

Communication Channels

February 16, 2021

Roadmap

Message-based communication

Properties of a Communication Channel

Internet Protocols

UDP

TCP

Multimedia Applications and End-to-end Argument

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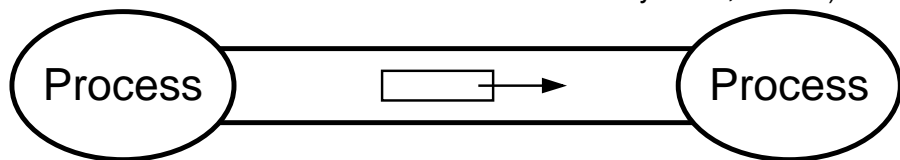
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Distributed System

Definition A distributed system consists of a **collection of** distinct **processes** which are spatially separated and **which communicate with one another by exchanging messages**. (L. Lamport, "Time, Clocks and the Order of Events in a Distributed System", CACM)

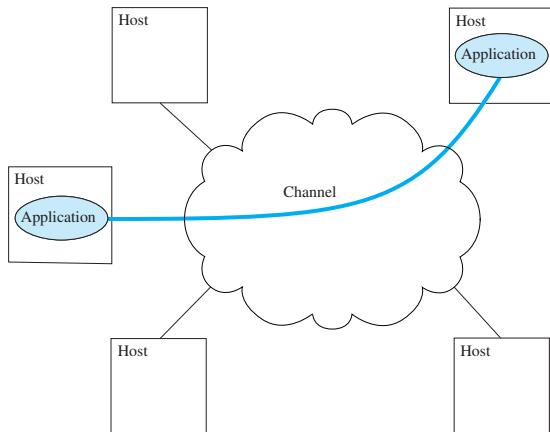


What is a message? is an **atomic** bit string

- ▶ Its format and its meaning are specified by a communications protocol

Message-based Communication and Networking

- The transport of a message from its source to its destination is performed by a computer network.



- The network can be abstracted as a communication channel
 - What are the properties of such a channel?

Distributed Computing Fallacies (Sun People)

Some assumptions proved wrong:

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- For more information, you can check:
- Arnon Rotem-Gal-Oz, [Fallacies of Distributed Computing Explained](#)
 - Too much hype, almost ... "evangelist" style
 - Stephen Asbury, [The Eight Fallacies of Distributed Computing](#)
 - An entertaining talk.

Latency

Numbers Everyone Should Know

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns



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- ▶ With or without flow control
- ▶ Number of ends of the channel

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Question Why these properties?

Connection-based vs. Connectionless

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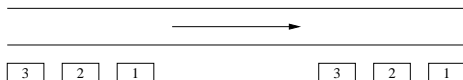
Connectionless: the processes need not set up the channel, can exchange data immediately – analogous to mail

Reliability (loss of packets)

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Reliable: ensure that the data sent is delivered to the respective destination

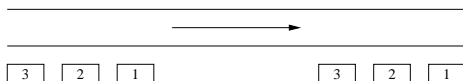
- ▶ under some assumptions;
- ▶ if not, the communicating processes are notified



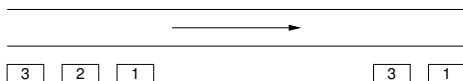
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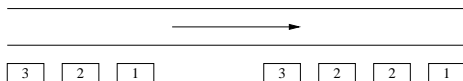
Unreliable: it is up to the communicating processes to detect the loss of messages and proceed as required by the application



Reliability (duplication)

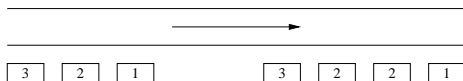
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“Generates” duplicates: the channel may deliver duplicated messages to the destination – it is up to the recipients to detect the duplicates:

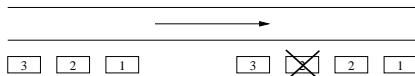


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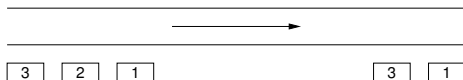
No duplicates: the channel ensures that it delivers each message to its recipients at most once:



Order

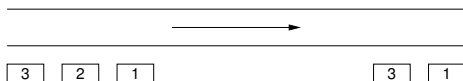
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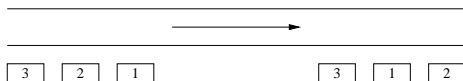


Order

Ordered: ensures that the data is delivered to its recipients in the order in which it was sent:



Unordered:



If it is important to preserve the order, it is up to the application to detect that the data is out of order and if necessary to reorder it

IMP order and reliability are orthogonal

Communication Abstraction

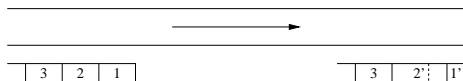
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Message (datagram): the channel supports the transport of messages – sequences of bits processed atomically – analogous to mail

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Stream the channel does not support messages. Essentially, it works as a pipe for a sequence of bytes – analogous to Unix pipes



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Flow control: prevents "fast" senders from overflowing with data "slow" recipients

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Number of ends of the communication channel

unicast, or point-to-point only two ends;

broadcast all nodes in the "network";

multicast subset of nodes in the network

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Identification of the communicating processes

- ▶ "Name" of the process itself
- ▶ "Name" of the channel endpoint, e.g. phone number

(Process Identification on the Internet (IPv4))

Question How do identify a process on the Internet?

