CS168
Introduction to the Internet: Architecture and Protocols

Sylvia Ratnasamy

Fall 2022

Today

- What is (this course on) the Internet about?

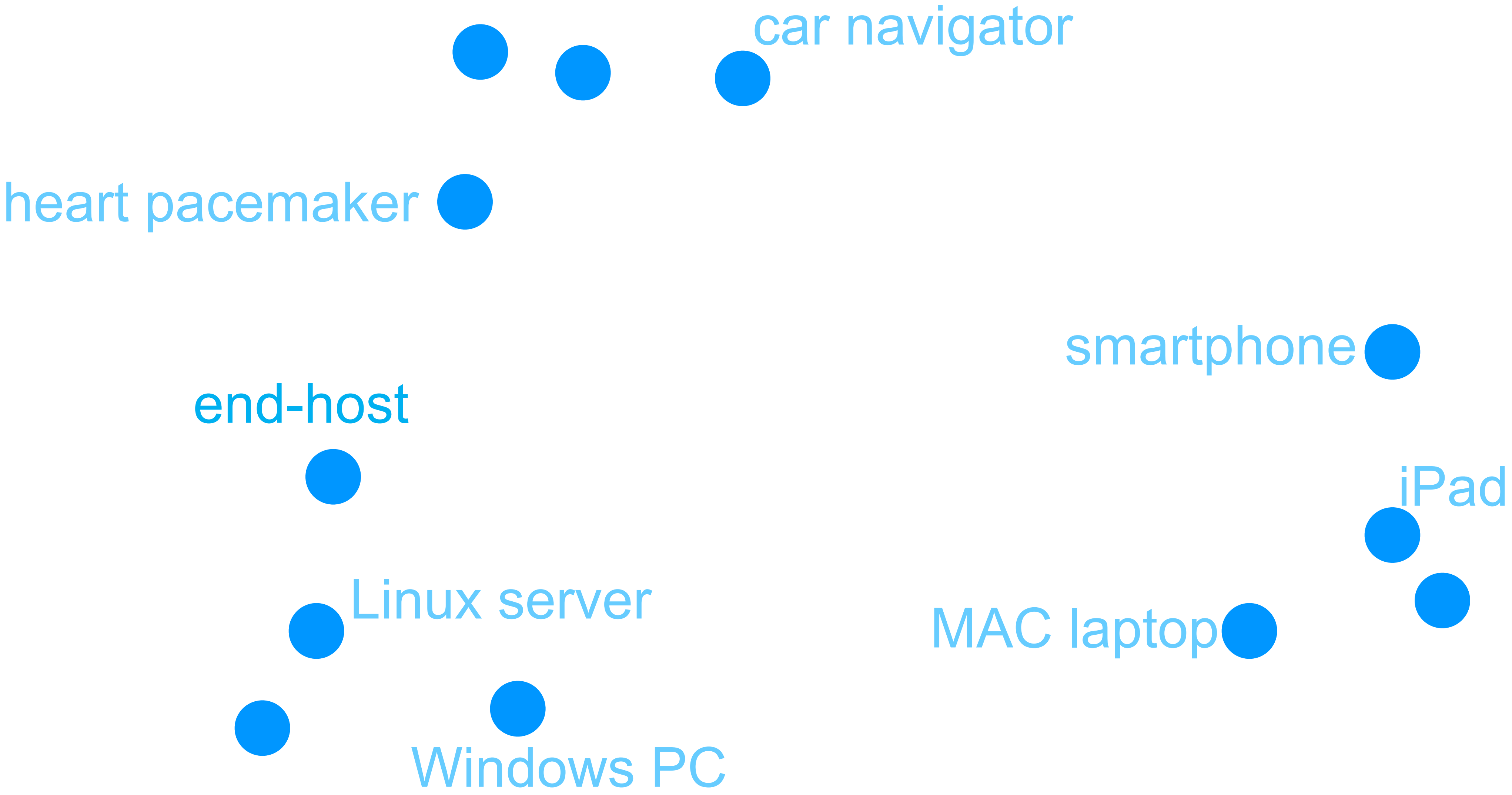
  [quick break]

- Class logistics

- Internet
- Protocols
- Architecture

Two Meanings of “Internet”

- The infrastructure that ties together computing devices
  - TCP, IP, BGP, DNS, OSPF, …
- The ecosystem of applications built on top of the above infrastructure
  - facebook, google, twitter, ….
- In this class, we use the first definition!



