CS168
Introduction to the Internet: Architecture and Protocols

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Spring 2020

Today

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

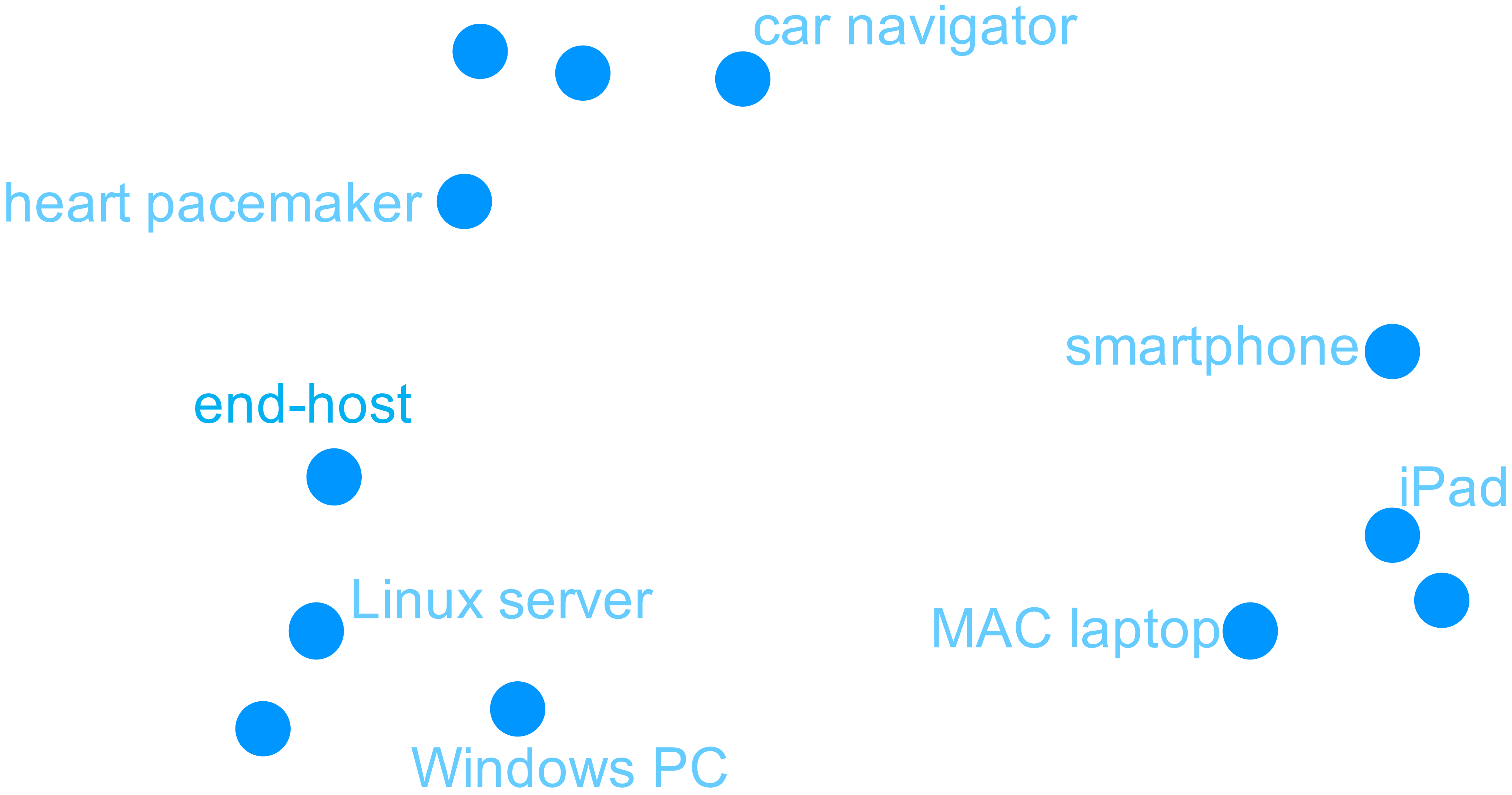
  [quick break]

- **Class logistics**

- **Internet**
- **Protocols**
- **Architecture**

Two Meanings of “Internet”

- **The infrastructure that ties together computing devices**
  - TCP, IP, BGP, 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

