CS168
Introduction to the Internet: Architecture and Protocols

Sylvia Ratnasamy and Rob Shakir

Spring 2024

Today

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

Instructor: Rob Shakir

- Background
  - Got into networking via a startup he founded in 2003
  - Learnt a lot through "just doing it”
  - Tech lead for multiple global networks, including British Telecom
  - Moved to the US to join Google and now a lead architect and engineer working on Google’s global WAN network

Instructor: Sylvia Ratnasamy

- Background
  - PhD from UC Berkeley
  - Worked at Intel Research for ~10 years
  - Joined the UCB 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)

- Sarah McClure

- Efsane Soyer

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

- Tess Despres

- Abhi Ganesh

- Ethan Jackson

- Bryce Wong

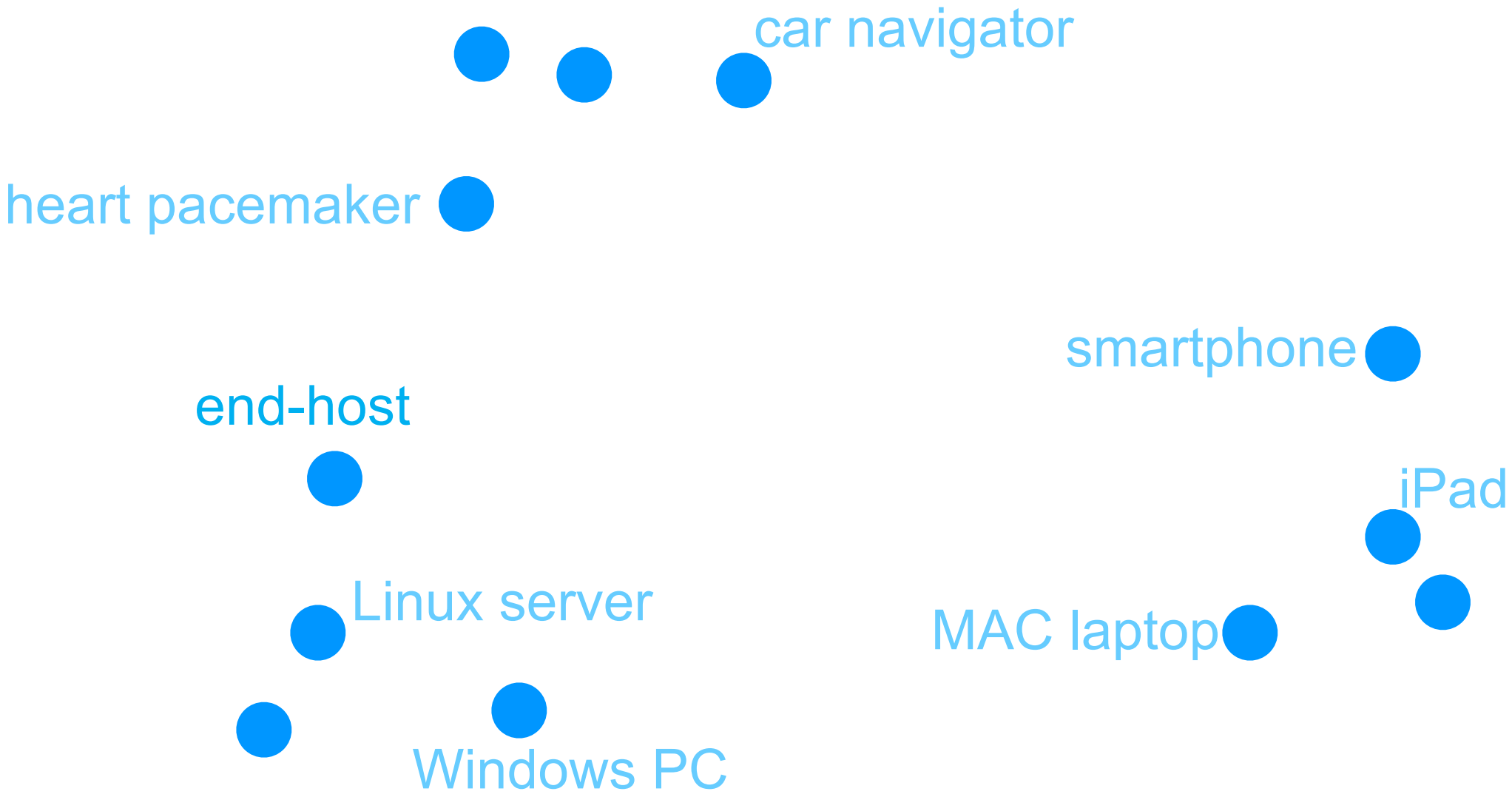
Today

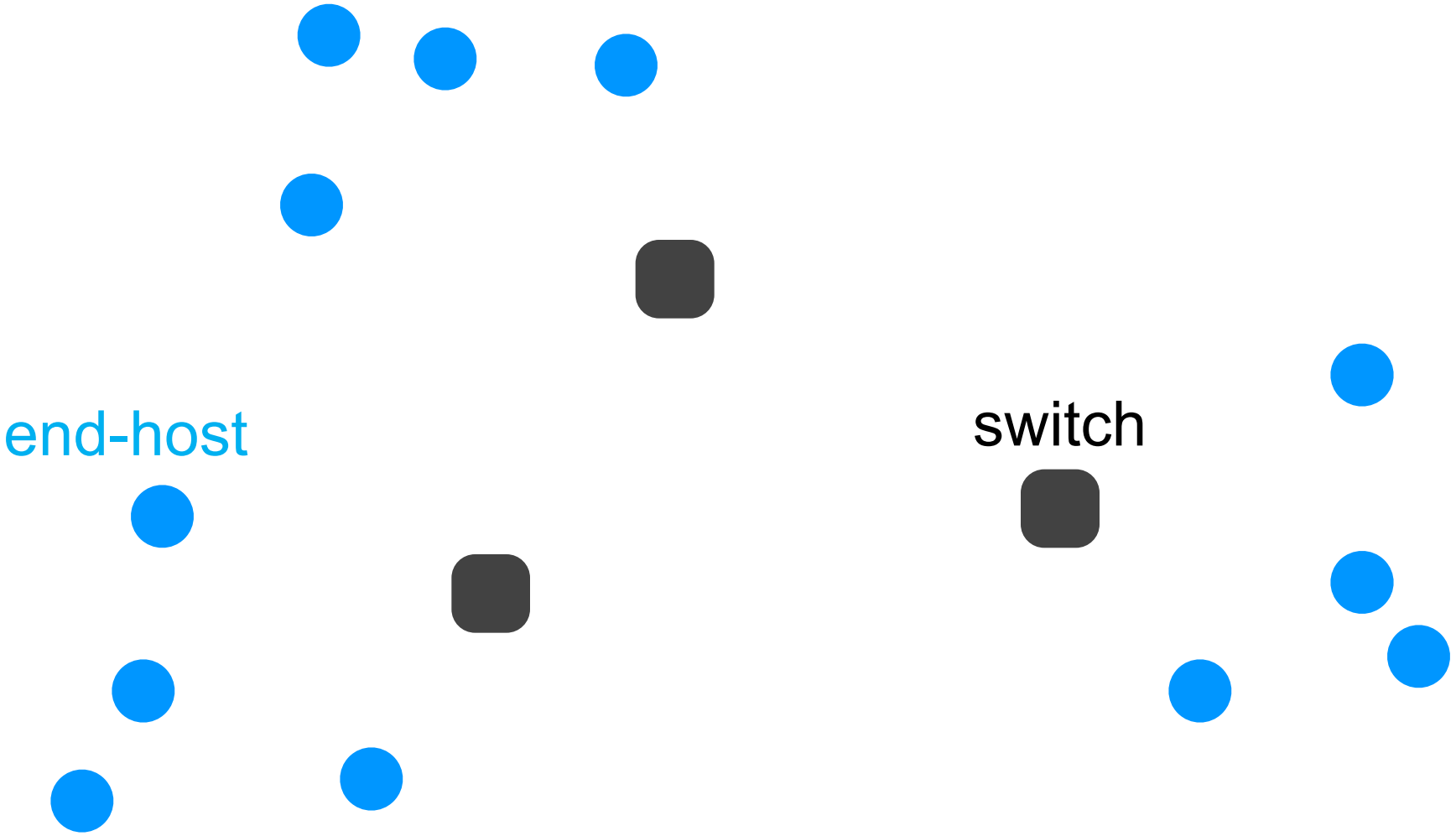
- Introductions
- What is (this course on) the Internet about?
- Class logistics

