Design Principles

14-740: Fundamentals of Computer Networks
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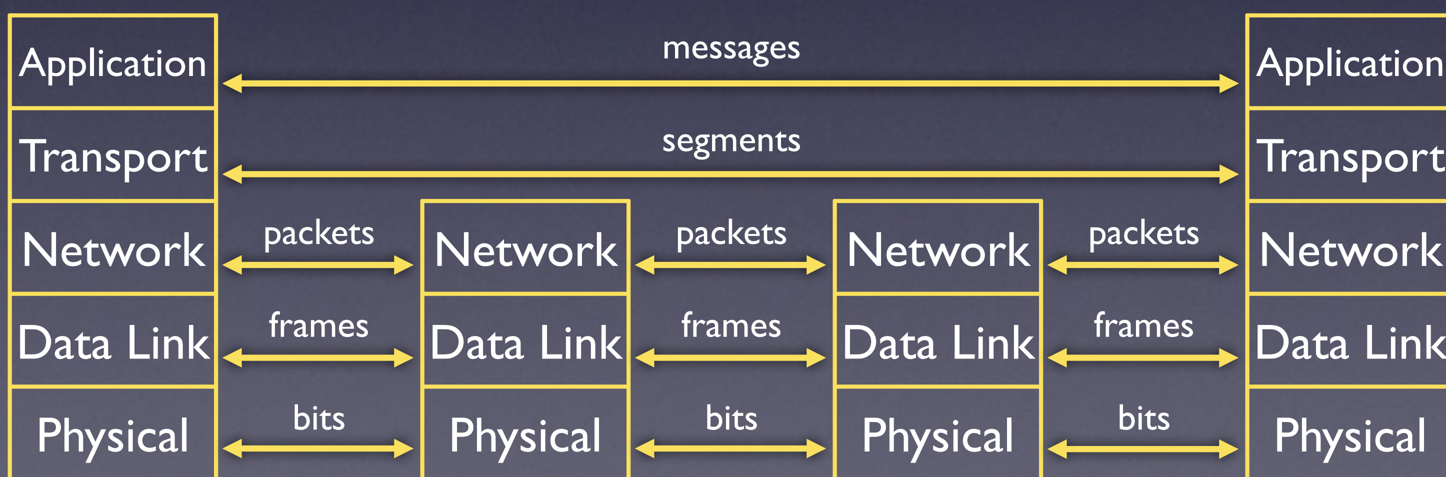
Material from Computer Networking: A Top Down Approach, 7th edition. J.F. Kurose and K.W. Ross

Administrivia

- No Paper Review for today
  - Next lesson: Review Norton2010
    - NOTE: Not Norton2003!
  - Do not review RFC 2901, but skim it
- Paper review feedback (Clark88)
  - Make it short & sweet
  - No need to quote the paper

Last Lecture

- Layered Architecture
  - Why layers?
  - What goes into each layer?
    - Service, interface, protocol
- ISO OSI model (7-layer cake)