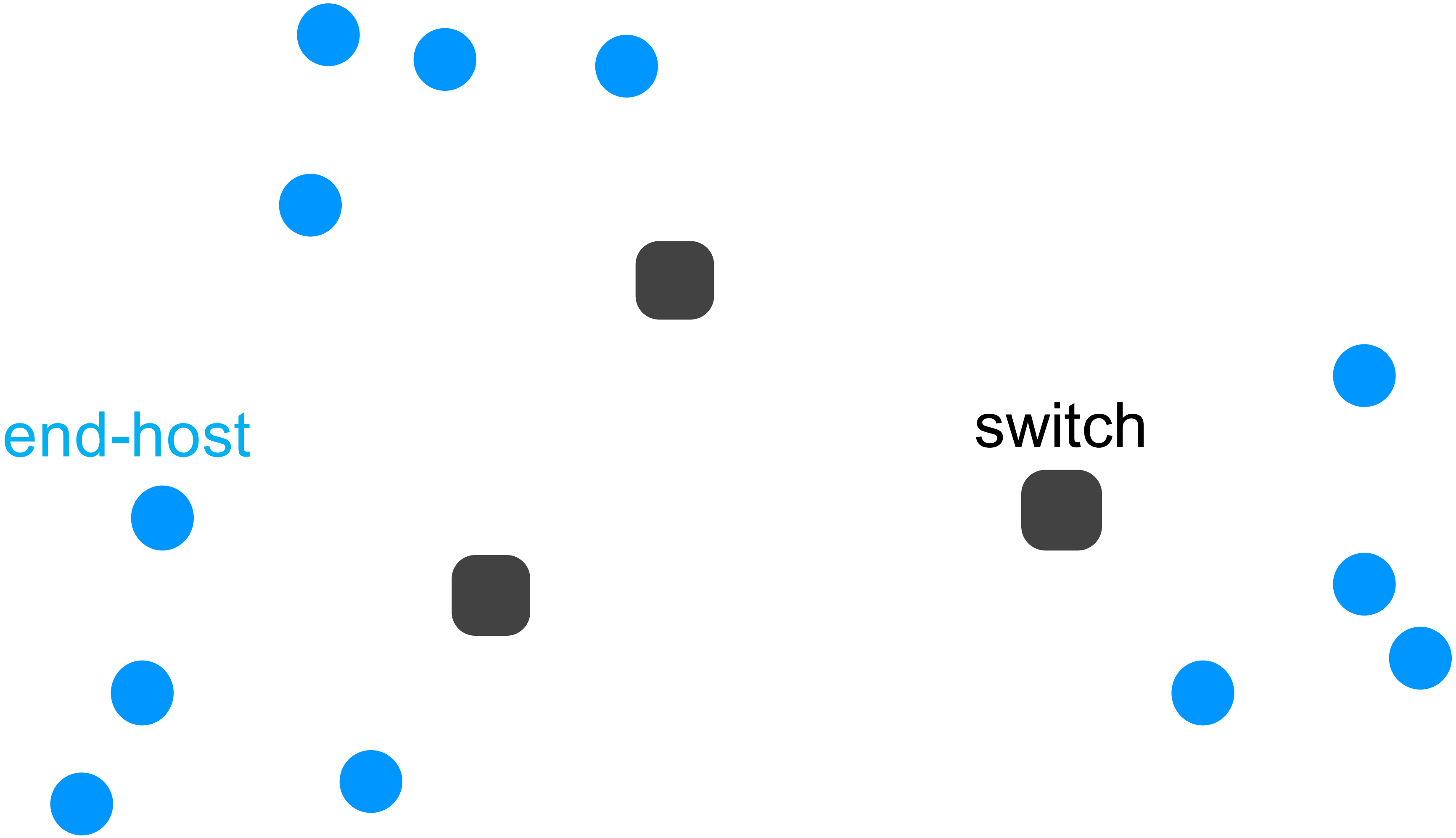
end-host

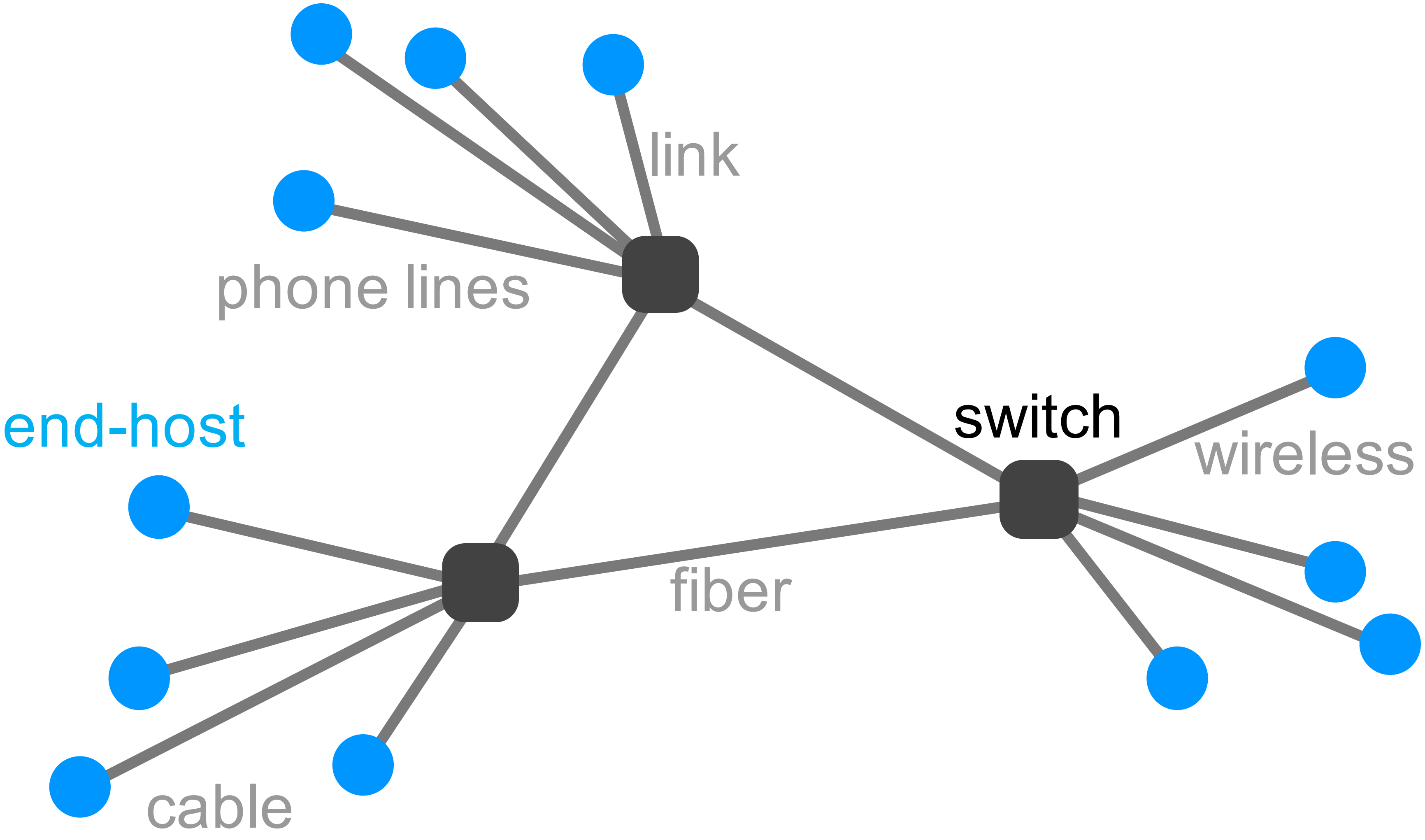
iPad

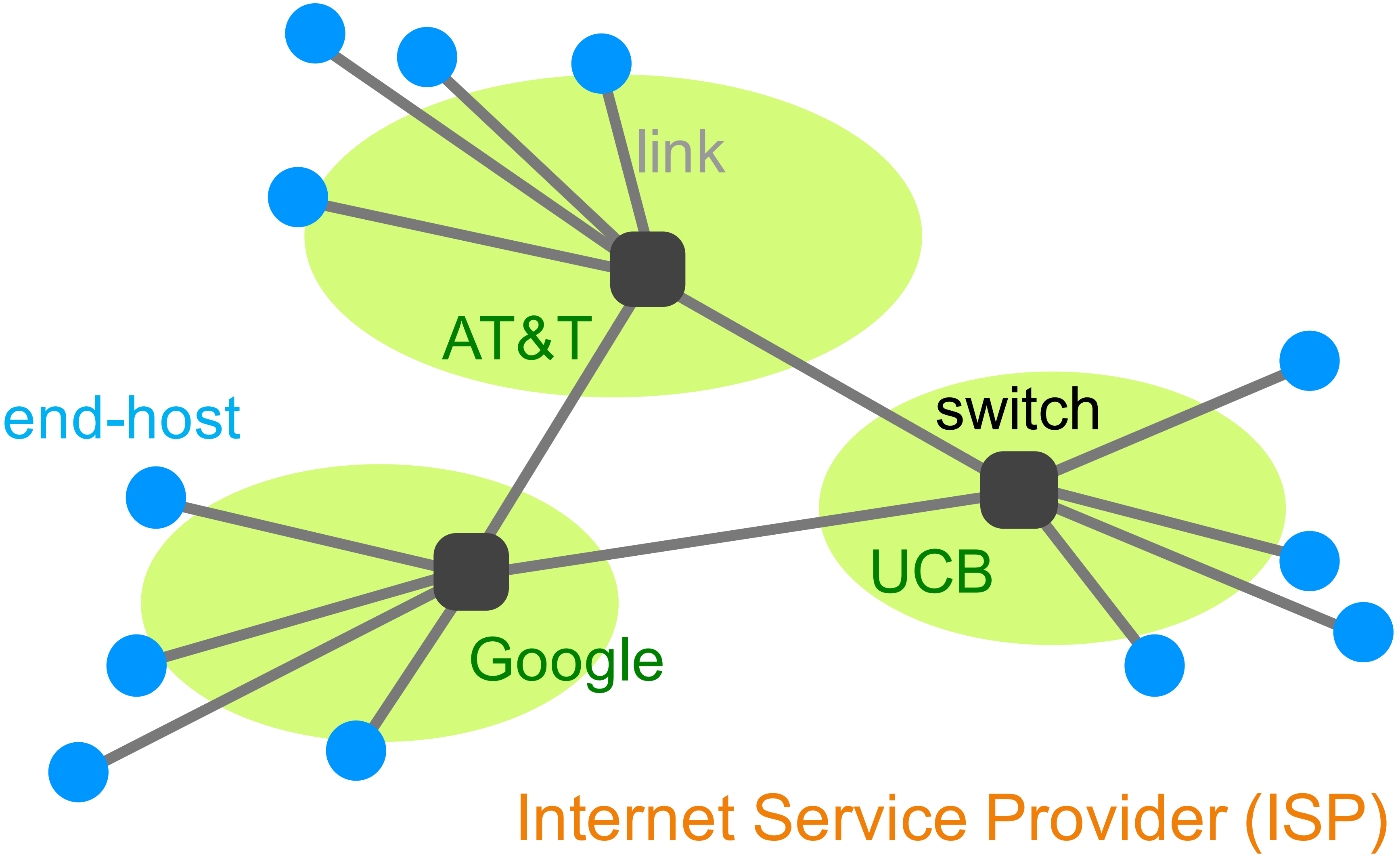
