Systems in 60 Minutes

Raymond Xu
raymondxu.io

Roadmap for this talk

What happens when you visit google.com?

- Horizontally
- Vertically

Roadmap for this talk

What happens when you visit google.com?

- Horizontally
- Vertically

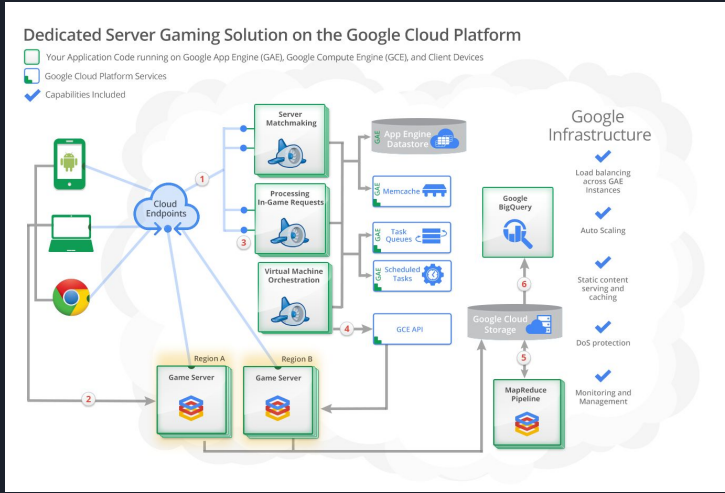
What’s the best way to learn new systems?

Roadmap for this talk

What happens when you visit google.com?

- Horizontally
- Vertically

What's the best way to learn new systems?



Source: Google Cloud Platform Solutions

Roadmap for this talk

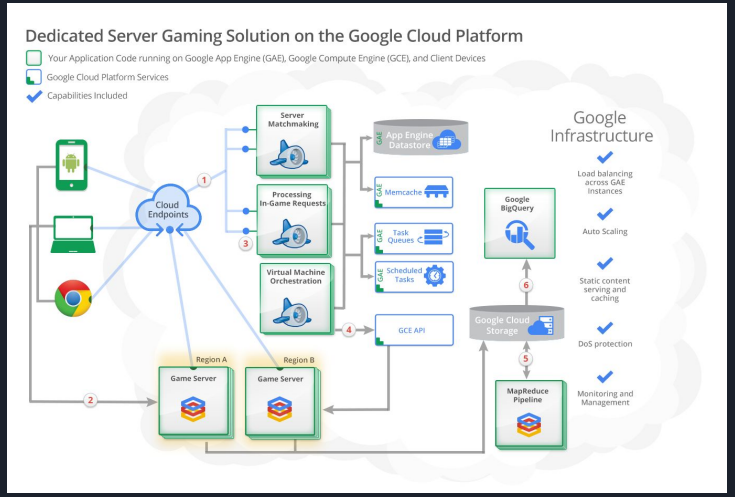
What happens when you visit google.com?

- Horizontally
- Vertically

What's the best way to learn new systems?

"Envoy is a high performance C++ distributed proxy designed for single services and applications, as well as a communication bus and "universal data plane" designed for large microservice "service mesh" architectures."

https://www.envoyproxy.io/



Source: Google Cloud Platform Solutions

Roadmap for this talk

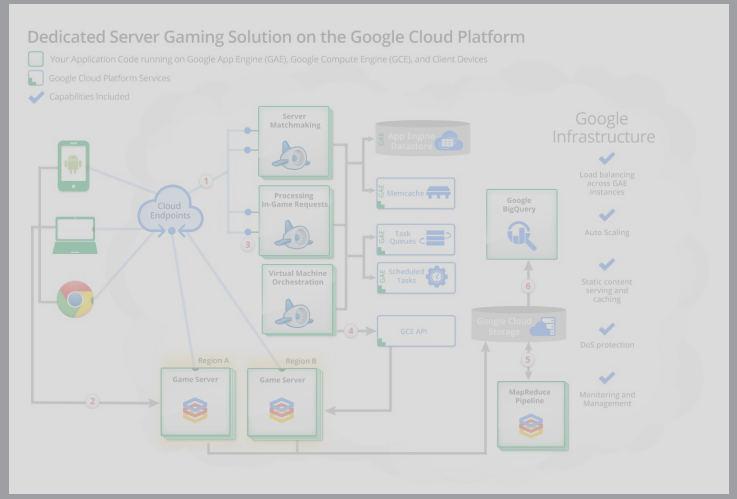
What happens when you visit google.com?

- Horizontally
- Vertically

What's the best way to learn new systems?