car navigator

heart pacemaker

smartphone

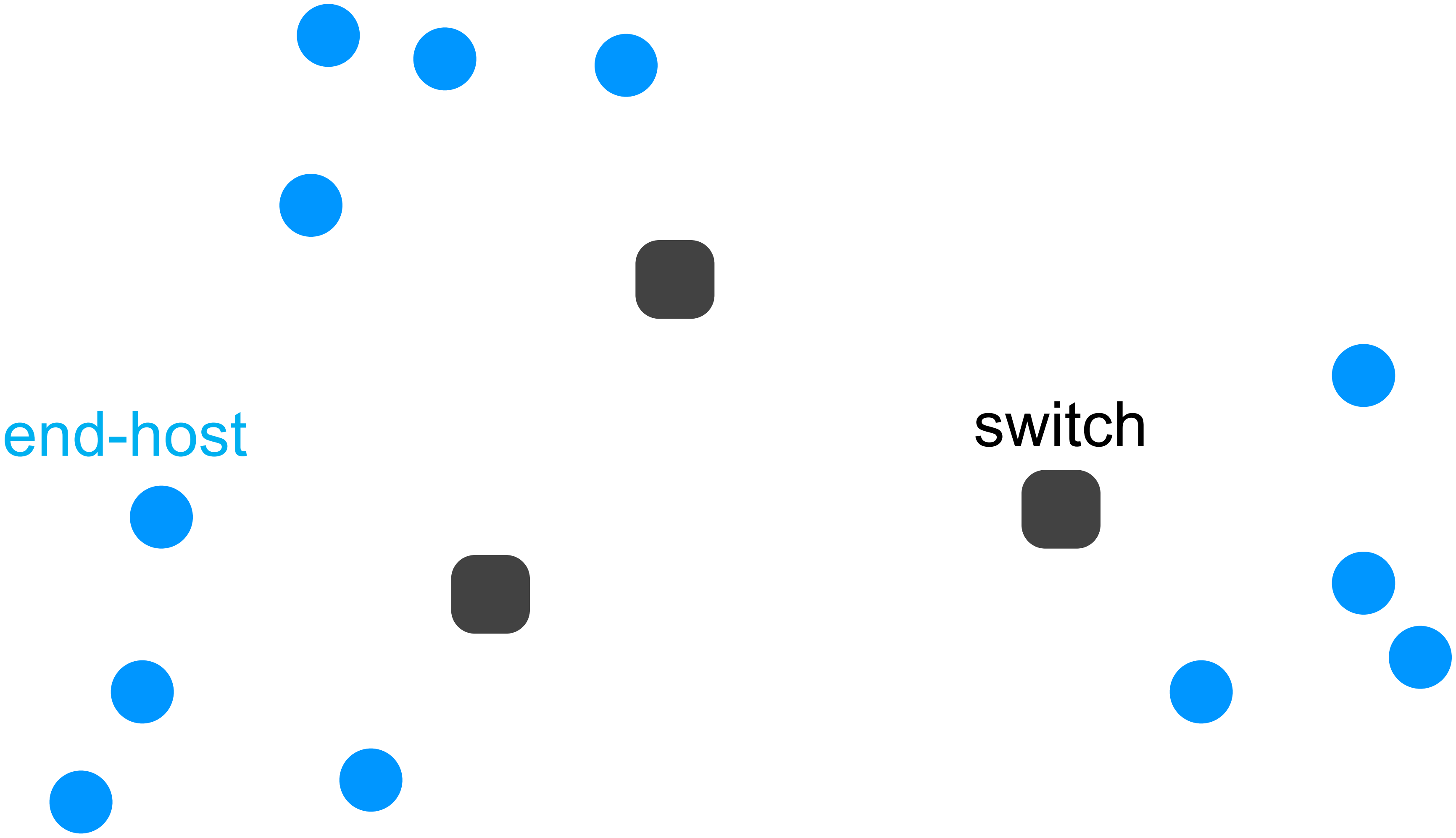
end-host

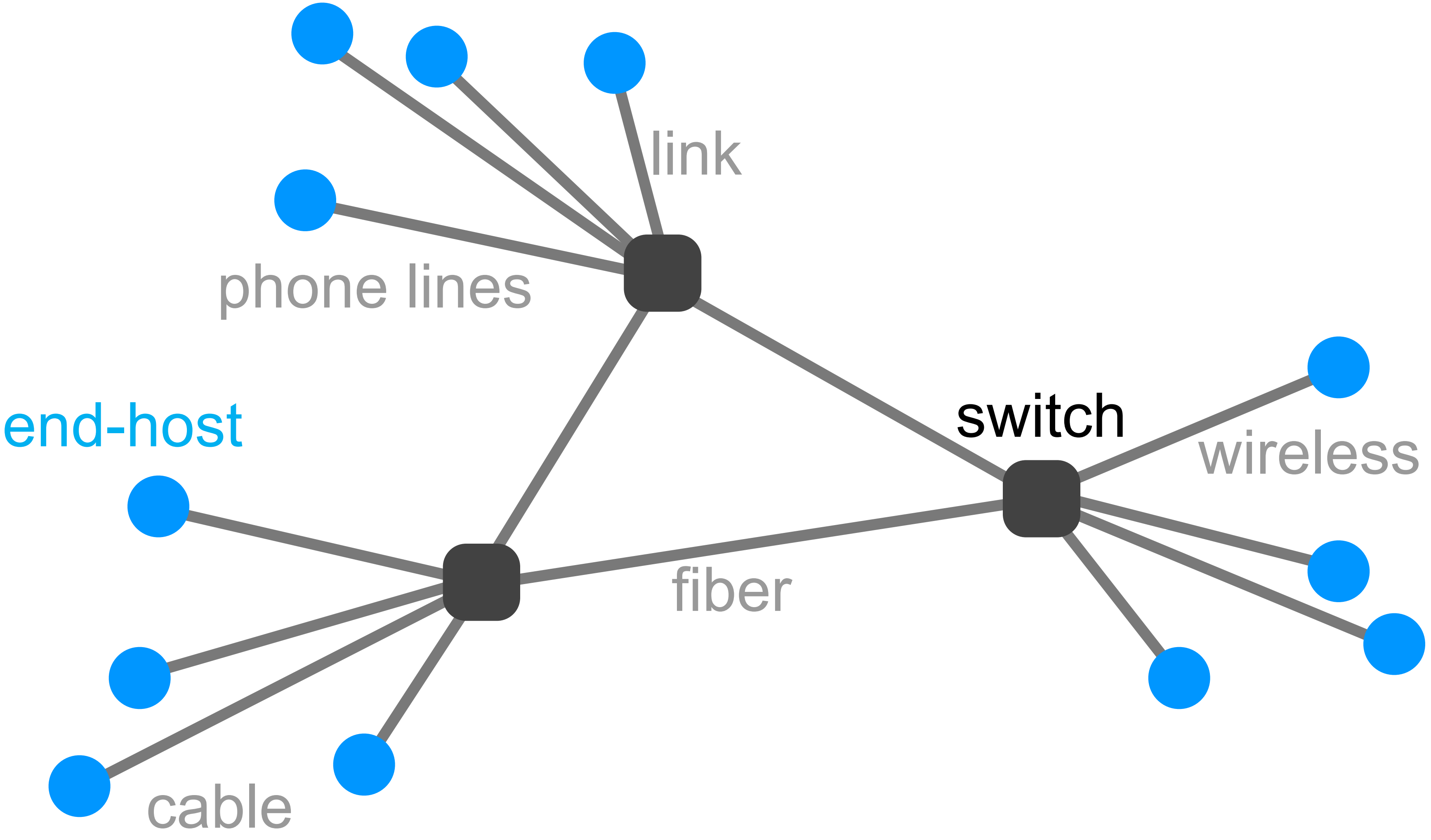
iPad

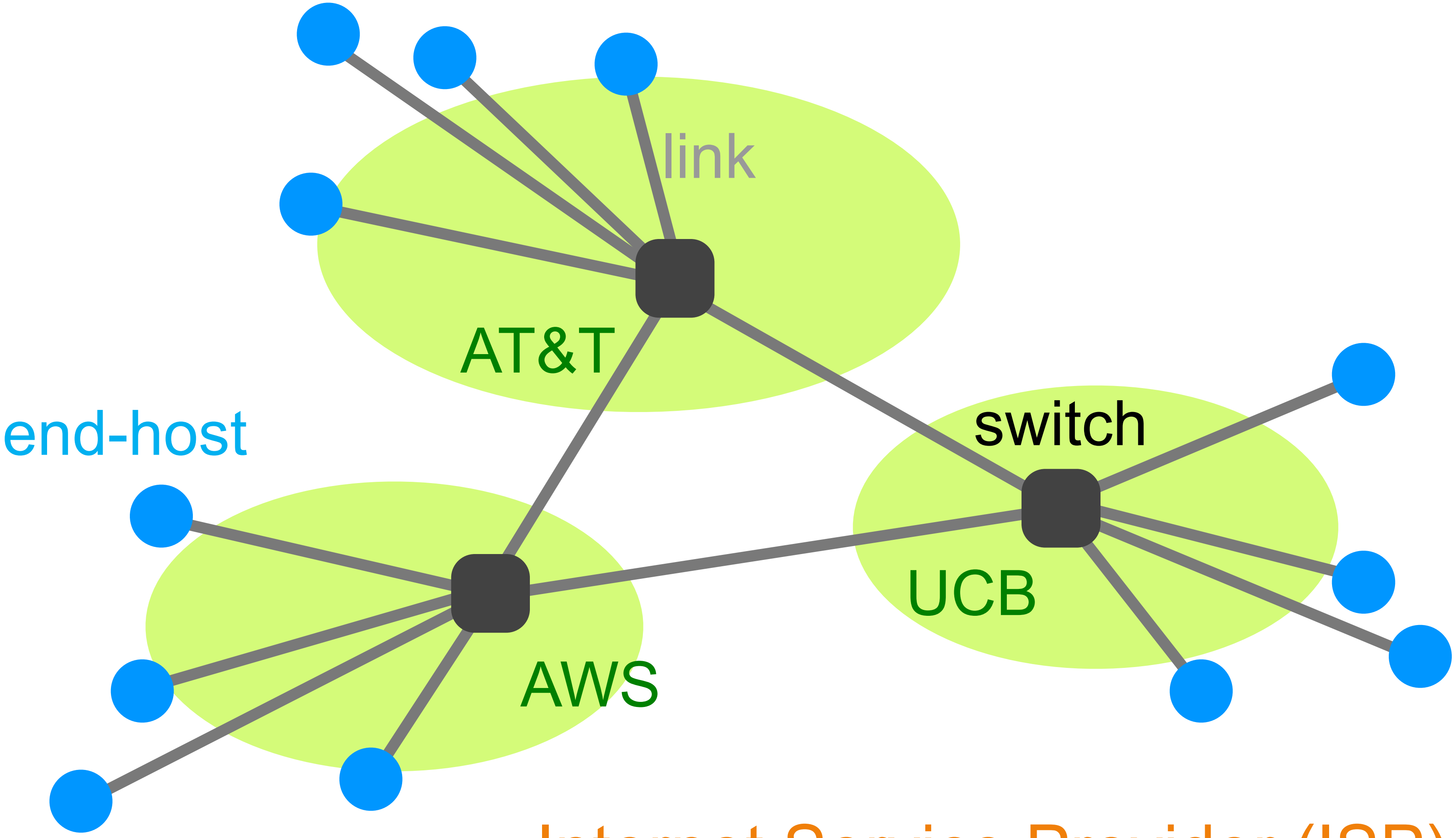
Linux server

MAC laptop