Linux server

MAC laptop

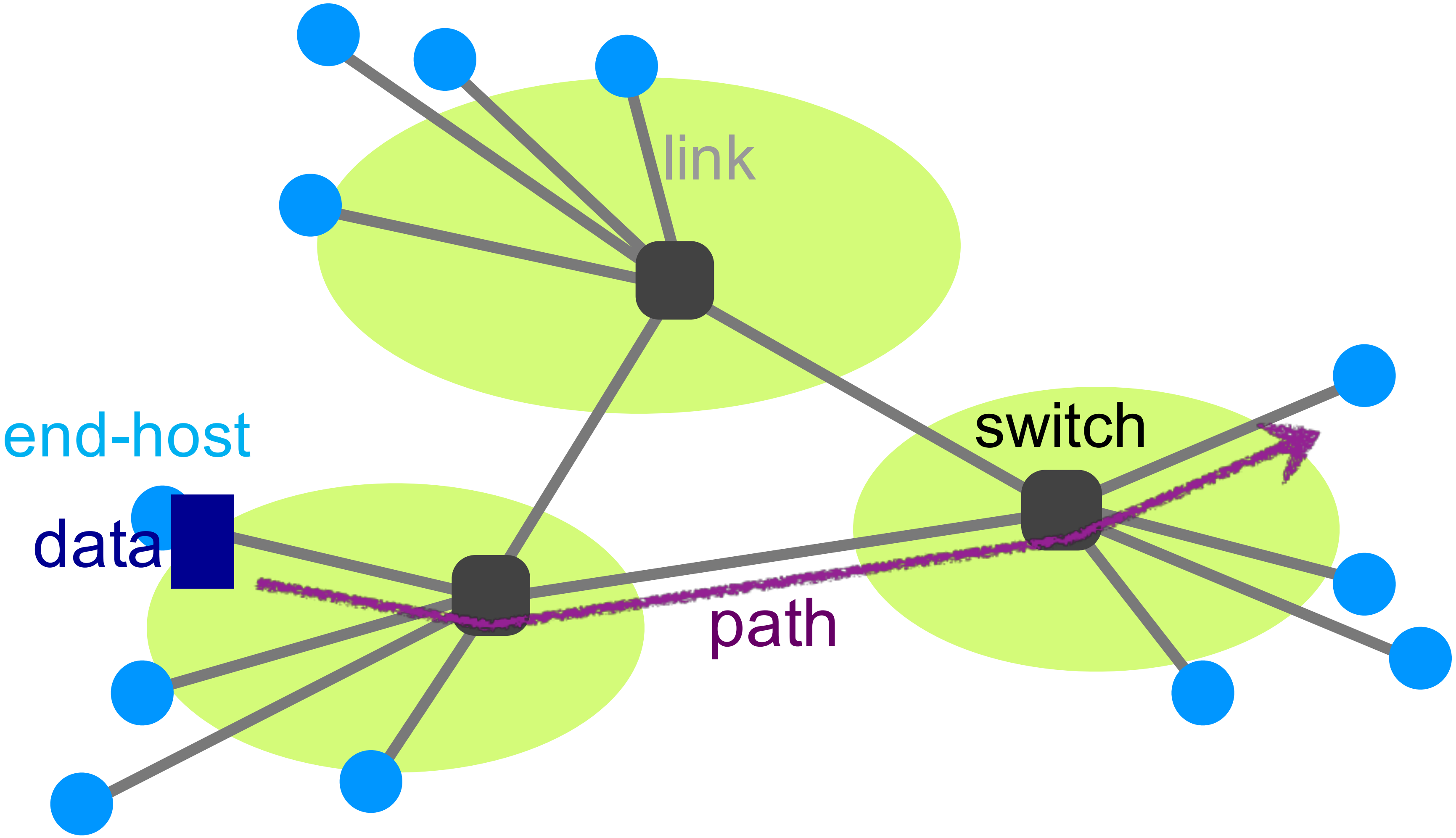
Windows PC


end-host
switch


link
phone lines
end-host
switch
wireless
fiber
cable


link
AT&T
end-host
switch
UCB
Google
Internet Service Provider (ISP)