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Answer By a pair of identifiers:

IP Address :

- ▶ Identifies the computer on the Internet;
- ▶ It is a 32-bit, usually represented in *dotted decimal*, e.g.: 193.136.28.31.

Port Number :

- ▶ Identifies the endpoint of a communication channel inside a computer (transport layer identifier)
- ▶ It is a 16-bit integer (between 0 and 65535);
- ▶ By convention, some ports are reserved for some services.

Clarification The (*IPAddress*, *PortNumber*) pair actually identifies the endpoint of the communication, the process may change

This is similar to a residence phone number: the person that answers a call may change.

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Internet Protocols

Application	Specific communication services
Transport	Communication between 2 (or more) processes.
Network	Communication between 2 computers not directly connected with each other.
Interface	Communication between 2 computers directly connected.

- ▶ On the Internet, the properties of the communication channel provided to an application depend on the transport protocol used (UDP or TCP):
 - ▶ The design of a distributed application depends on the properties provided by the chosen transport protocol

Summary of the Properties of the Internet Transport Protocols

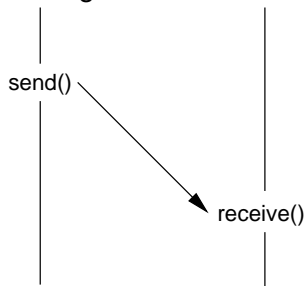
Property	UDP	TCP
Abstraction	Message	Stream
Connection-based	N	Y
Reliability (loss & duplication)	N	Y
Order	N	Y
Flow control	N	Y
Number of recipients	1/n	1

- ▶ The abstraction provided by TCP stems from the API, or is it intrinsic to the protocol?

UDP: Observation (1/3)

- ▶ UDP channels transport messages – UDP datagram:

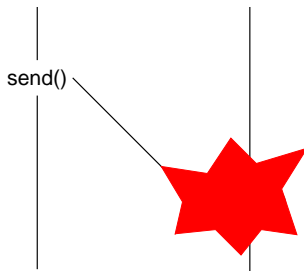
- ▶ Basically, its API supports two operations: *send()* e *receive()*;
- ▶ Each message is transmitted by invoking `send()` once;
- ▶ If delivered, the message will be delivered atomically, in a single invocation of `receive()`



- ▶ *Datagrams* have a maximum size of 65535 bytes:
 - ▶ Applications may have to **split** the data to send in datagrams before transmitting, and **reassemble** the data from the fragments after receiving

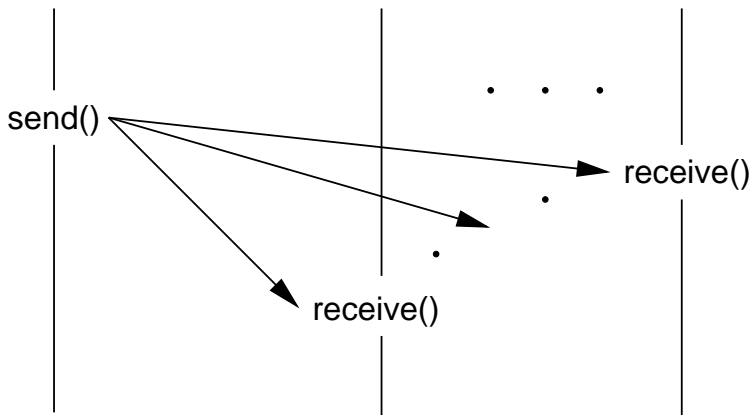
UDP: Observations(2/3)

- ▶ UDP being connectionless:
 - + allows a process to start transmitting data immediately;
 - requires the specification of the the other channel endpoint on every invocation of *send()*.
- ▶ UDP provides no reliability guarantee
 - ▶ UDP datagrams may be lost or even duplicated;
 - ▶ If the application cannot tolerate the loss, or the duplication, of datagrams, it will have to detect and recover from such an event



UDP: Observations(3/3)

- ▶ UDP has no flow control
 - ▶ A receiver may be flooded with requests and run out of resources (e.g. buffers) to receive other messages.
- ▶ UDP supports *multicast*, by invoking `send()` once, it is possible to send a copy of a given message to several processes.