Roadmap

- TCP/IP Architecture
- Goals of TCP/IP Design
- End-to-End argument

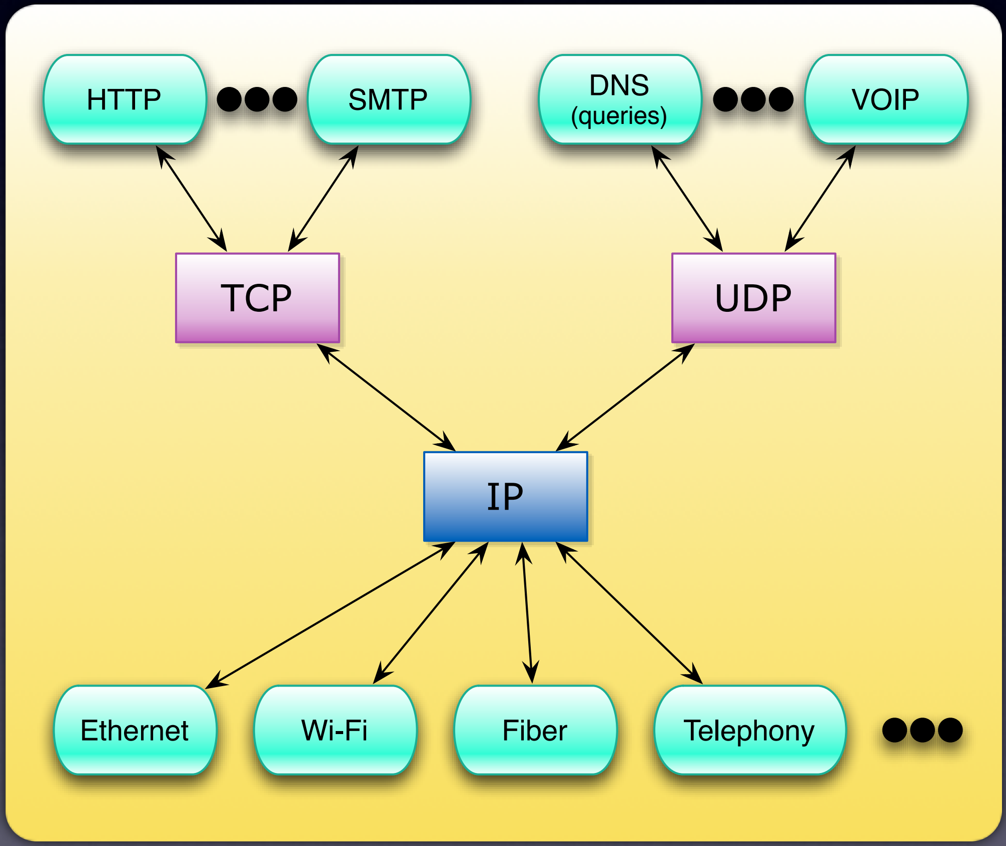
TCP/IP Architecture

Distributed applications

Reliable stream service

User datagram service

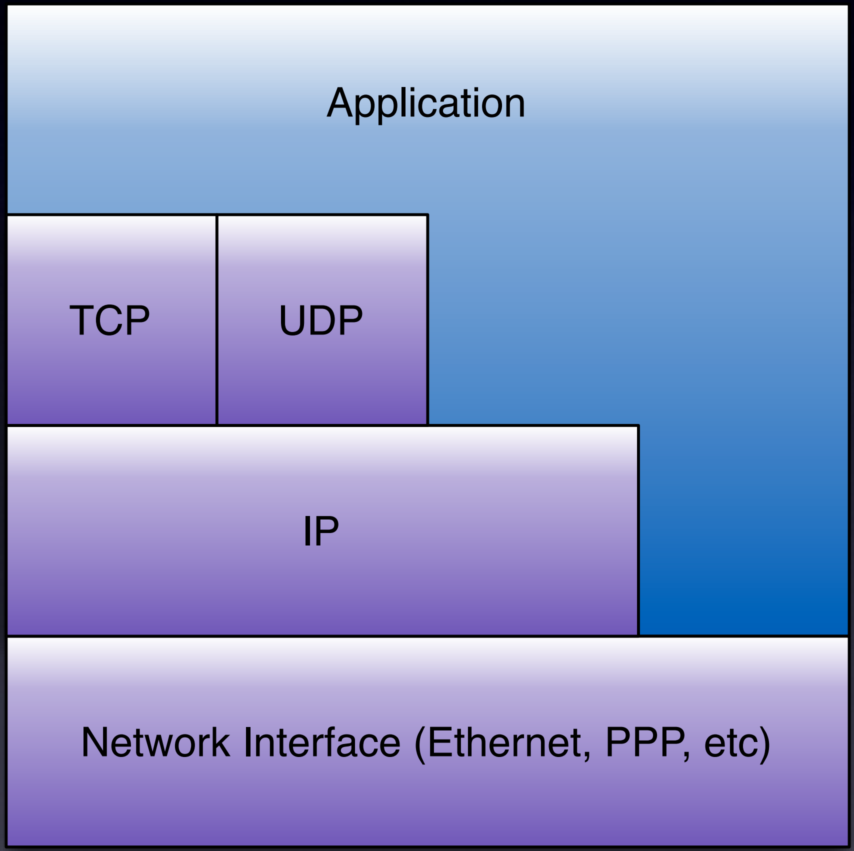
Best-effort connectionless packet transfer



