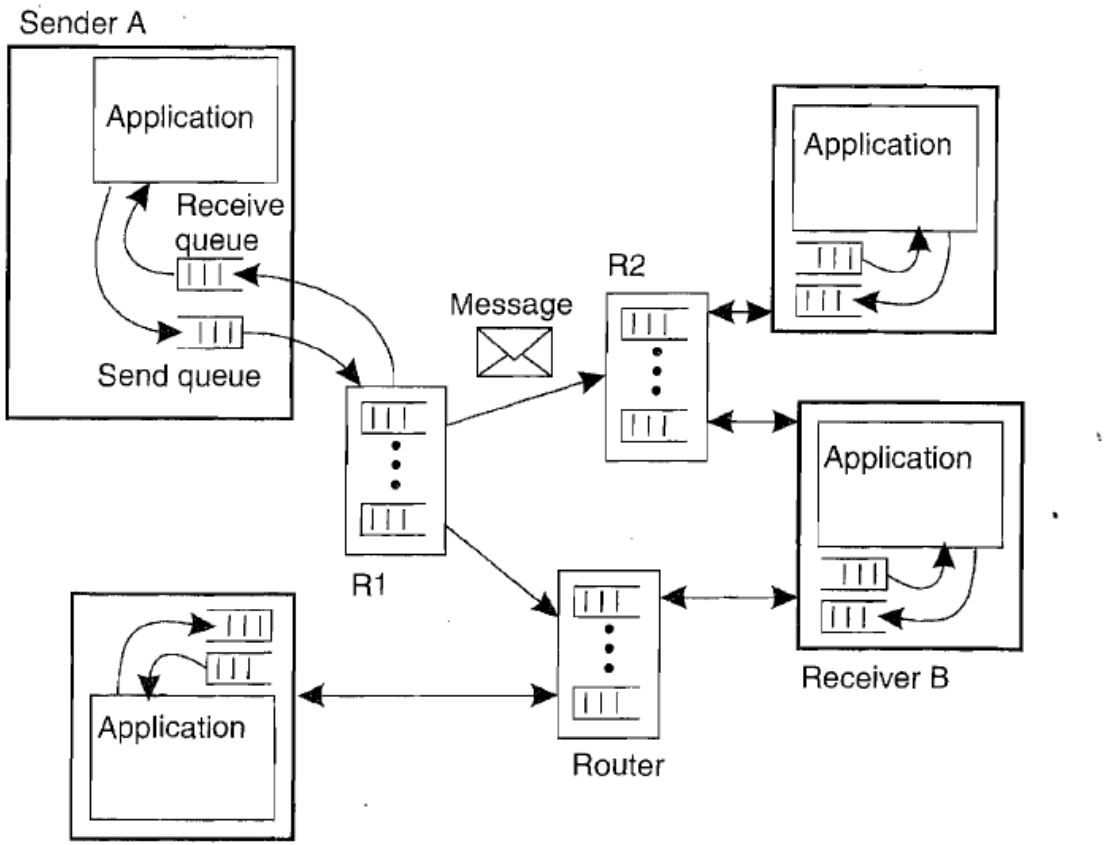
- Queues make sender and receiver loosely-coupled
- Modes of execution of sender/receiver:



Source: Tanenbaum & Van Steen

Queue Interface

Put	Put message in queue
Get	Remove first message from queue (blocking)
Poll	Check for message and remove first (non-blocking)
Notify	Handler that is called when message is added



- Source / destination decoupled by **queue names**
- **Relays:** store and forward messages
- **Brokers:** gateway to transform message formats

Source: Tanenbaum & Van Steen

Employing Queues to Decouple Systems

Transaction T1: `TRANSFER`

```
BEGIN
  UPDATE account
  SET bal = bal + 100
  WHERE account_id = 'A';
  --
  UPDATE account
  SET bal = bal – 100
  WHERE account_id = 'B';
COMMIT
```