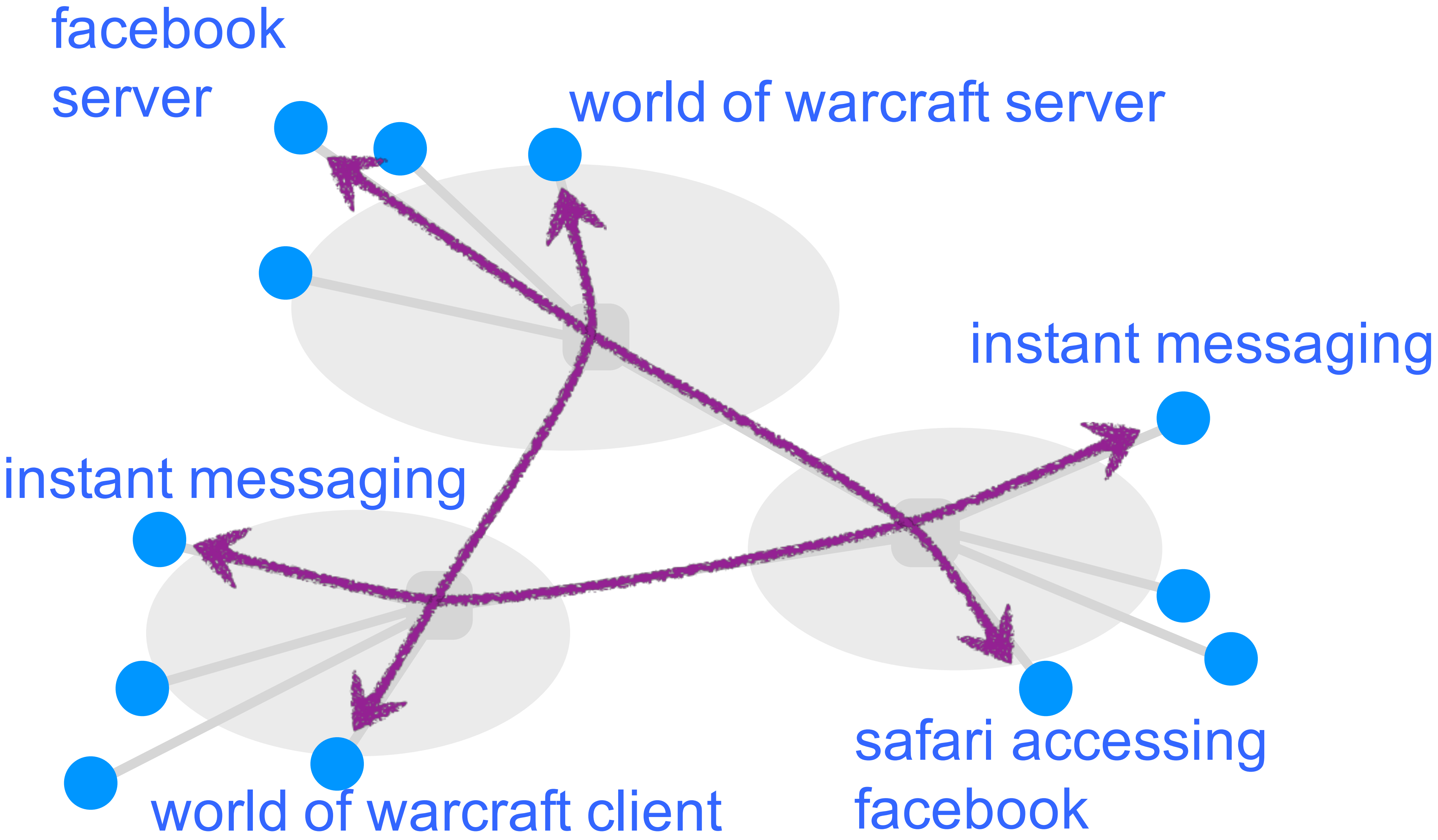
The Internet transfers data between end hosts