Windows PC


end-host
switch


link
phone lines
end-host
switch
wireless
fiber
cable



link

AT&T

end-host

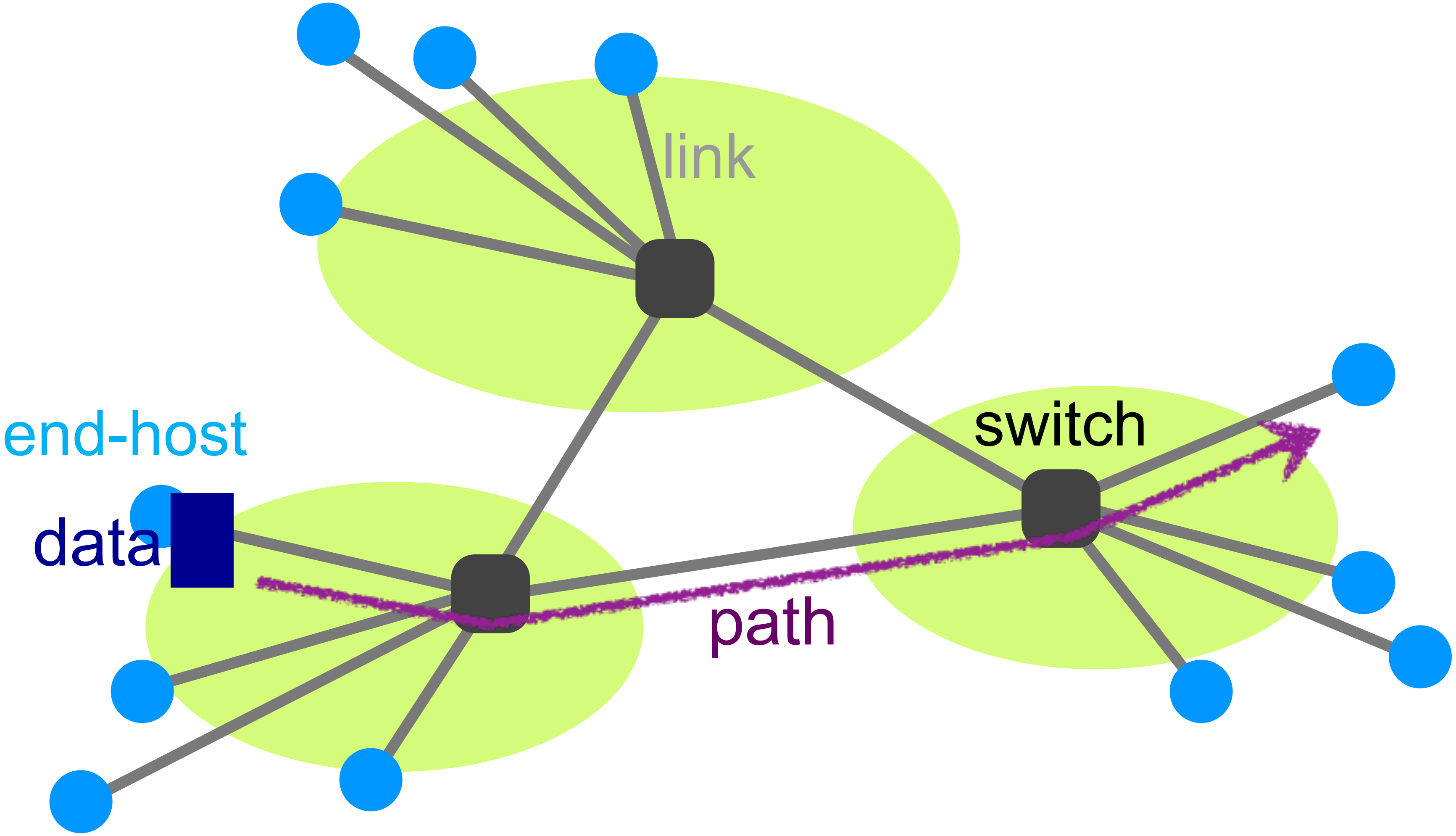
switch

UCB

AWS

Internet Service Provider (ISP)