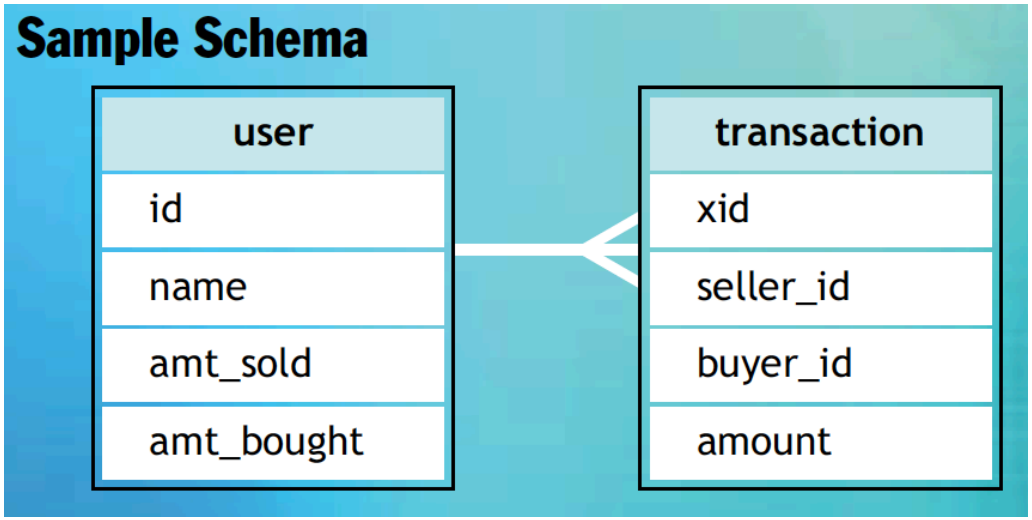
- What if we partition accounts A and B across different computers?
- How would you execute TRANSFER using Message-Oriented Middleware (MOM)?
- What guarantees can you still give? What happens to atomicity?

From ACID to BASE

- BASE
  - Basically-Available: only partitions affected by failure become unavailable, not whole system
  - Soft-State: partition state may be out-of-date, and events may be lost without affecting availability
  - Eventually Consistent: under no further updates and no failures, partitions converge to consistent state

A BASE Scenario

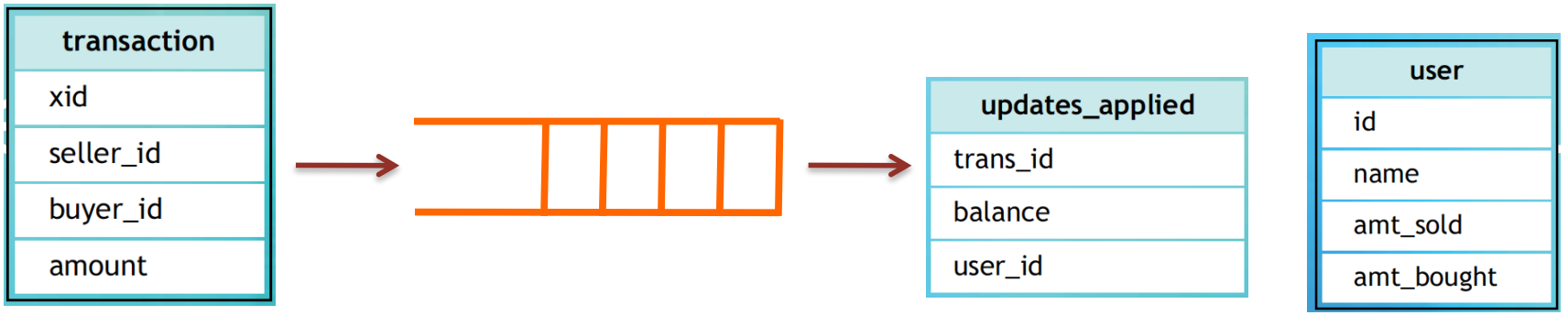
- Users buy and sell items
- Simple transaction for item exchange:




```
Begin transaction
  Insert into transaction(xid, seller_id, buyer_id, amount);
  Update user set amt_sold=amt_sold+$amount where id=$seller_id;
  Update user set amt_bought=amount_bought+$amount where id=$buyer_id;
End transaction
```

Source: Pritchett (partial)

Decouple Item Exchange with Queues




```
Record Transaction
Queue User updates
```