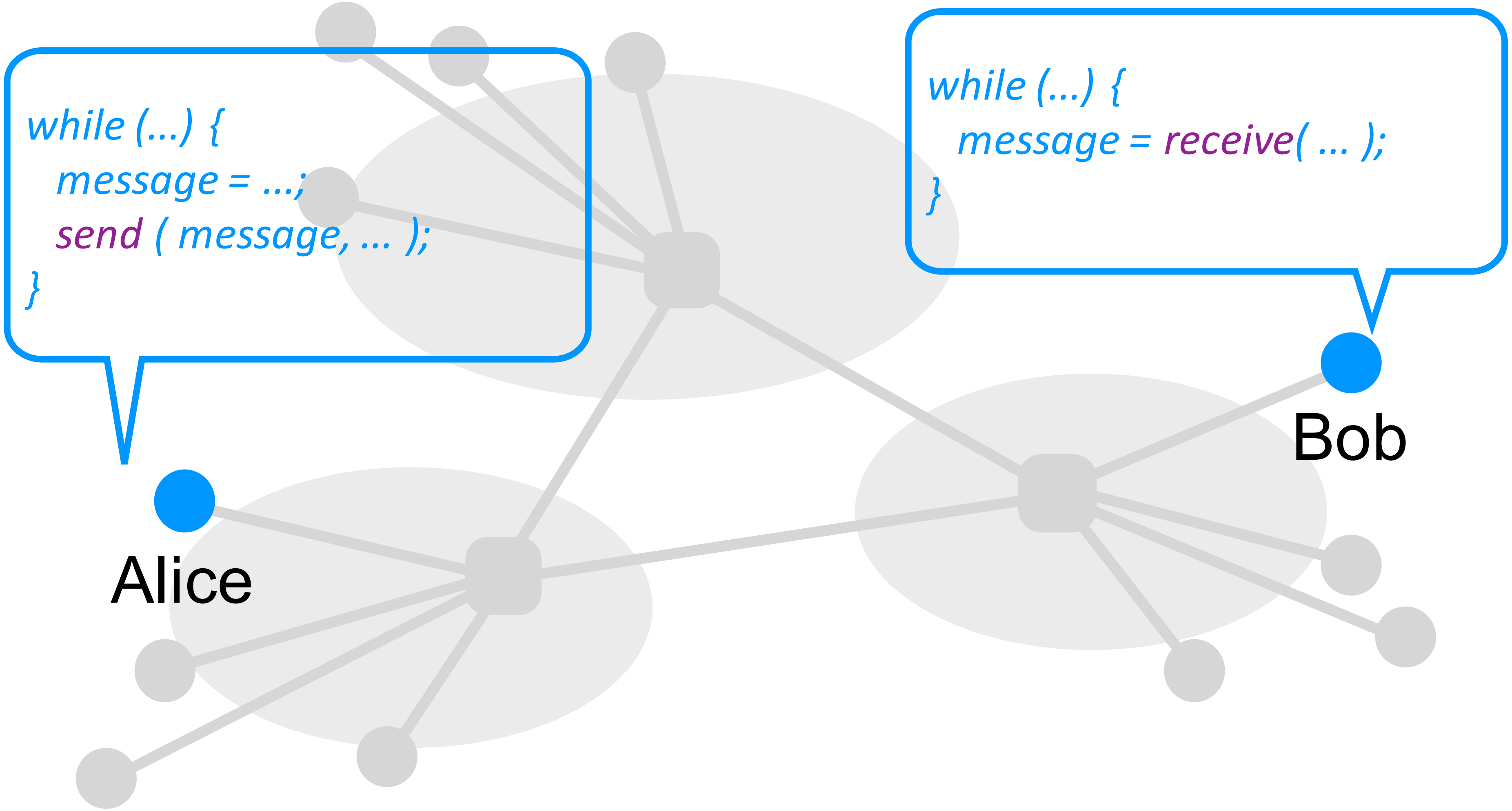


- **Internet**

- **Protocols**

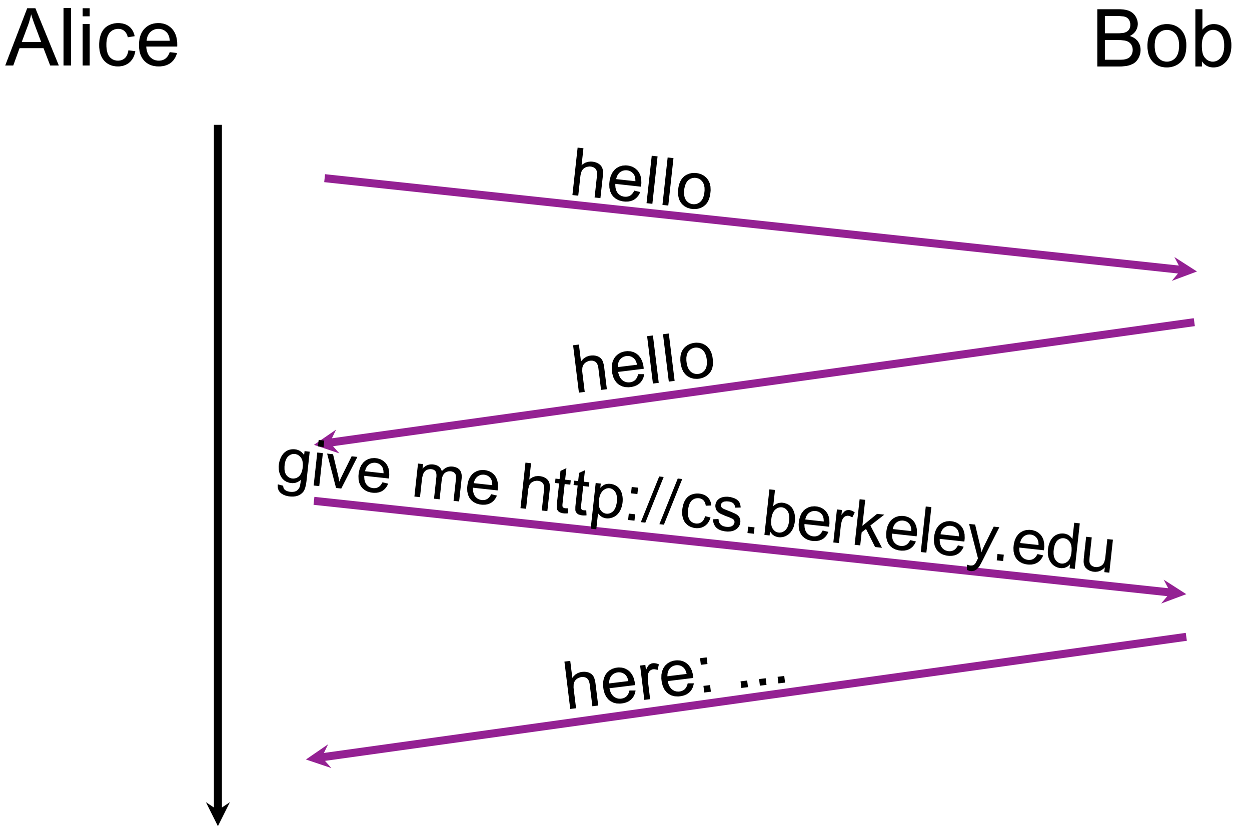
- **Architecture**

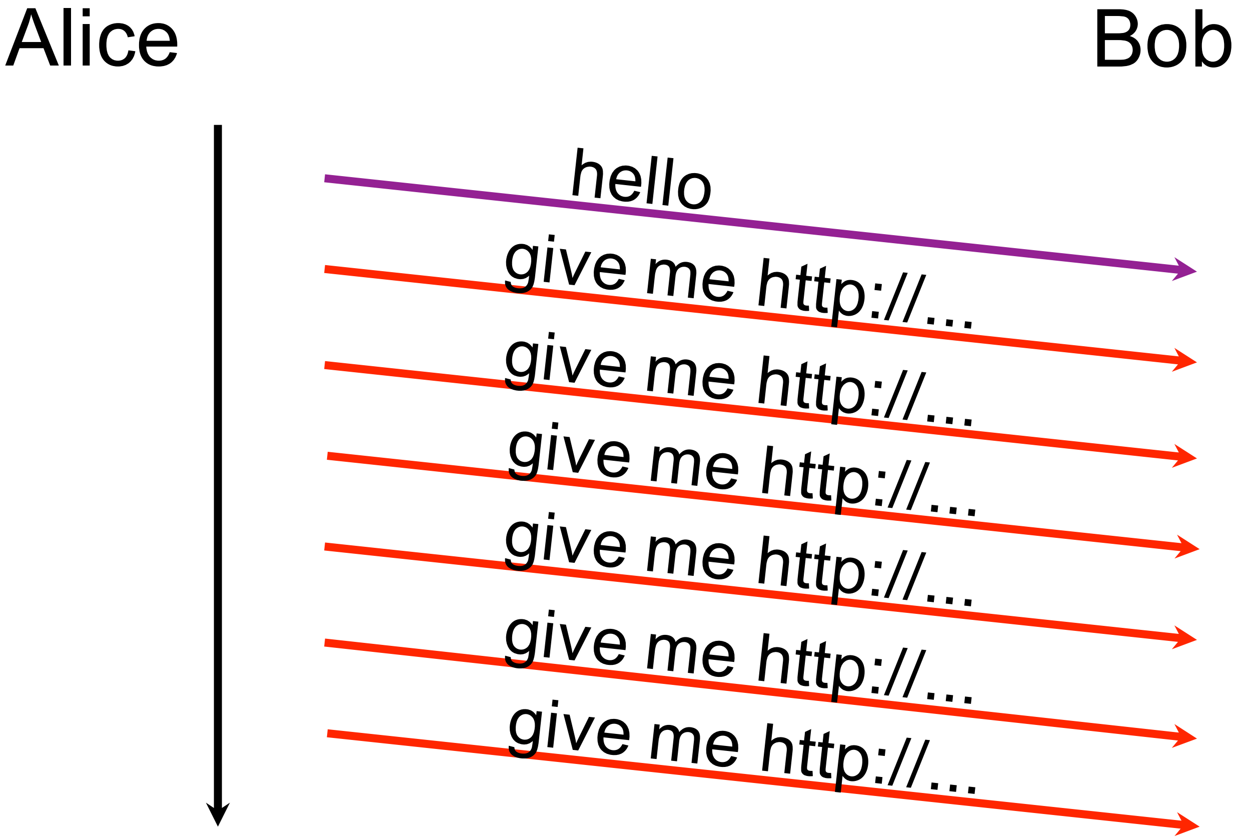

facebook
server
world of warcraft server
instant messaging
instant messaging
safari accessing
facebook
world of warcraft client



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

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


Alice
Bob
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

