Computer Networking

> You can't gaze in the crystal ball and see the future.
> What the Internet is going to be in the future is what
> society makes it.

Bob Kahn, co-creator of TCP and IP

The internet—along with all of the applications like the web which run on top of it
—has become the most critical force for technological progress of our era. The
largest and most impactful technology companies were once semiconductor
companies like Intel, later they were software companies like Microsoft, now they
are internet companies: Facebook, Google and Amazon among the largest in the
world. But for all of our reliance on computer networks, a privileged minority can
boast a strong understanding of them.

In this course we will cover the key protocols that enable the internet, the web,
and other applications of computer networking. This should empower you not only
to make the most of present networking technologies but also to help build the
future.

RECOMMENDED RESOURCES

While it's possible to complete this course simply by participating in classes, you
will see the most value if you do the suggested prework and investigate some of
the "further study" references.

Our recommended text for the course is Kurose and Ross
Computer Networking: A Top-Down Approach (referred to as K&R below). The
content changes very little from one edition to another, so the fifth edition (or even
fourth, at a pinch) is sufficient and likely much cheaper to buy second hand. The
chapter references below are for the fifth edition.

For those who prefer video lectures, we suggest Stanford's
Introduction to Computer Networking available via Lagunita, their MOOC platform.
Corresponding sections of the course are referred to as "ICN" below.

There is also a worthwhile series of very short videos on miscellaneous networking topics by a former University of Buffalo lecturer. These may be a good place to look for a definition or explanation of a specific topic or protocol.

Finally, some of our suggested further study resources are protocol specifications (particularly RFCs) and papers. These can be incredibly valuable, as networking is a dynamic field where practice often precedes theory and shorter non-academic material better conveys the motivation for a given set of decisions.

CLASSES

1 - The Big Picture: Layers of Protocols

Our first class explores the history of computer networks and presents the layered model. We and the K&R book both use a simplified 5-layer version of the OSI 7-layer networking model.

Suggested prework: chapter 1 of K&R, particularly 1.5 ("Protocol Layers") and 1.7 ("History of Computer Networking"); or, ICN sections 1.0-1.8.

Further study:

- Paper:
  OSI Reference Model—The ISO Model of Architecture for Open Systems Interconnection
- Website: Brief History of the Internet
- Book: Where Wizards Stay Up Late: The Origins Of The Internet

2 - Application Layer: HTTP

Commonly called the web, HTTP has become a ubiquitous protocol employed well beyond its original purpose of delivering HTML pages to browsers. This class covers the HTTP protocol in depth, given its degree of usefulness.

Suggested prework: chapters 2.1.5-2.2.4 of K&R or sections 5.5-5.6 of ICN.

Further study:

- RFC 1945 (HTTP/1.0)

- [RFC 2616](#) (HTTP/1.1)
- [RFC 7540](#) (HTTP/2)
- Website: [HTTP/2 FAQs](#)
- Video: [Yesterday's perf best-practices are today's HTTP/2 anti-patterns](#)

3 - Application Layer: DNS, SMTP, FTP and Others

There are perhaps 100 or more application layer protocols. They are common enough that you may be involved in developing one at some point. For this lesson, we have selected three to cover three in detail.

Suggested prework: chapters 2.3-2.5 of K&R, or sections 5.8-5.10 of ICN (note: ICN covers only DNS, whereas K&R also covers SMTP and FTP).

Further study:

- Paper: [Development of the Domain Name System](#)
- [RFC 1034](#) and [RFC 1035](#)
- [RFC 5321](#) (SMTP)
- [RFC 1939](#) (POP3)
- [RFC 3501](#) (IMAP)
- [RFC 959](#) (FTP)

4 - Transport Layer: TCP and UDP

This class covers the important transport layer, the tradeoffs between TCP and UDP, and how TCP guarantees reliability and ordering.

Suggested prework:

- Chapter 3 of K&R - particularly 3.3 and 3.5
- And/Or Unit 2 of ICN ("Transport")

Further study:

- Video (2min): [Go-back-n sliding window animation](#)
- Paper: [A Protocol for Packet Network Intercommunication](#) (Cerf and Kahn's early paper)

- RFC 793 (TCP)
- RFC 768 (UDP)
- Video: QUIC: next generation multiplexed transport over UDP
- Draft protocol:
  QUIC: A UDP-Based Secure and Reliable Transport for HTTP/2
- Oral history interview with Bob Kahn

5 - Network Layer: The Internet Protocol and Routing

This class covers the internet protocol itself, the overall problems of addressing and routing, and how routing tables are maintained without manual intervention.

Suggested prework: chapter 4 of K&R, particularly 4.4, or Unit 1 of ICN ("The Internet and IP").

Further study:

- RFC 791 (IPv4)
- RFC 2460 (IPv6)
- RFC 4443 (ICMPv6)

6 - The Link Layer and Local Area Networks

Having proceeded from applications down through the transport and network layers, we still need to account for how data is reliably transmitted via physical media like wires and air. This class covers ethernet and 802.11 (Wi-Fi) as well MAC, ARP and other important protocols at the link layer.

Suggested prework: chapter 5 of K&R, particularly 5.1, 5.4 and 5.5; or Unit 7 of ICN ("Lower Layers").

Further study:

- RFC 826 (ARP)
- IEEE 802.11 standard
- Video: Oral history of Bob Metcalfe inventor of Ethernet

7 - Security

Security was not a first class concern of the pioneers of computer networking, and so is not at the core of its most important protocols, so much as retrofitted around them. It is however a critically important consideration in using computer networks, so this class covers the means to which we go to secure internet communication at every layer, including SSL/TLS, PGP, IPSec and WPA.

Suggested prework: K&R chapters 8.2 and 8.5, or Unit 8 of ICN ("Security").

Further study:

- Khan Academy cryptography course
- Book: Applied Cryptography by Bruce Schneier
- RFC 5246 (TLS)

8 - The Future of Networking

Computer networking is an incredibly dynamic domain, driven by significant commercial imperatives, consumer demand, and a vibrant research community. We use our final class to explore some current developments toward a potential future for networking technologies.

Suggested prework: watch Van Jacobson on A New Way to look at Networking and read the IPFS white paper

Further study:

- RFC 3550 (RTP)
- ISO standard for DASH
- Video: Scaling the Netflix Global CDN
- WebRTC draft specification