Diverse network technologies

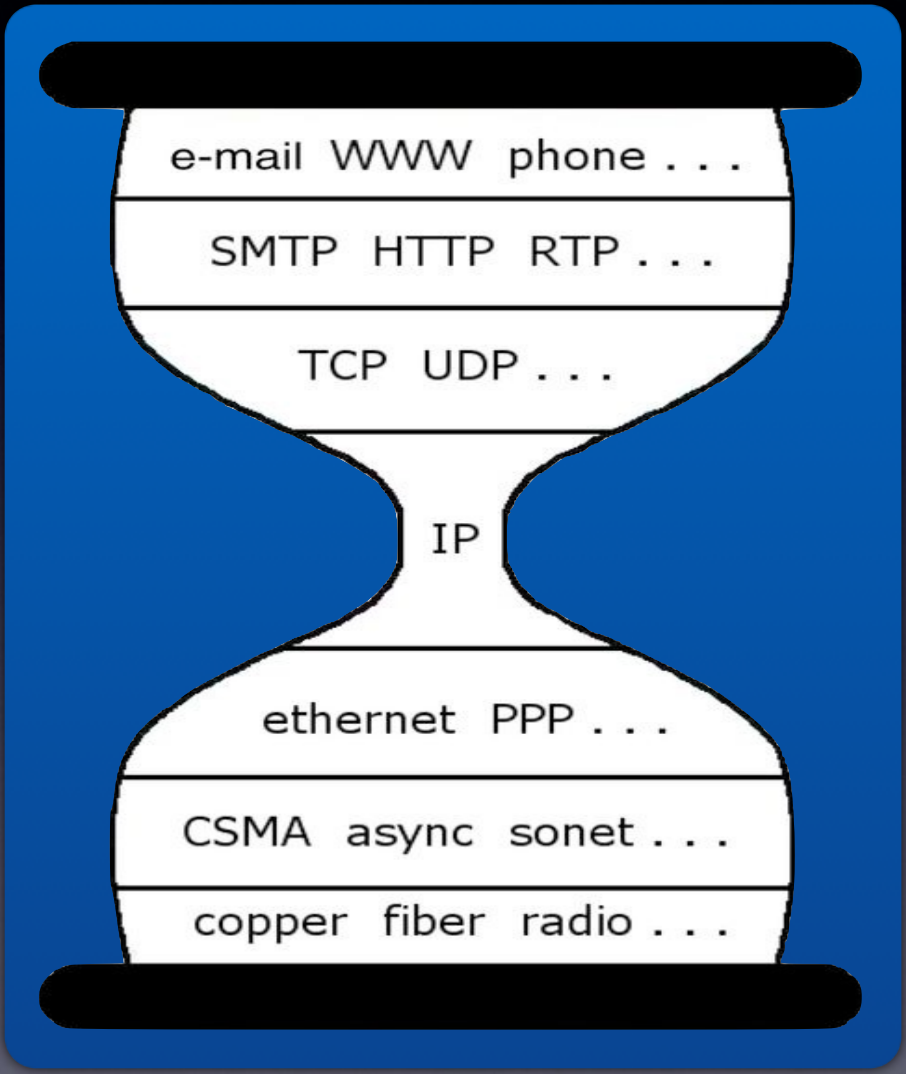
Architecture Features: #1

- Is strict layering implied?
- No. Applications are free to bypass the defined transport layer and to directly use IP
  - or the data-link technology for that matter
  - or to build on top of regular applications (like HTTP, SSL)