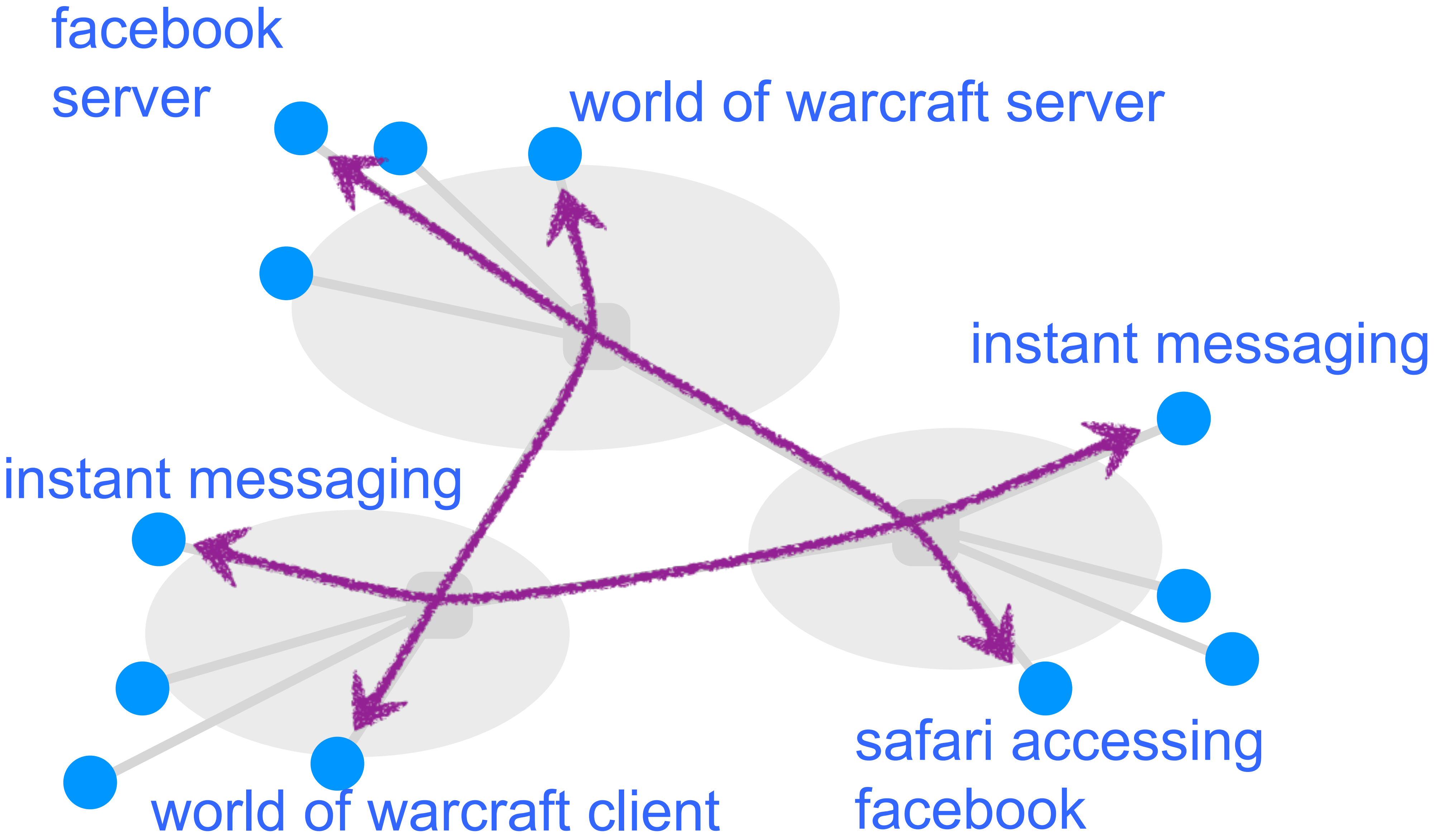
The Internet transfers data between end hosts