- 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**

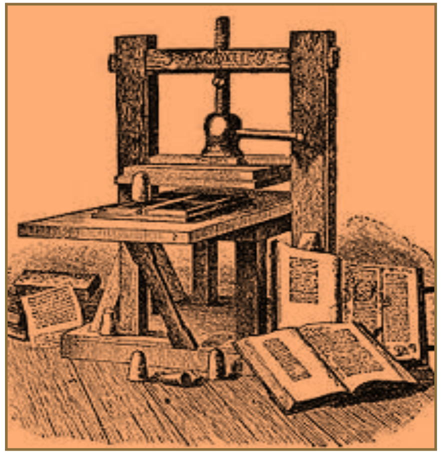
- **Protocols**

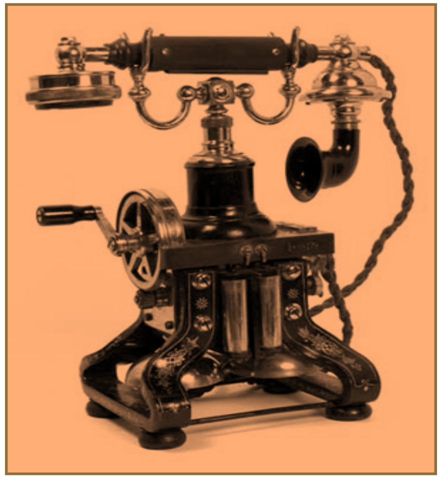
- **Architecture**

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





nat'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*?

It's just another network – communication theory folks

What's with all these TLA protocols?– everyone

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

A few defining characteristics of the Internet…

Network versus “The Internet”