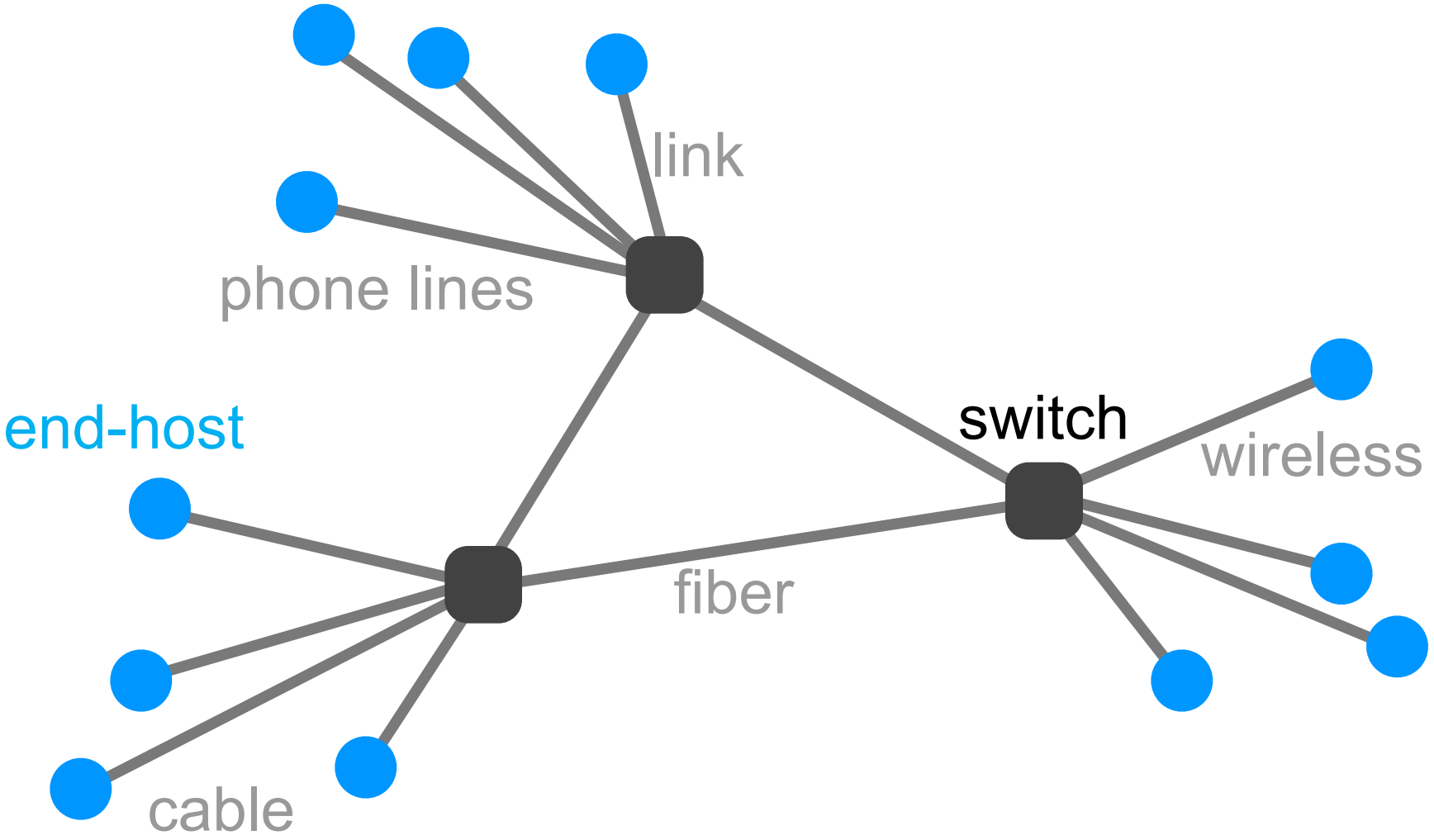
- Internet
- Protocols
- Architecture