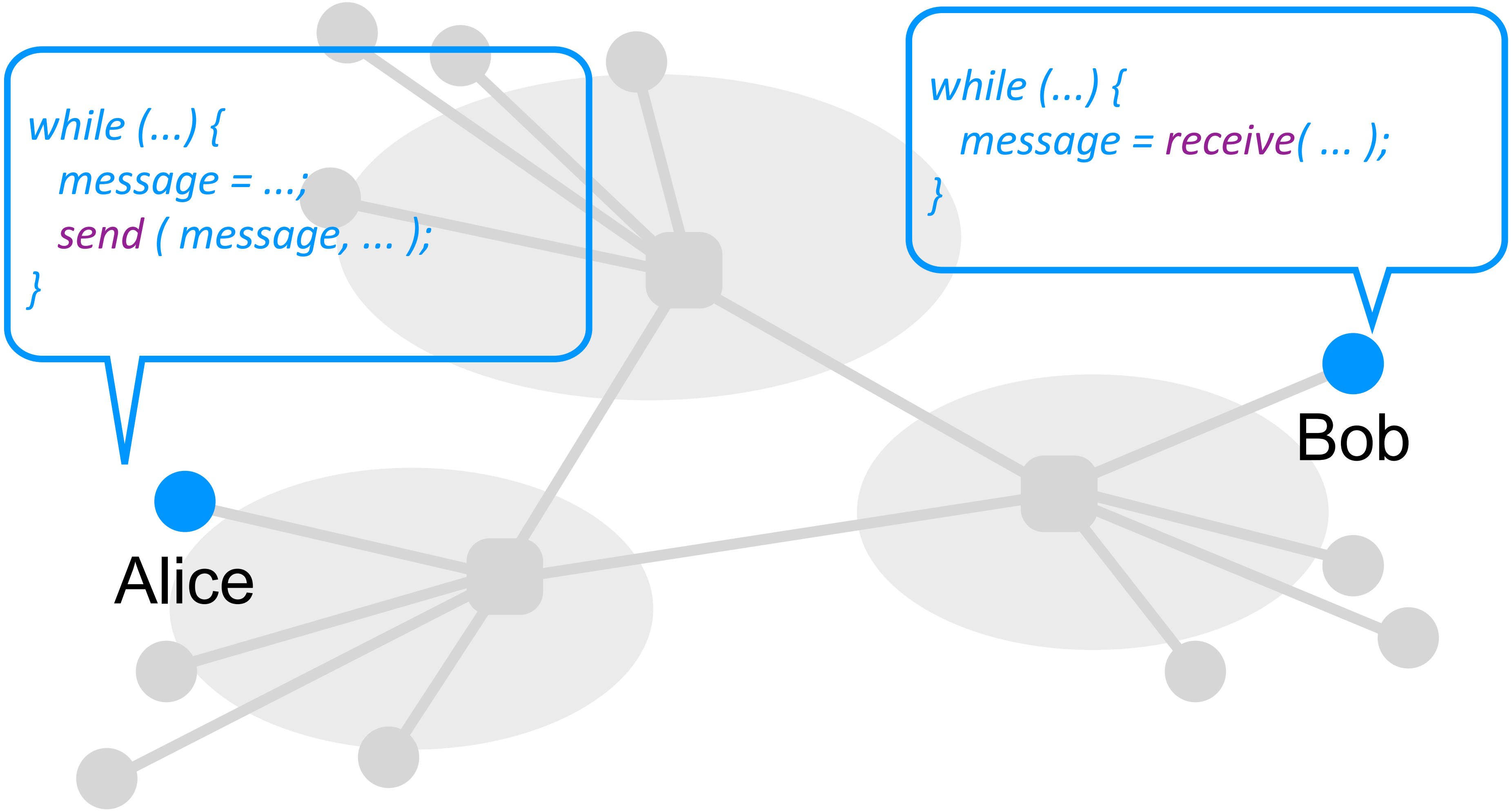


- Internet

- Protocols

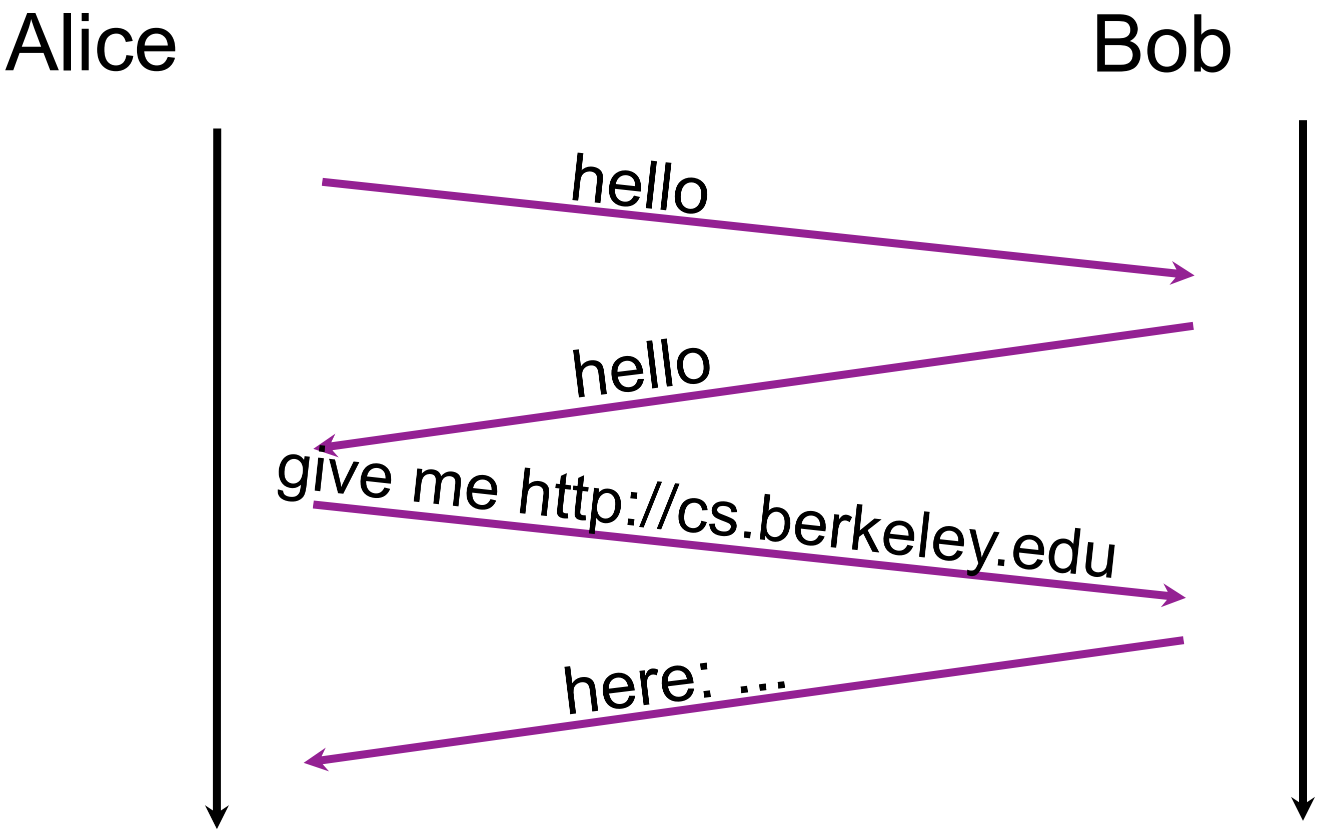
- Architecture


facebook
server
world of warcraft server
instant messaging
instant messaging
world of warcraft client
safari accessing
facebook