"Envoy is a high performance C++ distributed proxy designed for single services and applications, as well as a communication bus and "universal data plane" designed for large microservice "service mesh" architectures."

https://www.envoyproxy.io/

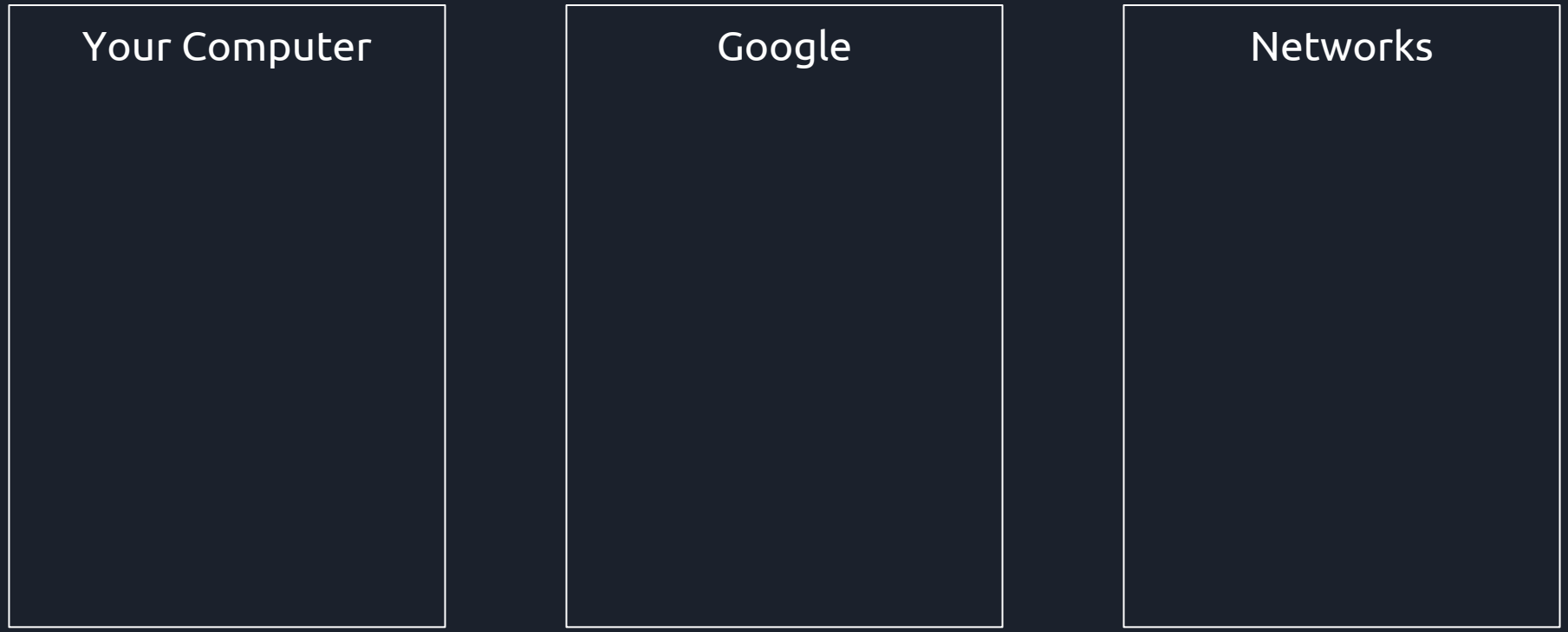


Source: Google Cloud Platform Solutions

Horizontal

Your Computer → Networks → Google → Networks → Your Computer

Vertical



Vertical

Your Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Networks

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Networks

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

- Applications
- Operating System
- Hardware
- Physics

Networks

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Computer

Networks

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Computer

x 1,000,000

Networks

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Computer

x 1,000,000

+ Distributed Systems

Networks

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Computer

x 1,000,000

+ Distributed Systems

Networks

- Protocols
- Infrastructure
- Physics

Computers store and manipulate data.

Networks transfer data.

Computers store and manipulate data.

Networks transfer data.

Data

Data can be anything

- Text
- Images
- Videos

All data can be represented one-dimensionally with 1s and 0s (bits)

How do you interpret a sequence of bits?

- Character encodings

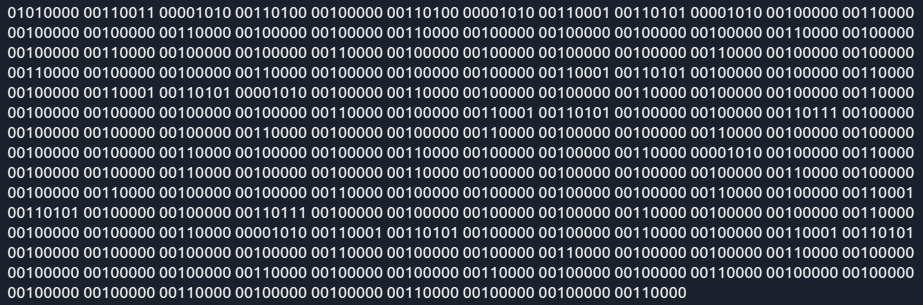
Data

PPM example (a simple image file format)