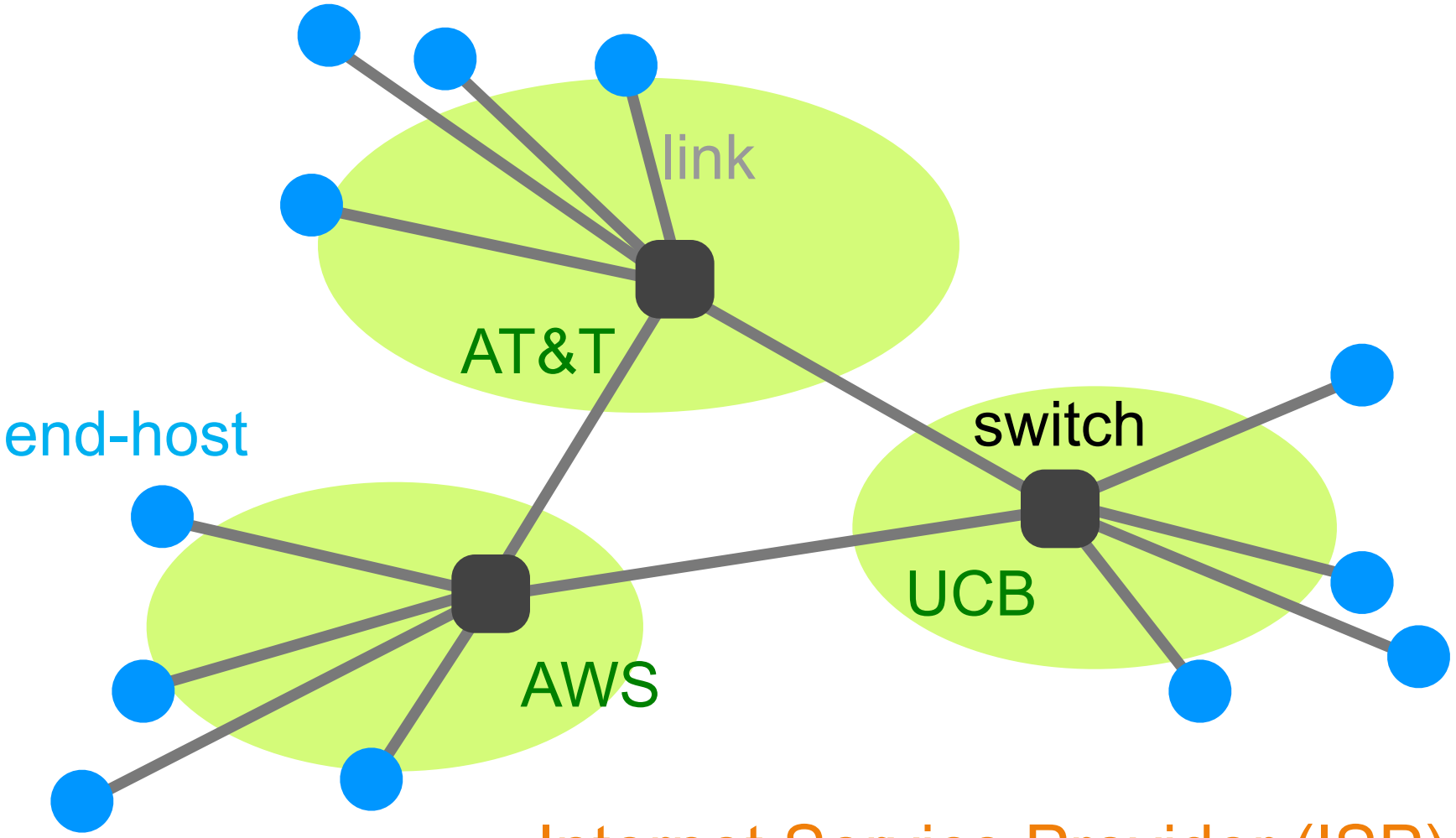
Two Meanings of “Internet”