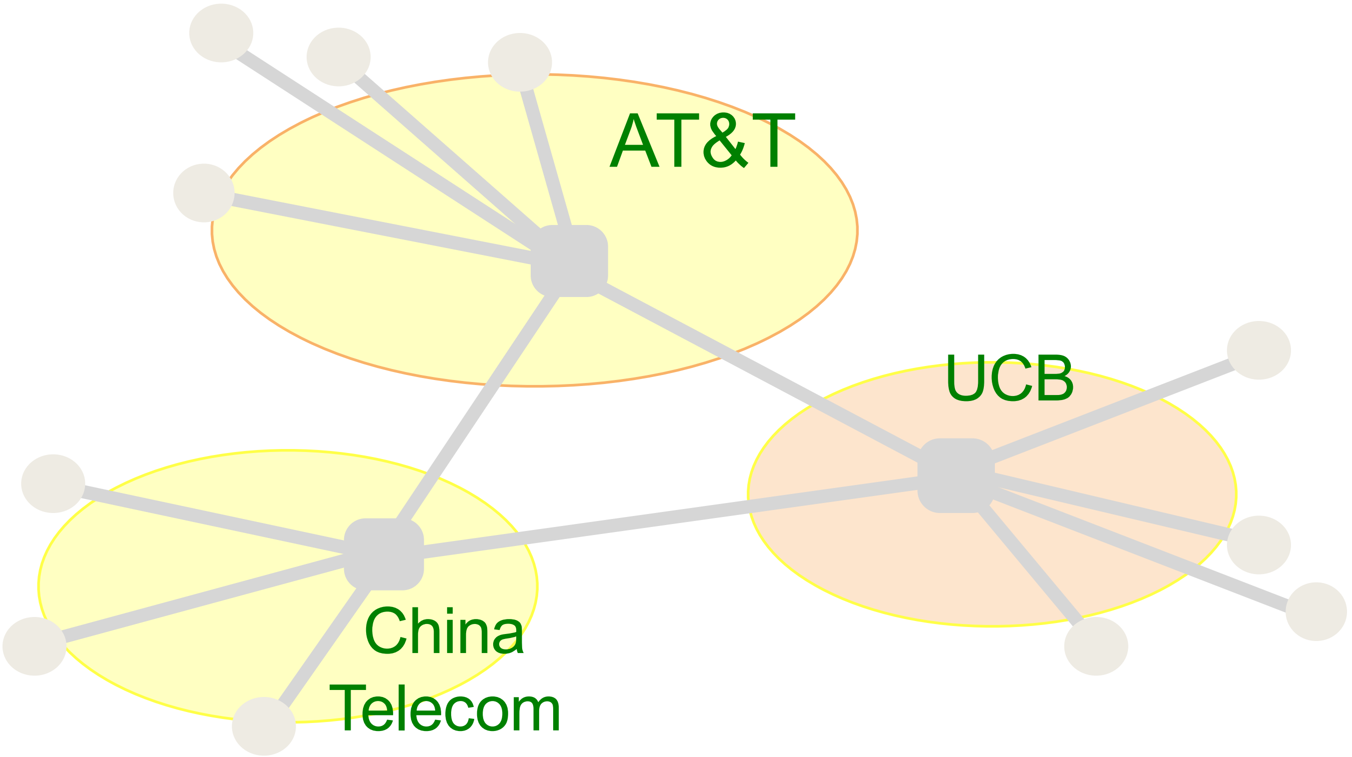
- **There are many kinds of network technologies (switches and links)**
  - Ethernet, optical, wifi access points, DSL modems, Infiniband switches, …

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

Tremendous scale

- 3.8 Billion users (51% of world population)
- 1.24 Trillion unique URLs (web pages)
- Every second, we generate ~ 6000 tweets, 40,000 Google queries, 2M 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 endpoints)
- 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)
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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?**
- 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**

Enrollment and wait list

- **Class size will not increase**

- **Wait-listed students will be admitted as and when registered students drop the class**
  - I do not process the waitlist, so please do not ask me whether/when you'll get off the waitlist
  - If you're planning to drop, please do so soon!

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

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

- **Classroom instructors:** Sylvia Ratnasamy and Murphy McCauley

Instructor: James (Murphy) McCaul

- **Background:**
  - PhD student; soon joining the faculty at Mt. Holyoke College
  - Research contributions on a range of networking topics
  - Built one of the first SDN controllers!
  - Teaching experience: CS168, CS194, CS61c
- Will lecture on select topics and oversee projects

Instructor: Sylvia Ratnasamy

- **Academic background**
  - PhD from UC Berkeley
  - Worked in industry ~10 years
  - Returned to UCB to join the faculty in 2011
  - Co-founded a startup (Nefeli Networks) in 2016
  - 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!

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

- **Classroom instructors:** Sylvia Ratnasamy and Murphy McCauley

- **Head TA**
  - Michael Alan Chang

- **Project leads**
  - Lloyd Brown
  - Jichan Chung
  - Zhihong Luo

- **Section TAs**
  - Huilin Chen
  - Rafael Felix
  - Silvery Fu
  - Ilian Herzi
  - Tian Qin
  - Ian Rodney
  - Eyal Sela
  - Kevin Svetlitski
  - Vasu Vikram
  - Shriya Vohra
  - James Zhu

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**
  - Survey posted on piazza

Special weekly LOST meeting

- **Leaders: Ian Rodney and Eyal Sela**
    - Time/Place: 1:00-2:00pm in Soda 420

- A safe space if you have lost contact with class
    - A chance to reconnect, and then catch up

- If you are confused about details, ask in section/OH

- If you have no idea what I'm talking about: go to LOST!

- Not a substitute for attending a normal section

Class workload

1. **Two projects (due in ~3 weeks)**
   - One on routing, one on transport protocol design
   - Goal is to learn networking, not programming
   - No partners

2. **Self-tests after class**

3. **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%
Midterm exam	25%
Final exam	30%

Self-tests

- Self-test quiz posted on bcourses 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 identify what topics need explanation
    - And help you identify if you are confused or lost
- 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
  - 1 sheet for midterm, 2 sheets for final
- **Midterm**: March 12, in class during normal lecture hours (11:00am-12:29pm)
  - There will be no alternate time!
- **Final**: May 14, 8-11am
- **Alternate final:** May 14, 11:30am-2:30pm (location TBA)
  - *Must have permission from me to take the alternate final (respond to Piazza form)*
- Other arrangements must be discussed with me
  - Will be *after* normal final but please wait to arrange

Lectures and participation

- Class will be webcast but attendance is **highly** recommended
  - I will make my slides available online a few minutes before class

- 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 Piazza during lecture

- If you have a quick question and don’t want to ask me, then ask on Piazza
  in 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 Gradescope to hand in assignments
- Class recordings available under the “Course Capture” tab on bcourses
- Use Piazza for all other intra-class communication
- Copy Michael Chang on any emails sent directly to me or Murphy.

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
  - Datacenter networks
  - (A little bit on) wireless, advanced network functions, security

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…

- Make sure you are on piazza

- If you plan to drop, please do so ASAP

- LOST section starts this week (January 24)

- Discussion sections will start on January 27