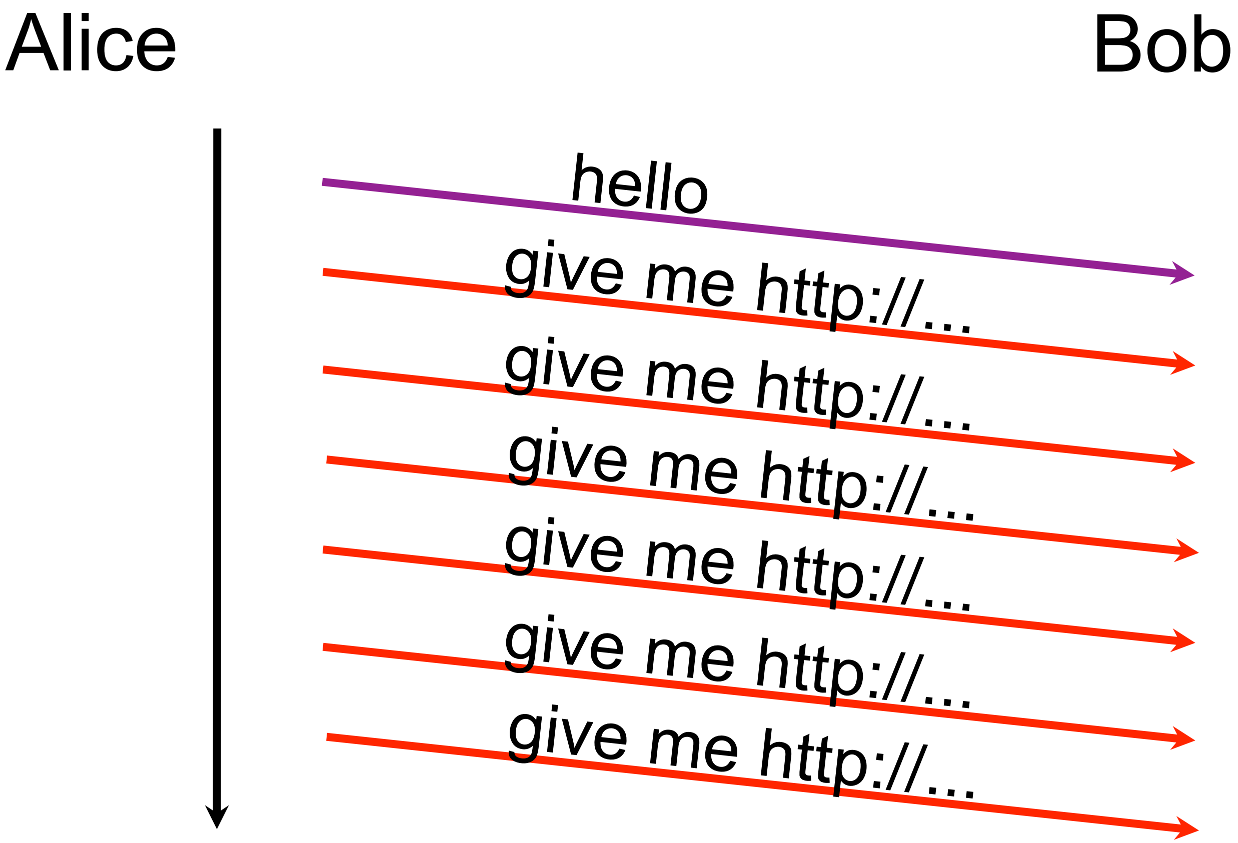


```
while (...) {
   message = ...;
   send ( message, ... );
}
```

```
while (...) {
   message = receive( ... );
}
```



Alice
Bob
hello
hello
give me http://cs.berkeley.edu
here: ...


Alice
Bob
hello
give me http://...
give me http://...
give me http://...
give me http://...
give me http://...
give me http://...

Protocol

- A specification of the messages that communicating entities exchange
  - their syntax and semantics

- Very much like conversational conventions … determining who should talk next and how they should respond

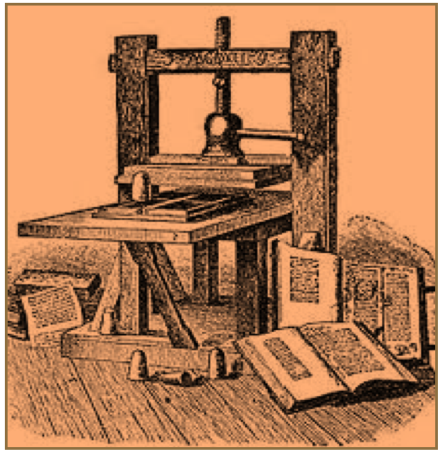
- Designing a good protocol is harder than it first seems!

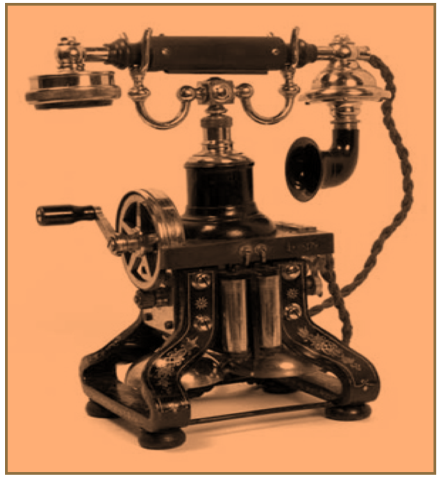
- Internet
- Protocols
- Architecture

Why study the Internet?

The Internet has and is transforming everything

- The way we do business …
  - retail, advertising, cloud computing
- The way we have relationships
  - Facebook, twitter,
- The way we learn
  - Wikipedia, search engines, MooCs
- The way we govern
  - E-voting, censorship, cyber-warfare
- The way we cure disease
  - digital health, remote surgery





What’s your formal model for the Internet? -- theorists

Aren’t you just writing software for networks? – OS community

You don’t have performance benchmarks??? – hardware folks

But why is the Internet *interesting*?