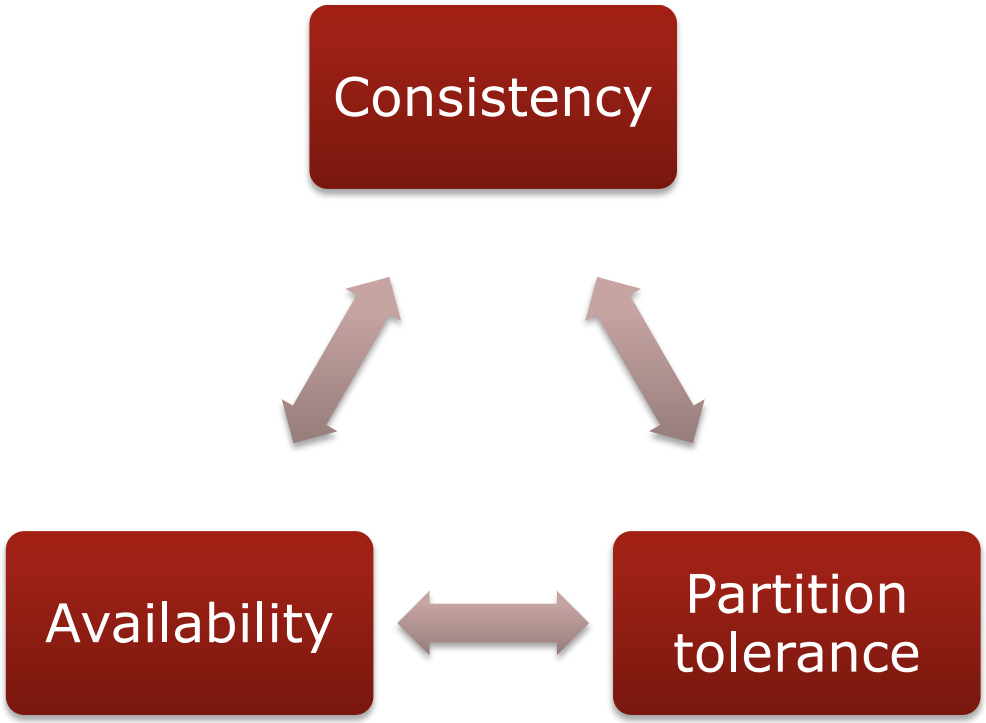
- **Issues**
  - Tolerance to loss
  - Idempotence
  - Order

```
Peek Queue for message
    Check if update applied
    If not
        Update User amounts
        Record update as applied
Remove message from queue
```

Source: Pritchett (partial)

The CAP Theorem

- Consistency: client perceives set of operations occurred all at once (i.e., atomicity)
- Availability: every operation terminates in intended response
- Partition tolerance: operations complete, even if components are unavailable



CAP Theorem:
A scalable service cannot achieve all three properties simultaneously

Source: Pritchett (partial)

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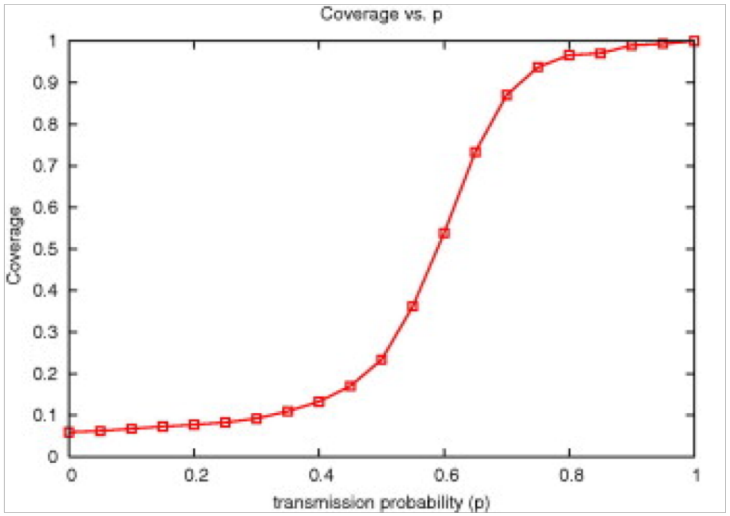
More details in compendium