TCP: Observations (1/3)

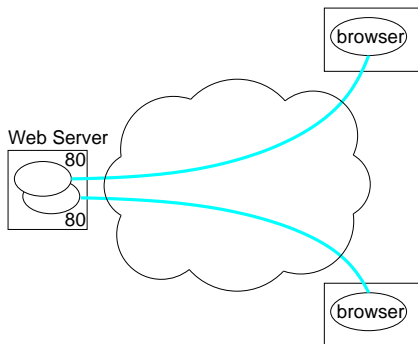
- ▶ TCP channels are **stream** channels, i.e.:
 - ▶ They are similar to Unix *pipes* on Unix, except:
 - ▶ They can be used for communication between processes in different computers;
 - ▶ They are bidirectional channels – i.e. it is possible to send data in both directions simultaneously
- ▶ Although we can also use `send()` and `receive()` to exchange data:
 - ▶ TCP does not ensure the "separation" between *bytes* sent by invoking two `send()` calls;
 - ▶ `write()` and `read()` match better TCP semantics
 - ▶ actually, the Java API uses the many "stream" classes to exchange data via TCP
- ▶ If it is essential to preserve message boundaries, it is up to the application to implement it. How?

TCP: Observations(2/3)

- ▶ TCP is connection-oriented. Communication with TCP has 3 phases:
 1. Connection set up
 2. Data exchange
 3. Connection tear down
- ▶ TCP ensures reliability (both loss and duplication of data):
 - ▶ In the event of communication problems, the connection may be aborted and the processes on its ends notified
- ▶ TCP ensures flow control
 - ▶ Prevents data loss because of insufficient resources
 - ▶ Nevertheless, TCP may be vulnerable to *denial-of-service* attacks, i.e. *SYN attacks*.

TCP: Observations(3/3)

- ▶ TCP channels have only two endpoints, supporting the communication between only two processes
- ▶ Unlike what happens with UDP, TCP channels on the same computer may have the same port number:
 - ▶ A TCP channel is identified by the pairs (IP Address, TCP Port) of its two endpoints;
 - ▶ This allows the concurrent service of several clients in client-server applications, for example on the Web:



TCP vs. UDP

Why not always use TCP?

- ▶ It provides "more" than UDP

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Can you pay the cost?

- ▶ Connection must be set up before data exchange
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 - ▶ TCP ensures in-order delivery

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Some applications cannot E.g. Internet telephony

- ▶ It is very sensitive to delays
- ▶ But can tolerate some loss

TCP provides a service that it does not need (recovery of lost data), at a cost that may be too high

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Real-time Interactive Audio and Video e.g. Skype

- ▶ Two-way communication

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Requirements

Bandwidth do not tolerate large variations

Packet delay and also its jitter (i.e. its variation) are particularly critical

Packet loss not that stringent

Internet Protocols and Multimedia Applications

- ▶ But the Internet is designed on the **best-effort** principle
 - ▶ It does not provide any guarantees, especially regarding packet-loss rate, bandwidth, packet delay and its jitter
- ▶ "Tricks people play"

Bandwidth Use compression

Delay and its jitter

- ▶ For non-RT applications we can use buffering
- ▶ For RT applications we can reduce the jitter by engineering a delay
 - ▶ And rely on the end-to-end argument

Packet loss

- ▶ Streaming apps can use plain TCP, as long as the buffers are large enough
- ▶ Interactive RT apps use forward-error-correction (FEC)
 - ▶ Encoding standards (e.g. MPEG) often support FEC
- ▶ Rely on the end-to-end argument (this is explicitly referred in the article)

End-to-End Argument (around 1980)

- ▶ This is a design principle for layered systems, and states:
If you have to implement a function **end-to-end**
don't implement it on the lower layers
unless there is a compelling performance enhancement

Saltzer, Reed and Clark, "End-to-End Arguments in [...]"

- ▶ The main examples in the paper are drawn from data communication systems, but the authors also give other examples
"For the case of the data communication system, this range includes encryption, duplicate message detection, message sequencing, guaranteed message delivery, detecting host crashes, and delivery receipts. **In a broader context, the argument seems to apply to many other functions of a computer operating system, including its file system.**"
- ▶ Why is this relevant for distributed applications?
 - ▶ Distributed applications are often layered
 - ▶ On the Internet, you have to choose between TCP and UDP
- ▶ This is a design principle, not a physics law

Dave Andersen's (?) Algorithm

Do you need everything TCP provides?

- ▶ If yes, you are done.

If not: can you pay the cost?

- ▶ If yes, you are done

If not Use UDP

- ▶ Implement what you need on top of UDP