Architecture Features: #2

- "Hourglass" figure!
- Reflects the central philosophy of the Internet Architecture
  - IP over everything! IP is the glue
  - IP is a common method of exchanging packets over a wide collection of networks
- Above IP: lots of stuff
  - Arbitrary many transport and application protocols
- Below IP: lots of stuff
  - Arbitrarily many network technologies



“Hourglass” importance

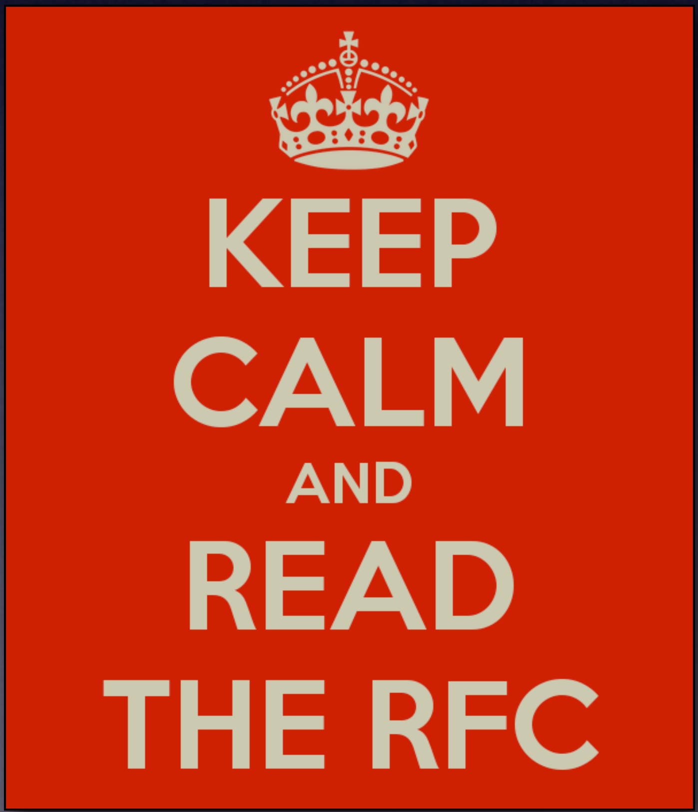
- The narrow waist represents a minimal and carefully chosen set of global capabilities
- Allows higher-level applications and lower-level communication technologies to co-exist, share capabilities and evolve rapidly
- Critical to the Internet’s ability to adapt rapidly to new user demands and changing technologies
- Drawback: Changing IP is difficult (see IPv6)

Architecture Features: #3

- Internet Engineering Task Force (IETF)
  - Standardization community for Internet protocols
- For a new protocol to become standard:
  - A detailed protocol specification, beaten up by a “working group” of experts in the area
  - At least two independent implementations
  - Emphasis on “rough consensus and running code”

Sidebar: Request for Comments

- Every IETF standard is published as an RFC
  - Proposed / Draft standards
  - Must have at least 2 (why??) independent implementations of each part of the standard
  - Internet standards
  - Experimental protocols
    - check out RFC 1149
      - Available at ietf.org/rfc/rfc1149.txt
  - Information documents
  - Historical standards
- Not all RFCs are standards
- What is special about RFC 2773?