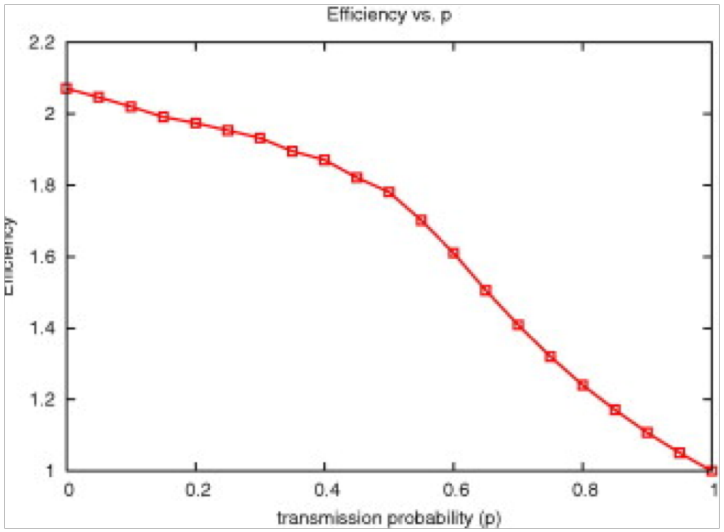
Source: Saltzer & Kaashoek & Morris (partial), Tanenbaum & Steen (partial)

A Word about Gossip

- **Epidemic protocols**
  - No central coordinator
- **Gossiping**
  - If P is updated it tells a random Q
  - If Q already knows, P can lose interest with some percentage
  - Not guaranteed that all nodes get infected by update
- **Anti-entropy**
  - Each node communicates with random node
  - Round: every node does the above
  - Pull vs. push vs. both
  - Spreading update from single to all nodes takes O(log(N))



Coverage vs. trans prob



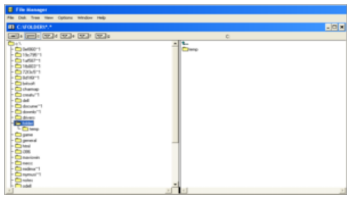
Efficiency vs. trans prob

Source: Haas et al. (partial)

Questions so far?

Recall: Fundamental abstractions

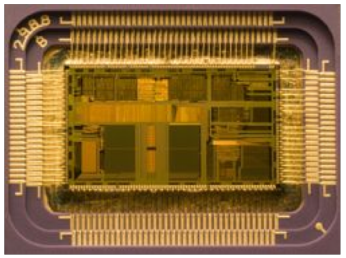
- Memory
  - Read/write



- Interpreter
  - Instruction repertoire
  - Environment
  - Instruction pointer

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

Networks implement link abstraction



- Communication links
  - Send/receive

Source: Saltzer & Kaashoek & Morris (partial)