What’s with all these TLA protocols?– everyone

But the Internet seems to be working now … – my parents

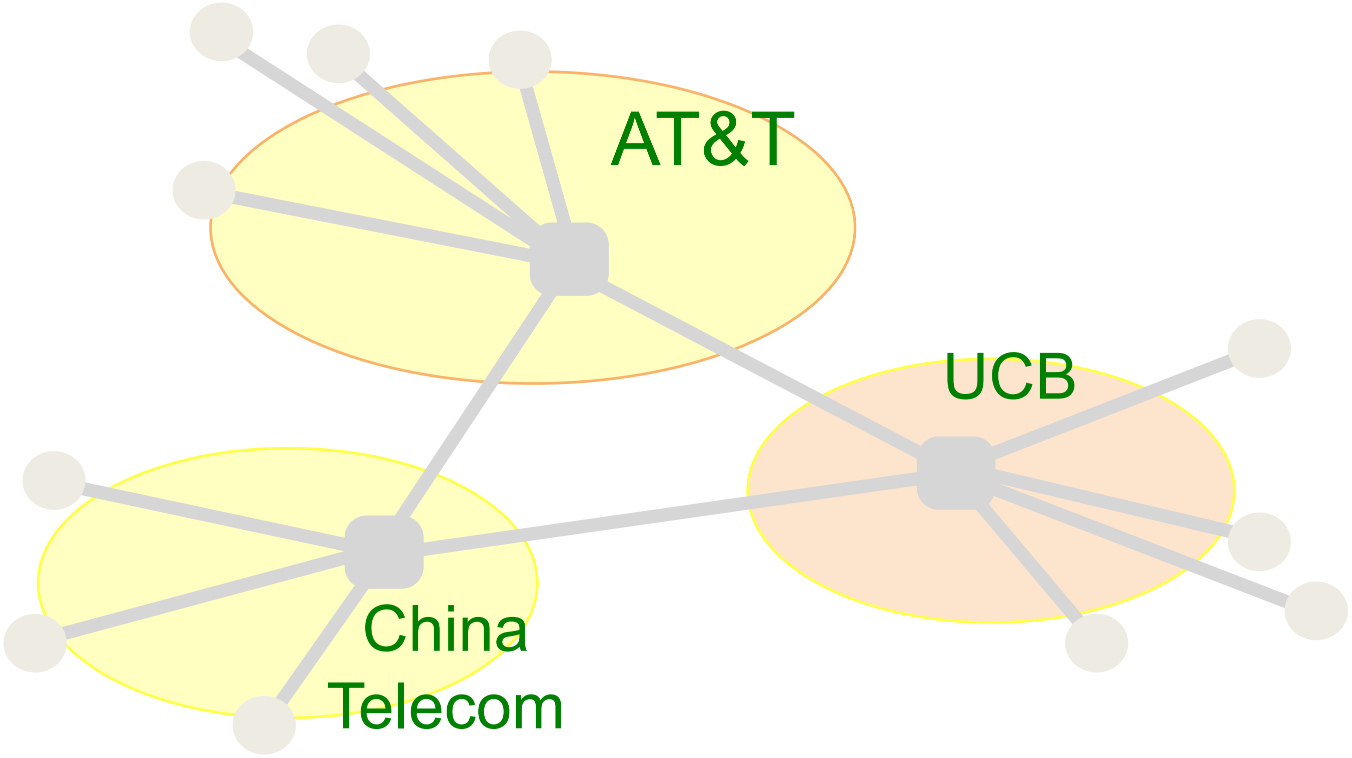
A few defining characteristics of the Internet…

Network versus “The Internet”

- There are many kinds of network technologies (switches and links)
  - Ethernet, optical, wifi access points, DSL modems, Infiniband switches, …
- The Internet is not a new/particular kind of network technology
- Instead, the Internet ties different networks together
  - The Internet

A federated system

Interoperability is the Internet's most important goal!



The Internet interconnects over 40,000 independently operated networks

A federated system

- Fundamental challenge: how do you interconnect competing entities?
  - Competing network providers must cooperate to serve their customers!

- Leads to a constant tussle between business and technical factors
  - Real-world incentives determine topology, path selection, diagnostics, and more

- And complicates innovation
  - How do you differentiate when interoperability relies on supporting a common protocol?
  - Upgrading “the Internet” is not an option

Tremendous scale

- >5 Billion users (51% of world population)
- 1.24 Trillion unique URLs (web pages)
- Every second, we generate >6000 tweets, >60,000 Google queries, >3M emails

The phrase "Internet scale" is now used refer to such systems

Enormous diversity and dynamic range

- Technology: optical, wireless, satellite, copper,…
- Communication latency: microseconds to seconds (10^6)
- Bandwidth: 1Kbits/second to 1 Terabit/second (10^8)
- Packet loss: 0 – 90%
- Endpoint devices: sensors, cell phones, datacenters,…
- Applications: skype, live video, gaming, remote medicine,…
- Users: the governing, governed, operators, selfish, malicious, naïve, savvy,…

Asynchronous Operation

- Fundamental constraint: speed of light

- Consider: how many cycles does your 3GHz CPU in Berkeley execute before it can possibly get a response for a message it sends to a server in NY?
  - Berkeley to New York: 4,125 km
  - Traveling to NY and back at 300,000 km/s: 27. 5 milliseconds
  - 3,000,000,000 cycles/sec * 0.0275 = 84,000,000 cycles!

- Thus, communication feedback is always **dated**

Prone to Failure

- Many components along a path
  - software, switches, links, network interface cards, wireless access points, modem,…
- Consider: 50 components, that work correctly 99% of time → 39.5% chance communication fail
  - Plus asynchrony → takes a long time to hear (bad) news

Handling failure at scale was dealt with for the first time in the context of the Internet!

Constant evolution

1970s:

- 56,000 bits/second links
- < 100 computers in the US
- Copying files is the “killer” app

Today

- 10^{12} bits/second links
- 8B+ devices, all over the globe
- 2.45B people use facebook

Cannot design for a fixed target!

Recap: The Internet is …

- A federated system …
- of enormous scale …
- with tremendous dynamic range and diversity …
- that is asynchronous in operation …
- failure prone …
- and constantly evolving

Recap: The Internet is …

- Too complex for theoretical models
- “Working code” needn’t mean much
- Performance benchmarks are too narrow

The creation of the Internet required a new design paradigm
(One that changed computer science!)

The Internet design paradigm

- Decentralized control
- A best-effort service model
- “Route around trouble”
- Dumb infrastructure (w/ smart endhosts)
- The end-to-end design principle
- Layering
- Federation via a “narrow waist” interface

A radical departure from systems at the time

Example: a best-effort service model

- Fundamental question: what’s the right service model that a network should support?
  - “contract” between network and its users/end-hosts

- Some possibilities:
  - “guarantee that data will be delivered”
  - “guarantee that data will be delivered within X time”
  - “return a confirmation of successful delivery or an error”

- Instead, what the Internet supports: ”best effort” delivery of data
  - No guarantee on whether or when data will be delivered
  - No notification of outcome!

The Internet design paradigm

- Decentralized control
- A best-effort service model
- “Route around trouble”
- Dumb infrastructure (w/ smart endpoints)
- The end-to-end design principle
- Layering
- Federation via a “narrow waist” interface

A radical departure from systems at the time

Now routinely adopted in modern systems (e.g., cloud services)

The Internet design paradigm

- Decentralized control → SDN: centralize? → dSDN: (re)decentralize?
- A best-effort service model
- "Route around trouble"
- Dumb infrastructure (w/ smart endpoints) → NFV: richer in-network services?
- The end-to-end design principle → Edge computing?
- Layering → cross-layer coding
- Federation via a "narrow waist" interface

But it is just one design …

… and we're still debating the big questions

Backing up a level

- The Internet poses a design challenge like no other
- From its creation emerged a new design paradigm
- That shaped how we reason about the design of complex systems
  - What's the right prioritization of goals?
  - What are fundamental constraints?
  - How do we decompose a problem?
  - What abstractions do we need?
  - What are the tradeoffs?
- In short, a lesson in how to <u>architect</u> a (networked) system

- Internet
- Protocols
- Architecture

Network architecture*

- More about thinking rigorously than doing rigorous math
- More about understanding tradeoffs than running benchmarks
- More about practicality than optimality

Done right, can be a powerful thing

What (I hope) CS 168 will teach you

- How the Internet works
- Why it works the way it does
- How to reason through a complex (networking) design problem

Let’s take a quick break

Today

- What is (this course on) the Internet about?