- The infrastructure that ties together computing devices
  - TCP, IP, BGP, DNS, OSPF, …
- The ecosystem of applications built on top of the above infrastructure
  - amazon, 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

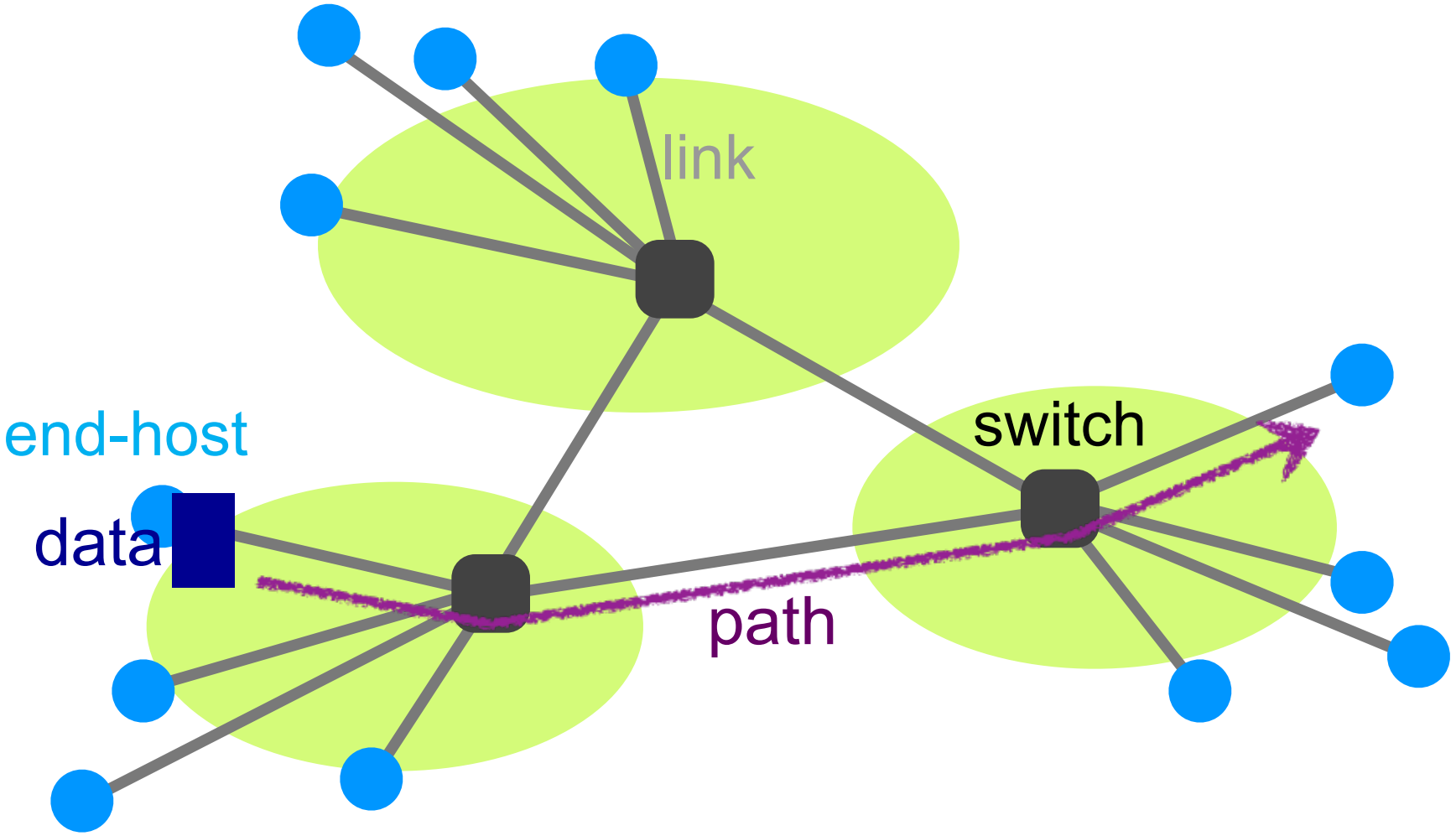

end-host
switch


link
phone lines
end-host
switch
wireless
fiber
cable

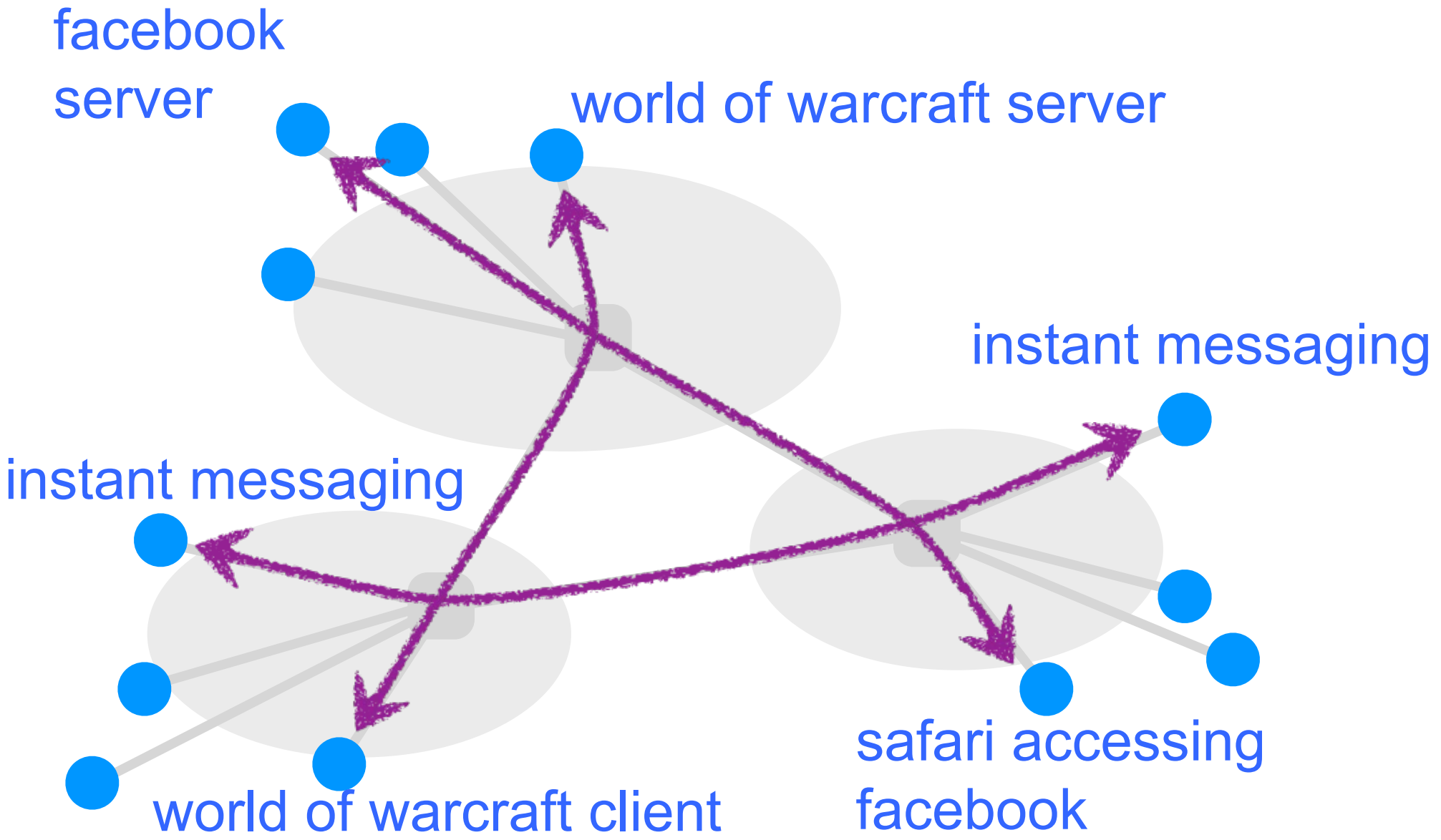


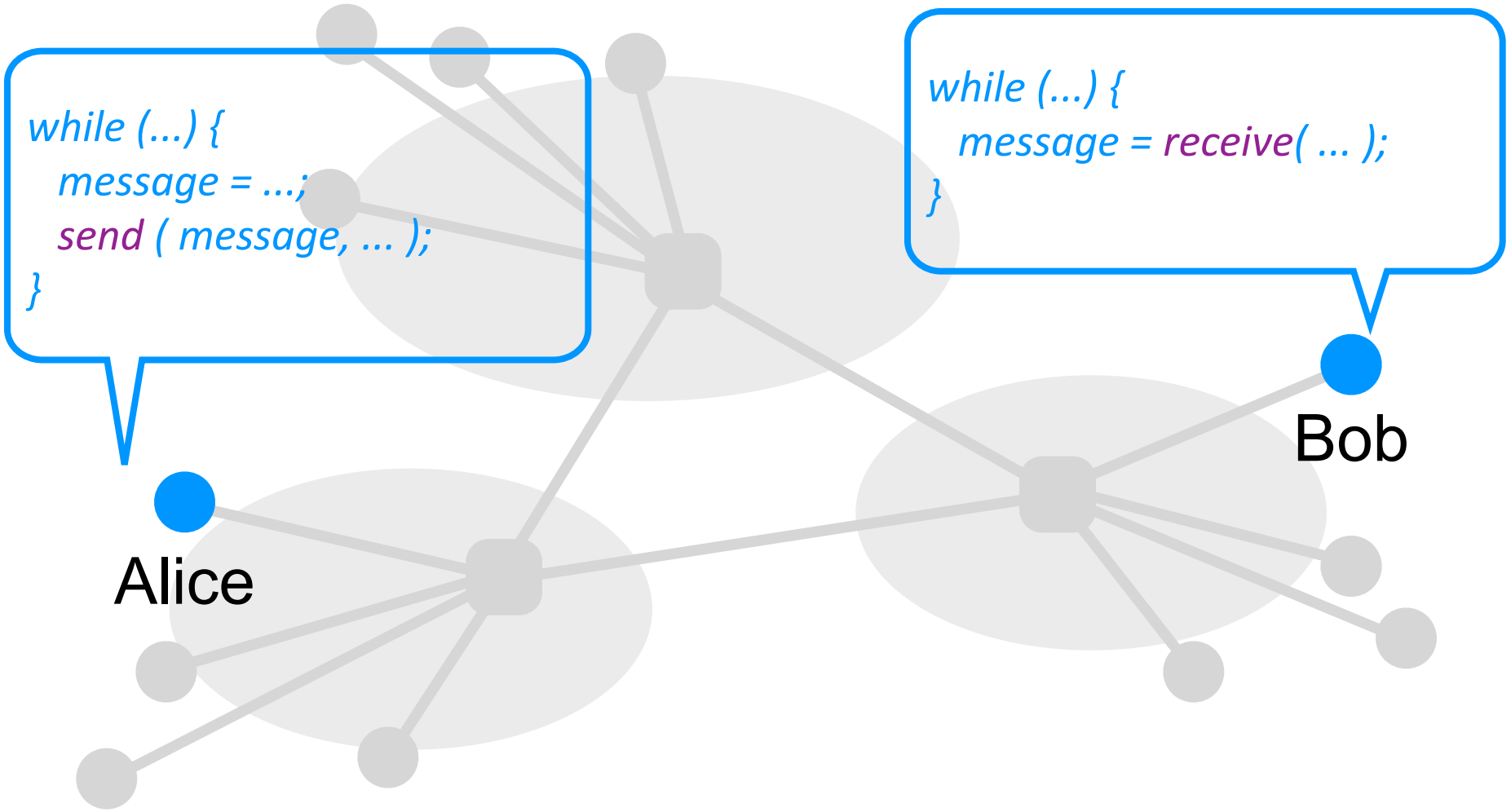
Internet Service Provider (ISP)