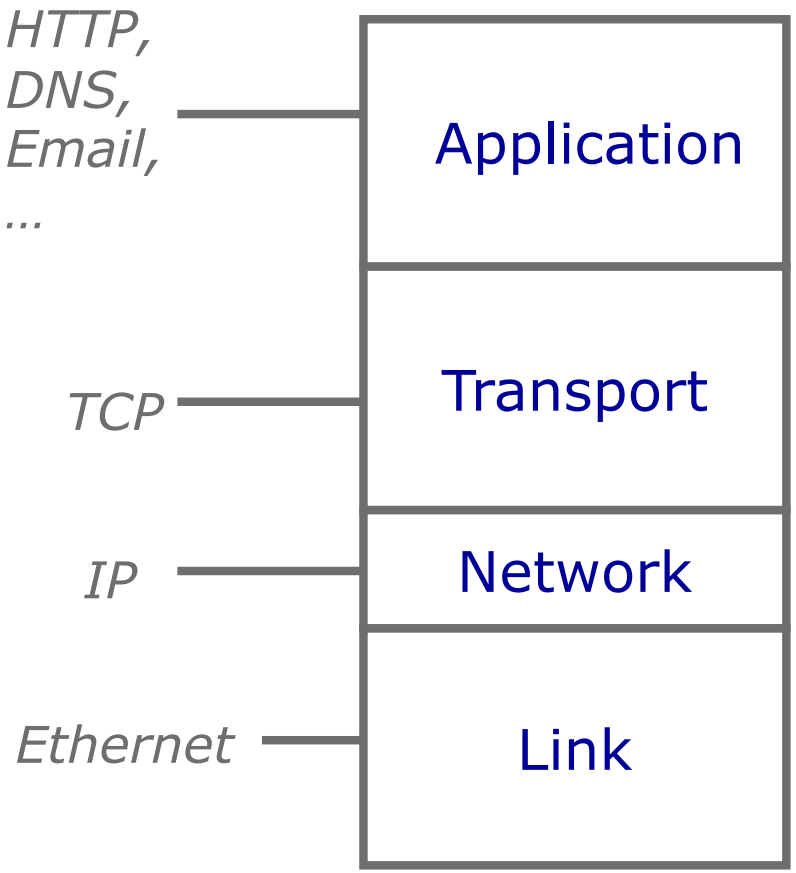
Recall: Computer Networks

- Naming service to find services
- Clients anywhere can communicate to services anywhere else
- Layers of **protocols** deal with details of data transmission and multiplexing of links

Protocols vs. APIs?

Recall: Protocols and Layering in the Internet

- Layering
  - System broken into vertical hierarchy of protocols
  - Service provided by one layer based solely on service provided by layer below
- Internet model
  - Four layers

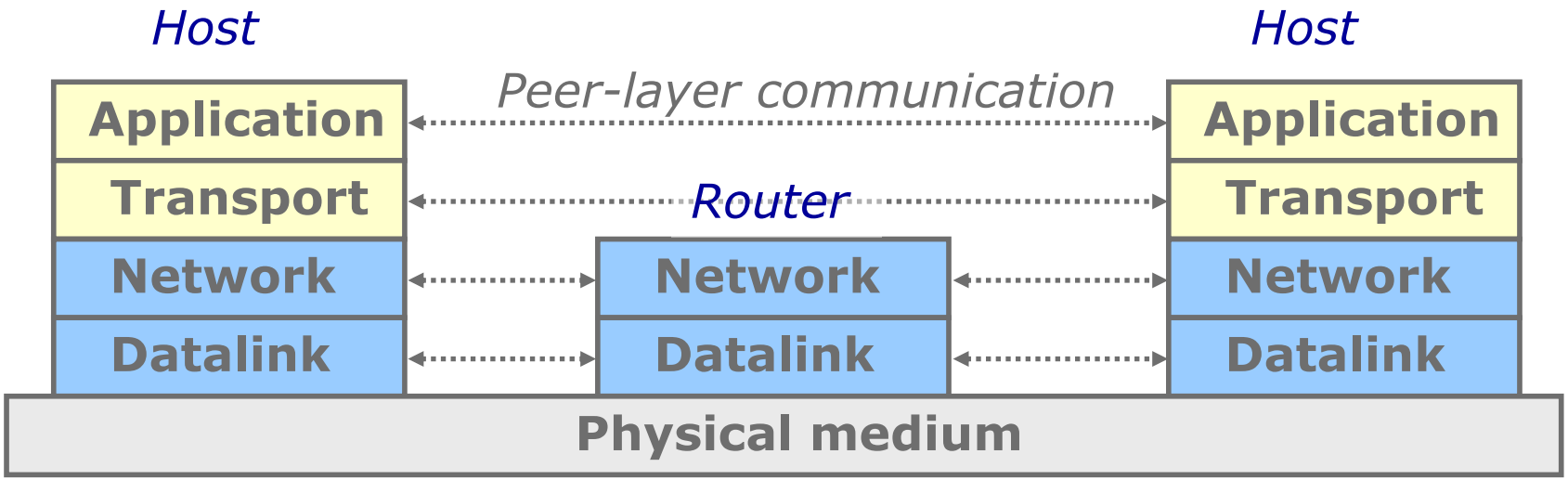


Do all servers in the network contain all layers?

Source: Katabi & Kaashoek & Morris & others (partial)

Recall: Layers in Hosts and Routers

- Link and network layers implemented everywhere
- End-to-end layer (i.e., transport and application) implemented only at hosts



Today's question: Why?