  [quick break]

- Class logistics

Teaching Staff (see course website for office hours and sections)

Instructor: Sylvia Ratnasamy

- Background
  - PhD from UC Berkeley
  - Worked in industry ~10 years
  - Returned to UCB to join the faculty in 2011
  - Co-founded a startup in 2016; spent 2021-22 at Google
  - Networking has been my focus throughout

- My teaching style
  - I’m a much better teacher when you engage with my questions!!
  - I talk too fast -- the more bored you look, the faster I talk!

Head TAs (see cs168.io for office hours and sections)

- Sean Kim

- Alex Krentsel

Project TAs (see cs168.io for office hours and sections)

- Silvery Fu

- Tenzin Ukyab

- Kenneth Lien

- Zhihong Luo

Section TAs (see cs168.io for office hours and sections)

- Sarah McClure

- Mark Theis

- Narek Galstyan

Enrollment and wait list

- Class size will not increase

- Wait-listed students will be admitted as and when registered students drop the class
    - Course staff do not process the waitlist!
    - If you’re planning to drop, please do so soon!

- Concurrent enrollment students will be admitted after the wait list is processed

Recordings

- Lectures will be recorded and posted online
  - We will make every effort to release videos on the same day as the lecture
  - See Sean’s post on Ed
- One section will be recorded
- Best-effort attempt to livestream the lecture on zoom, for the first few weeks
  - Will assess as we go - please do not rely on this

Sections

- All sections on Monday
  - Will cover material from the previous week’s lectures

- Go to whichever one you want, but please register your choice online

Class workload

1. Two projects (see website for deadlines)
    - One on routing, one on transport protocol design
    - Goal is to learn networking, not programming
    - No partners
2. Self-tests after class
3. One homework based on a research paper we'll read NEW
4. Exams: midterm and final

Grading

- Course grades curved according to recent guidelines
  - But I reserve the right to grade towards the lower end of the spectrum

Project 1	20%
Project 2	20%
Self-Tests	5%
Homework	5%
Midterm exam	25%
Final exam	25%

Extensions / Late Policy

- If you are a DSP student or have extenuating circumstances, fill out the extension form
- No extensions for self-quizzes
- For projects and homework, late assignments are penalized as →
- You may only submit once if you are more than 3 days late
- Projects turned in after Dec 9, 11:59pm receive no credit
- If you receive <50% on any project, you may redo it **ONCE** for up to 50% of the maximum score

Lateness	Penalty
< 24 hrs	-10%
< 48 hrs	- 20%
< 72 hrs	- 40%
>= 72 hrs	- 50%

Self-tests

- Self-test quiz posted after each lecture
    - Available by 5pm the day of the lecture and will remain open for a week

- Scores are not important, but you must try!
    - This will help us, and you, identify what topics need explanation

- Participation counts for 5% of your grade
    - Participation → fill out the form in some sensible manner
    - Can skip up to 3 self-tests without penalty

Exams

- All exams are closed book, open crib sheet
- Exam dates and time can be found on the schedule at http://cs168.io/
- Alternate exams will be offered in time slots directly following the regular exam
  - You must let us know and receive approval from us to take the alternate exam
  - See Sean’s post on Ed for requesting an alternate exam
  - DSP students will be accommodated as needed
  - There will be no additional alternates

Lectures and participation

- Class will be recorded but attendance is **highly** recommended
    - My slides will be available on the class website a few minutes before lecture

- Ask and answer questions!
    - It helps you understand
    - It helps others understand
    - It helps you stay awake
    - It helps me stay awake
    - It’s just more fun for all of us …

- Do sit towards the front and limit electronic access and **BE QUIET**!!

Questions answered in real-time!

- One or more TAs will be on Ed during lecture
- If you have a quick question and don't want to ask me, then ask on the real-time thread
- Don't use this for deep conceptual questions:
  - Ask those of me because you can't be the only one who is confused
- But if you missed something in passing, ask online in real-time!

Class communications

- Website: cs168.io
  - Assignments, lecture slides, announcements

- Use Ed for intra-class communication as much as possible

- Email cs168@berkeley.edu with any questions
  - Reaches me, Alex, and Sean

Course Material

- Disclaimer: we're still figuring out how to teach system architecture

- Focus on fundamental questions and tradeoffs
  - The broader design space, rather than the details of the solutions implemented today
  - Ideally, we do this together as a joint design exercise

- You will *also* have to learn the current design
  - But with a good understanding of where and why it falls short

- You will end up with a mix of the "big picture" and "details"

Fundamental questions

- How do you architect the Internet?
- How do you find a path from source to destination? (routing)
- How do you build reliable communication on top of an unreliable network? (transport)
- How do you share network resources across users? (congestion control)
- How do you federate a set of competing network providers?
- ....

First half of course: basics

- General overview
- Architectural principles
- Routing
- Reliable data transfer
- Naming and Addressing
- Etc.

Second half of course: advanced topics

- Congestion control
- Inter-domain issues
- Newer topics:
  - SDN and network management (guest lecture by Scott Shenker)
  - Datacenter networks
  - Cellular networks NEW
  - Read a research paper! NEW
  - 2 guest lectures from the lead architects of Google's global network NEW

What you will not learn…

- How to setup or operate real networks
- Tiny details of current network protocols or the Linux networking stack
- Instead, you will learn about the fundamental challenges in designing the Internet
    - And quite a bit about how the Internet currently addresses these
- Make sure this is what you're looking for!

Textbook

- J. Kurose and K. Ross, Computer Networking: A Top-Down Approach (7th edition, 2016)
  - 5th and 6th editions ok, but translate the reading assignments

- **You will not be tested on material we didn't cover in lecture or section**
  - Use as a reference and a source of examples

For next time…

- If you plan to drop, please do so ASAP

- See Sean's post on Ed regarding alternate exams

- Discussion sections will start on **August 29**

- Self quizzes start on **August 30**