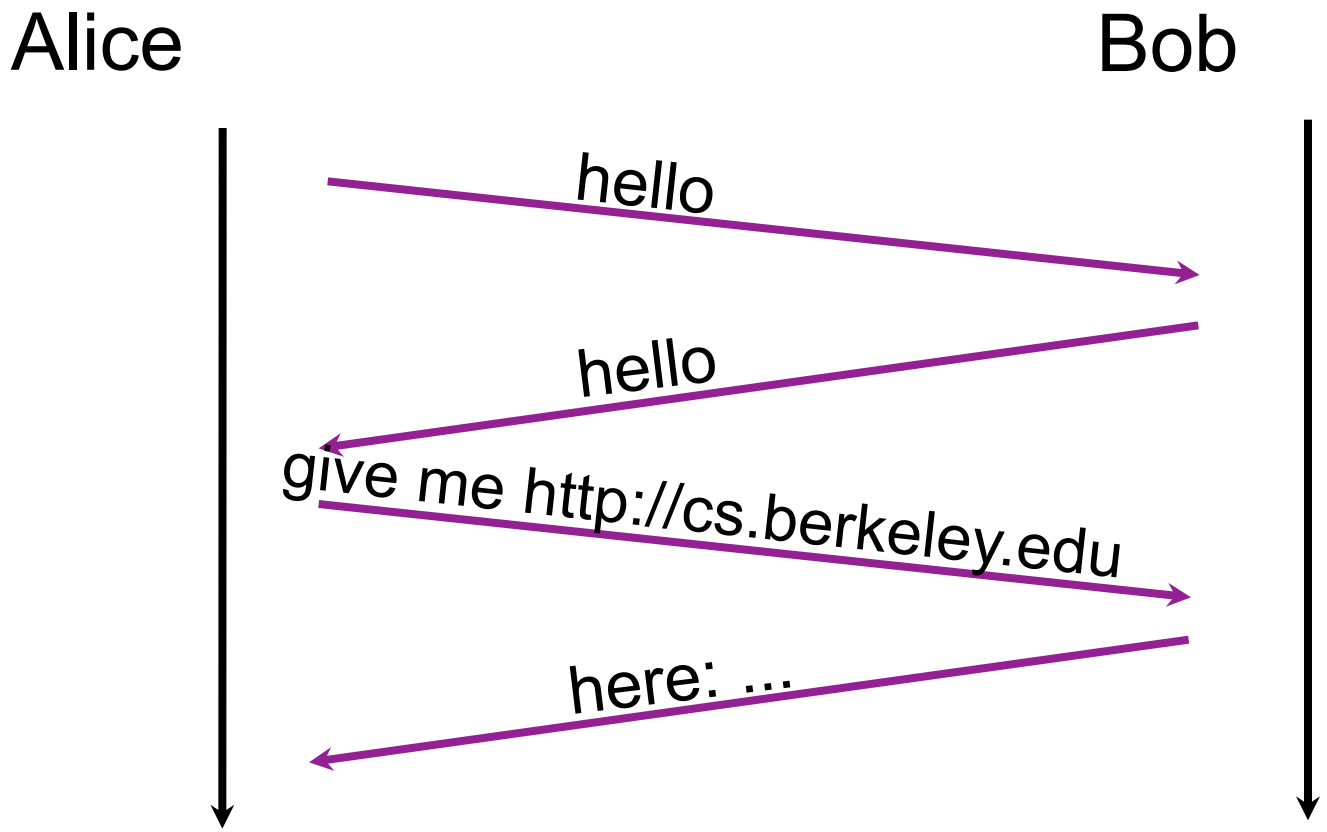
The Internet transfers data between end hosts



- Internet
- Protocols
- Architecture


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


while (...) {
message = ...;
send (message, ...);
}
while (...) {
message = receive(...);
}
Alice
Bob


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

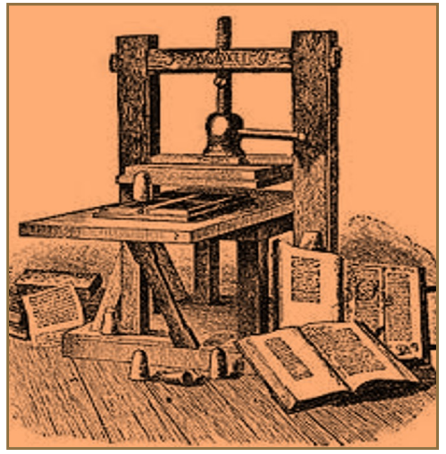
- Designing a good protocol is harder than it first seems!

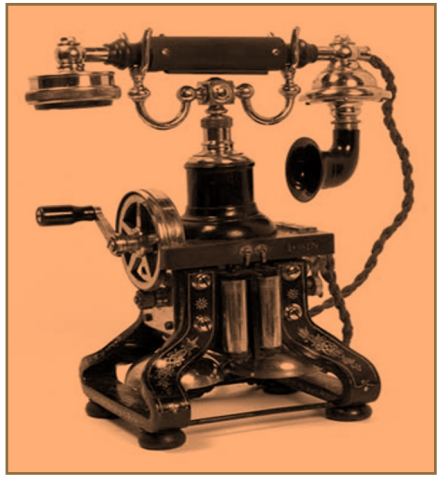
- Internet
- Protocols
- Architecture

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
  - Twitter, chat
- The way we learn
  - Wikipedia, ChatGPT, AR/VR
- 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