Source: Katabi & Kaashoek & Morris & others (partial)

End-to-end argument

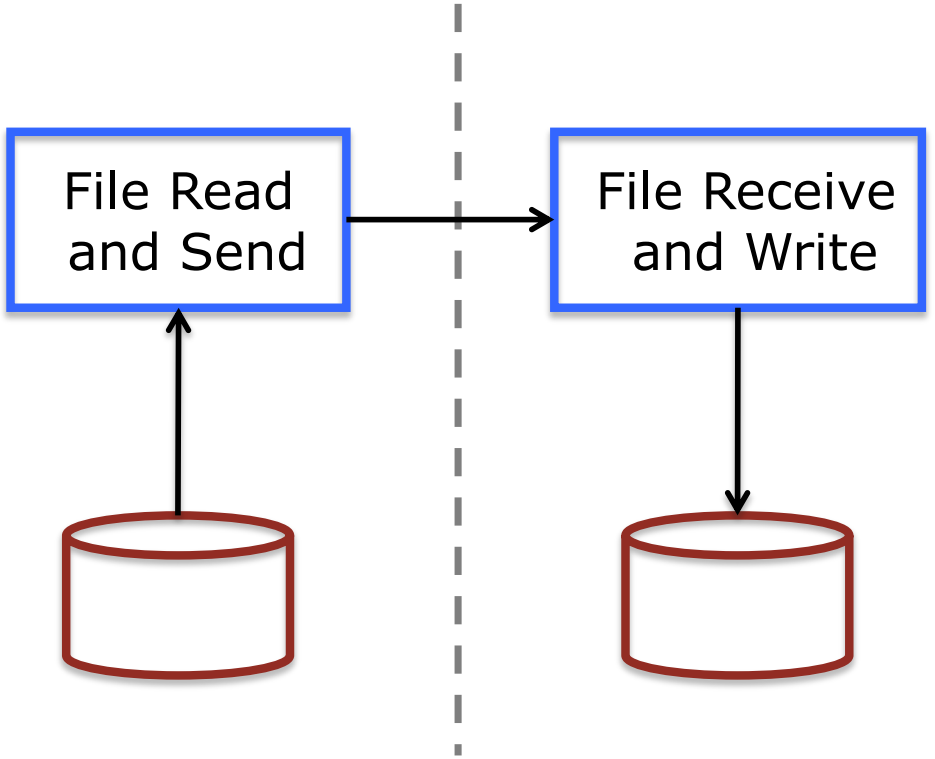
"The function in question can completely and correctly be implemented only **with the knowledge and help of the application** standing at the endpoints of the communication system. Therefore, providing that questioned function as a feature of the communication system itself is not possible. (Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.)"

Saltzer, Reed, and Clark

i.e., the application knows best! ☺

Careful File Transfer Application

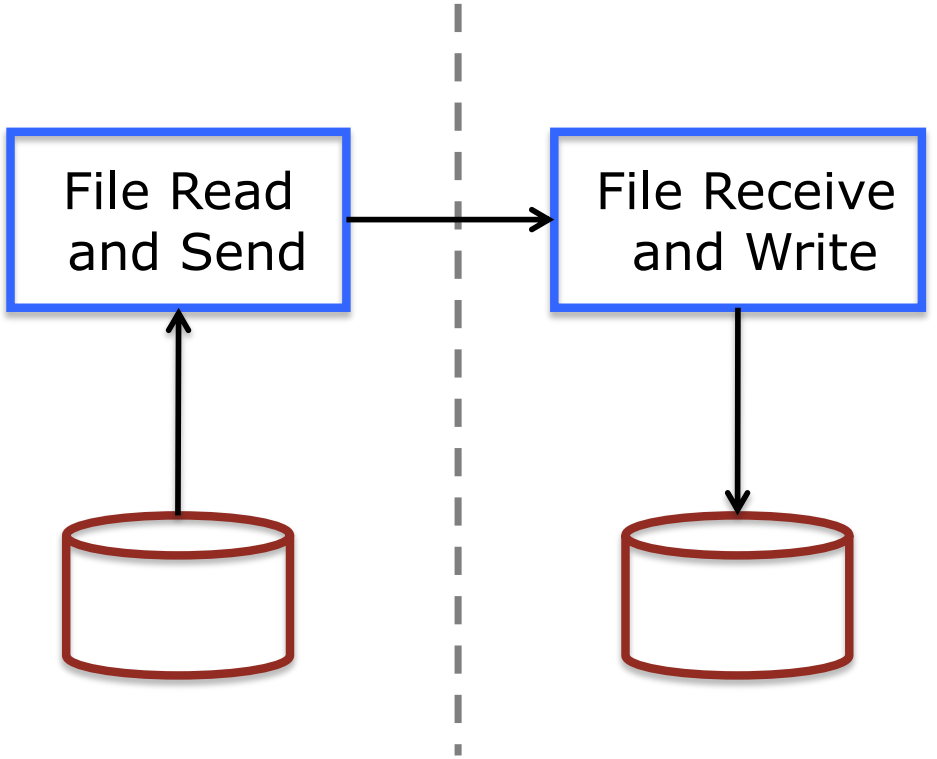
- Read from disk into memory
- Organize packets, pass to communication system
- Receive packets, re-organize file in memory
- Write file to disk