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Clark88 Paper

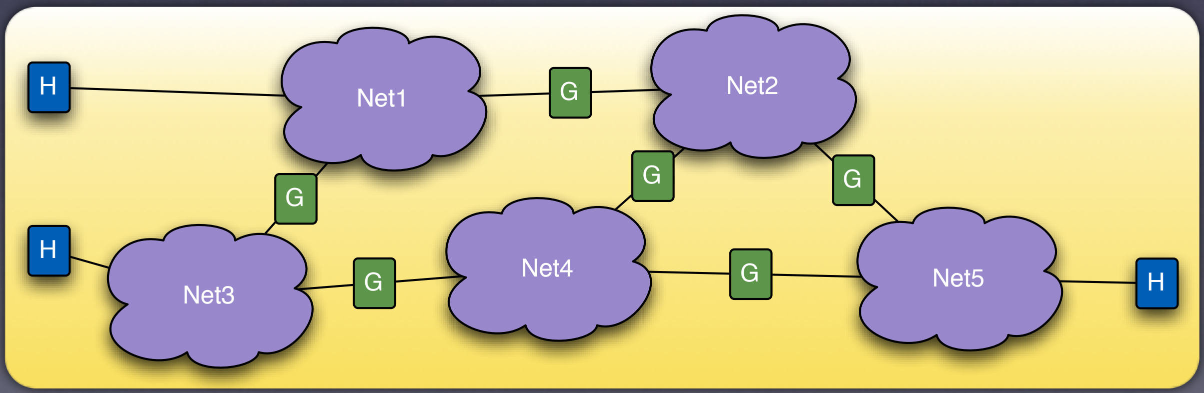
- *Design Philosophy of the DARPA Internet Protocols*, David Clark, ACM Sigcomm, 1988
- Attempts to give motivation and reasoning behind the TCP/IP architecture design
  - A list of goals, in order of priority
  - The goals were defined from the viewpoint of the U.S. government

Assumptions

- Each player in the Internet shares a common vision and sense of purpose
- Build network infrastructure to hook computers together
- Build applications to run on top
  - Not much thought on trustworthiness of entities
  - Not much thought on commercial players

Fundamental Goal

- *Interconnect existing networks*
  - The military must be able to communicate using radio and satellite, as well as wired networks
  - Needed to maintain separate administrative control for each network (think Army, Navy, etc)
  - Use well-understood technology: Store-and-forward packet-switching was known from ARPANET, add gateways to glue it together



- 2nd level goals: In order of importance
  - Continue despite loss of networks or gateways
    - Robustness against failure
  - Support multiple types of communication services
    - Connection-oriented vs connectionless
  - Accommodate a variety of networks – Ethernet, ATM
  - Permit distributed management of its resources
    - Network of networks
  - Be cost-effective (?)
  - Permit host attachment with a low level of effort
    - Rapid deployment of applications, services, networks
  - Account for resources used (?)

Robustness Against Failures

- Architecture needs to store state of a conversation
  - Answers “Where were we?” after an disruption
  - Which data was received, which was lost
  - Use this state to recover from loss of synchronization
- Where should this state be stored?
  - Approach #1: In the intermediate nodes
  - Approach #2: At the end-hosts
- What are the pros and cons of the two approaches?

Where should I leave my breadcrumbs?

- Approach #1: In the intermediate nodes
  - Requires replication of state everywhere
  - Difficult to build algorithms
  - Synchronization issues
- Approach #2: At the end-hosts
  - “Fate sharing”
  - If the end-host is lost, the state associated with its conversation is also lost
  - Much easier to engineer than replication

Stateless Network Core

- IP uses approach #2
  - Intermediate nodes (routers, gateways, switches, etc) do not have any state information about on-going connections
    - Stateless nodes
    - Also called a datagram network
      - Datagram is another word for packet
  - End-hosts ensure reliable delivery of data (if they care)

Intelligence of Internet Devices

- Dumb routers (or networks)
  - Really only supposed to do one thing and one thing fast – forwarding packets
  - Do not need to know much else!
- Smart hosts (or machines)
  - Responsible for a lot more
  - Reliability, flow control, congestion control, buffering ...
- Why is this changing today?
  - Next lecture on the provider and customer relationships between ISPs and companies

Types of Service

- Originally, TCP was thought to be enough
  - Audio conferencing (i.e. digitized speech) does not need strict reliability guarantee
  - Found out reliability is the main source of delay! Must wait for a lost packet to be retransmitted before sending rest of the received packets in sequence

Types of Service (2)

- Originally, TCP and IP were at the same layer
  - Decided to separate them
  - IP as the basic datagram building block
  - UDP was viewed as a building block for construction of multiple services
- A very wise decision indeed

Distributed Management

- Mostly achieved
- Networks can be administered separately
- Network can run different internal routing protocols
  - Original work included manual setting of routing tables!