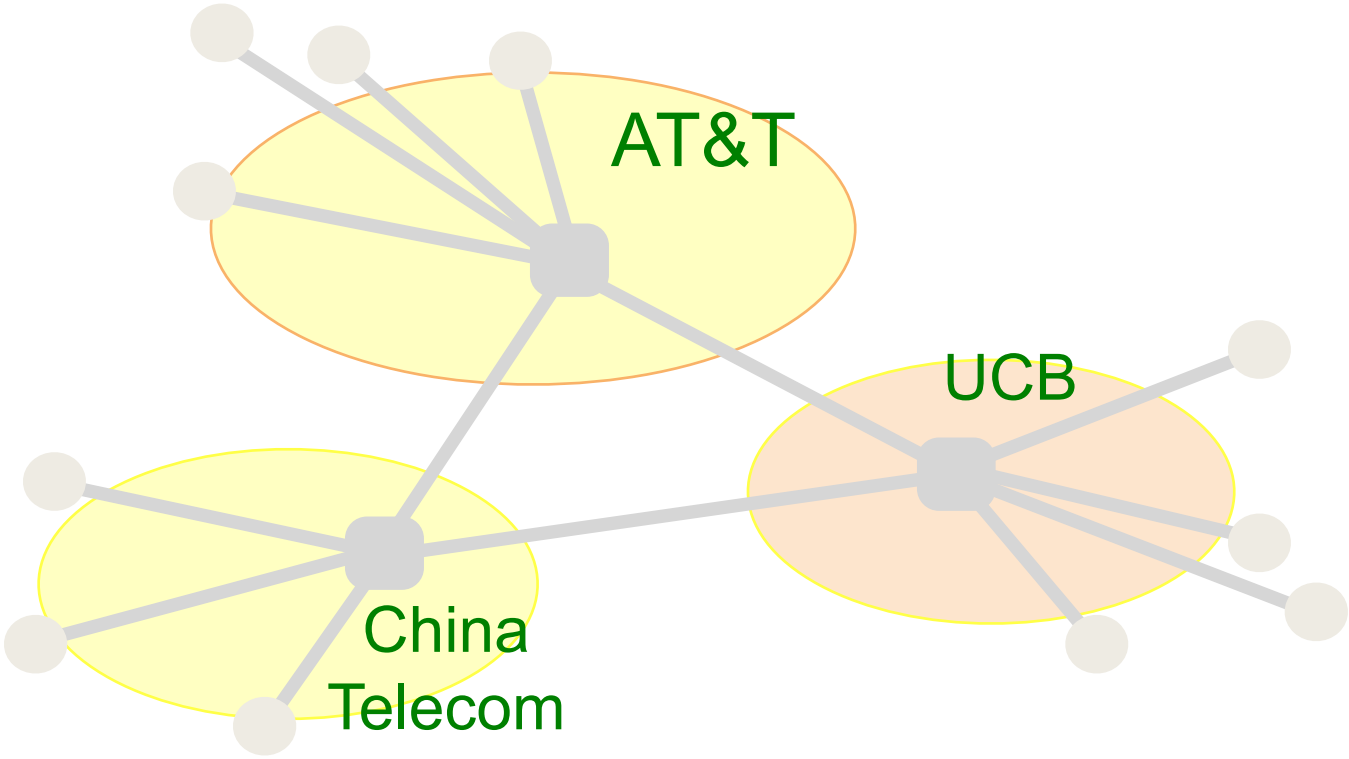
A few defining characteristics of the Internet…

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 100,000 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, …

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:

- 10^4 bits/second links
- < 100 computers in the US
- Copying files is the “killer” app

Today

- 10^{14} bits/second links
- 10B+ devices, all over the globe
- 3B+ facebook users; self-driving cars

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
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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 → "quality of service" guarantees?
- "Route around trouble"
- Dumb infrastructure (w/ smart endpoints) → in-network attack detection?
- 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 architect 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

Today

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

  [quick break]

- Class logistics

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

Lectures and participation

- Attendance is required and 5% of your grade (see website for details)
  - Will have occasional in-class quizzes
  - For full credit you must answer >20% of questions correctly on >50% of quizzes; no partial credit

- 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!!

Lecture slides and recordings

- Lecture slides will be available on the class website a few minutes before lecture
- Lectures will be recorded and posted online with a ~one week delay
- Section will cover material from the previous week's lectures; we will release a video covering section on the day of

Class workload

1. Attendance and in-class quizzes
2. Three projects (see website for deadlines, late policy, etc.)
   - Project#1: routing
   - Project#2: implement "traceroute" NEW
   - Project#3: implement a reliability protocol
   - No partners
3. One homework based on a research paper we'll read NEW(ish)
4. Exams: midterm and final

Grading

- Will grade following the department's latest guidelines
- See course website for extensions, late policies, etc.

Project 1	15%
Project 2	15%
Project 3	15%
In-class quizzes	5%
Homework	5%
Midterm exam	20%
Final exam	25%

Exams

- All exams are closed book, open crib sheet
- Exam dates and time can be found on the schedule at https://cs168.io
- Alternate midterm will be offered in the time slot directly after the regular exam
- Alternate final will be offered in the time slot immediately before the regular exam
  - With restrictions – look out for our Ed post with more information on this topic
  - DSP students will be accommodated as needed
  - There will be no additional alternates

Class communications

- Website: cs168.io
  - Assignments, lecture schedule, slides
- Announcements will be on Ed
- Use Ed for intra-class communication as much as possible
- Email cs168@berkeley.edu only if necessary
  - Reaches me, Rob, Efsane, and Sarah

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
- HTTP & the Web
- Newer topics:
  - Cellular and datacenters
  - 2 lectures on RDMA -- taught by Nandita Dukkipati from Google NEW
  - 2 guest lectures – tentatively on networking GPU/TPU clusters, and rural connectivity NEW
  - Read a research paper!

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
- Discussion sections will start next week, on 1/22
- In-class quizzes start next week