What can go wrong?
How can you work around it?

End-to-End Check and Retry

- Application tests if end-to-end function worked; if not, retries the whole function
- Careful file transfer uses a checksum
  - If checksum wrong, re-transfer the file
- Reliable data transmission not enough to eliminate all threats!



Network-Level Checks as Performance Enhancements

- *Inevitability of application-level check means communication system does not have to do anything then?*

- Multiple re-transfers can cost a lot
  - Especially when almost the whole file went through!

- Argument: Communication system should offer "some" reliability to reduce *frequency* of retransmissions, but not "perfect" reliability
  - E.g., error detection and correction in link-layer

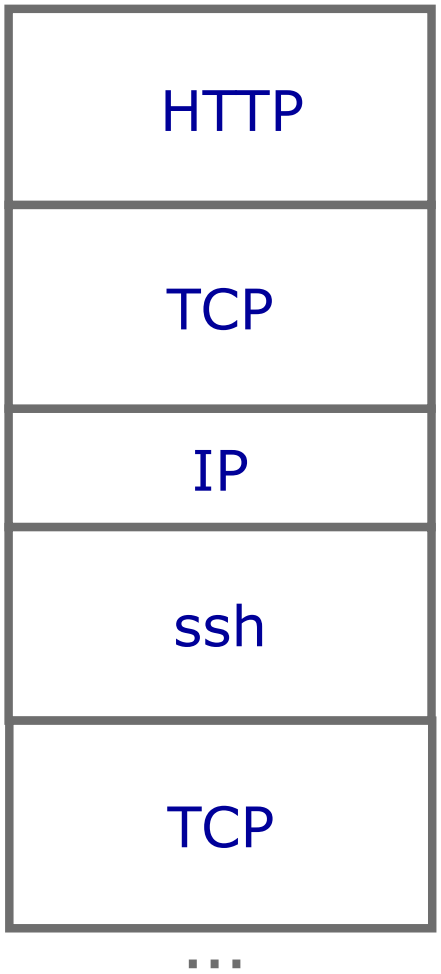
End-to-End Transport Protocols

- UDP
  - Ports + checksums
- TCP
  - Ordering + no missing nor duplicate data
  - Flow control, congestion avoidance
- RTP
  - Turns UDP checksums off
  - Timestamps packets

- Connection to RPC semantics
  - Request/response
  - At least once delivery: timers
  - At most once delivery: duplicate suppression

Power to the Edges: Clever Uses of Layering

- Nesting layers to the extreme: tunneling
  - Run link layer over TCP (Virtual Private Network)
- Router uses TCP as transport for routing protocol (e.g., BGP)
- P2P overlays (e.g., Skype)



Source: Katabi & Kaashoek & Morris & others (partial)

Other Examples of End-to-End Argument

- Secure transmission
- Distributed commit (e.g., 2PC)
- Exokernels
- Auditing logs and procedures
- Keeping multiple copies of data (e.g., replication and backup)

Philosophical Summary of End-to-End Argument

- System will hardly eliminate all errors
  - So it should implement what it does really well
- Some functionality needs help from application
- High-level checks necessary, however possibly costly
- System can provide performance enhancements to **reduce error frequency**

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Merry Christmas and a Happy New Year! ☺