Today's Management

- Improved with the introduction of BGP
- But managing routing policies is still a big issue in today's Internet
- Route hijacking: a network announces someone else's routes to attract traffic, a form of denial-of-service attack
- Misconfigurations are difficult to detect and recover from

Accounting of Resources

- Last on the list of goals
- Little (or no attention) in the original design
- Virtually no tools at that time – the U.S. military did not need accounting!

Today's Accounting

- Coarse-grained tools are widely in use
  - Bits-per-second, packet-per-second granularity
- Recent tools measure and monitor traffic based on flows, e.g. Netflow
  - Source/Destination pairs (or prefixes)
- Research in inferring traffic matrices

Roadmap

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Saltzer84 Paper

- J.H. Saltzer, D.P. Reed, and D.D. Clark, *End-to-End Arguments in System Design*, ACM Transactions on Computer Systems (4):277-88, Nov 1984
- States the “End-to-End” Argument
- A function that can be implemented at the application layer (i.e. end-points) should not be in the lower layers (i.e. network core)

End-to-End Arguments

- Eliminate duplication of function across layers
- Allows for more innovation
  - Core should not be tailored to any specific application
  - Shouldn't inhibit deployment of new things
- Reliability
  - "The simpler the core, the more reliable it is"

Exception: Performance Optimization

- A lower layer could implement a higher layer function if it is for improving performance
- Example: Wireless networks have very high loss rate
  - Inefficient to wait for application to realize a packet is lost and signal retransmit
  - The request for retransmit message may also be lost
  - Add reliability to the link layer
  - Most link layer technologies implement some sort of error correction mechanism
- WARNING: This is a complex design tradeoff

How about inventing a New Internet Architecture?

- How would you change the list of goals or priorities? Why?
- Do the design principles we covered still apply?
- See what David Clark says 15 years later

2002 Paper

- *Tussle in Cyberspace: Defining Tomorrow's Internet*, David Clark et al, 2002
- Revisiting old principles
- Suggesting new design principles
- Tussles: "Different stakeholders have adverse interests, each vie to favor their particular positions"

Moving Away?

- Operation in an untrustworthy world
  - Firewalls, content filters, DMZ, etc
- More demanding applications (YouTube, Netflix)
  - Implement using caches placed close to end users
- Dramatic growth of end-hosts
  - Refrigerators need an IP address? IPv4 has few
  - Network Address Translation (NAT) boxes
    - Map N public IP addresses to M end-hosts (connections) behind NAT, where M >> N

Moving Away from End-to-End

- ISP service differentiation
  - Keep enhanced services within the ISP's network, as competitive differentiator
- Less sophisticated users
  - Prefer simpler end hosts without constant need of software configuration, upgrade and maintenance
- Proliferation of non-"computer" end hosts

Routers are getting Smarter

- Quality of Service (QoS)
  - Routers forwards certain packets before others
- Software Defined Networking (SDN)
  - Router is "programmed" not just protocols
- Virtual Private Networks (VPNs)
- Accounting
  - Not designed into the architecture
- Management (ditto)

Lesson Objectives

- Now, you should be able to:
  - describe the internet's layered architecture according to the TCP/IP model and argue the importance of architectural features of that model
  - explain the role of the IETF in the internet's operation
  - describe the goals of the TCP/IP design according to Clark88 and identify the fundamental goal

Now, you should be able to:

- explain the ramifications of the robustness, multiple services and multiple networks goals on the design of the TCP/IP protocols
- explain Saltzer84's “End-to-End” argument. Be able to describe exceptional situations where it may not apply as well as ways in which the modern internet may be moving away from this design philosophy