01010000 00110011 00001010 00110100 00100000 00110100 00001010 00110001 00110101 00001010 00100000 00110000
00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00100000 00100000 00110000 00100000
00100000 00110000 00100000 00100000 00110000 00100000 00100000 00100000 00100000 00110000 00100000 00100000
00110000 00100000 00100000 00110000 00100000 00100000 00100000 00110001 00110101 00100000 00100000 00110000
00100000 00110001 00110101 00001010 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00110000
00100000 00100000 00100000 00100000 00110000 00100000 00110001 00110101 00100000 00100000 00110111 00100000
00100000 00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000
00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00110000 00001010 00100000 00110000
00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00100000 00110000 00100000 00100000
00100000 00110000 00100000 00100000 00110000 00100000 00100000 00100000 00100000 00110000 00100000 00110001
00110101 00100000 00100000 00110111 00100000 00100000 00100000 00100000 00110000 00100000 00100000 00110000
00100000 00100000 00110000 00001010 00110001 00110101 00100000 00100000 00110000 00100000 00110001 00110101
00100000 00100000 00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00110000 00100000
00100000 00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000
00100000 00100000 00110000 00100000 00100000 00110000 00100000 00100000 00110000

Data

PPM example (a simple image file format)



ASCII Character encoding...

Data

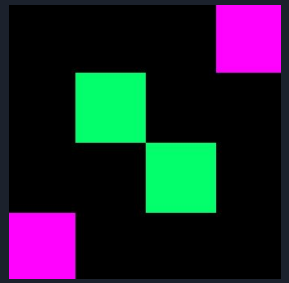
PPM example (a simple image file format)

```
P3
4 4
15
 0  0  0    0  0  0    0  0  0   15  0 15
 0  0  0    0 15  7    0  0  0    0  0  0
 0  0  0    0  0  0    0 15  7    0  0  0
15  0 15    0  0  0    0  0  0    0  0  0
```

Data

PPM example (a simple image file format)

```
P3
4 4
15
 0  0  0    0  0  0    0  0  0   15  0 15
 0  0  0    0 15  7    0  0  0    0  0  0
 0  0  0    0  0  0    0 15  7    0  0  0
15  0 15    0  0  0    0  0  0    0  0  0
```

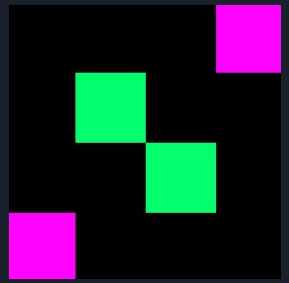


Data

PPM example (a simple image file format)

```
P3
4 4
15
 0  0  0    0  0  0    0  0  0   15  0 15
 0  0  0    0 15  7    0  0  0    0  0  0
 0  0  0    0  0  0    0 15  7    0  0  0
15  0 15    0  0  0    0  0  0    0  0  0
```

File type
Width Height
Maximum color value
R G B ...

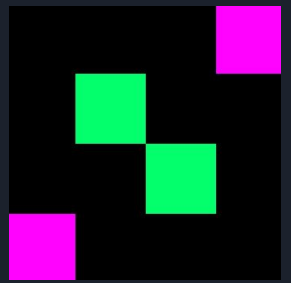


Data

PPM example (a simple image file format)

```
P3
4 4
15
 0  0  0    0  0  0    0  0  0   15  0 15
 0  0  0    0 15  7    0  0  0    0  0  0
 0  0  0    0  0  0    0 15  7    0  0  0
15  0 15    0  0  0    0  0  0    0  0  0
```

File type
Width Height
Maximum color value
R G B ...



Storing Data

Memory

- Voltage through a circuit indicates 1 or 0
- So with enough circuits we can represent arbitrary data
- Power loss = data loss

Storing Data

Hard Drive (Disk)

- Metal can be precisely magnetized/demagnetized
- Direction of magnetism indicates 1 or 0
- Platters can store data
- Does not need to maintain power

Manipulating Data

CPU

- Cleverly arranged circuits can model math
- Take some input state and deterministically produce some meaningful output state
- Defined instructions (code?!) allow us to tell the CPU what to do

ALU, MMU, CPU cache, Microprocessors

Operating System

Software that manages a computer’s hardware and runs programs

Intermediary layer between user and hardware, and applications and hardware

Kernel

- The most important part of an OS
- A program that controls the hardware
  - CPU, Memory, Devices

Kernel mode, Device drivers, Syscalls, Memory management, Multitasking, Scheduling, Interrupts

Applications

Built on top of the operating system API

Written in high level programming languages (typically)

Examples: Microsoft Office, Web Browsers, Compilers, Database Management Systems

Databases

Data stored on disk in a specific structured manner (think file formats)

A Database Management System (DBMS) sits on top of the database and allows other applications to interact with the data

A Primitive Database

```
db_set () {
      echo "$1,$2" >> database
}

db_get () {
      grep "^$1," database | sed -e "s/^$1,//" | tail -n 1
}
```

Source: Martin Kleppmann, Designing Data-Intensive Applications

A Primitive Database

```
db_set () {
      echo "$1,$2" >> database
}

db_get () {
      grep "^$1," database | sed -e "s/^$1,//" | tail -n 1
}
```

```
$ db_set 123 raymondxu.io

$ db_set 456 pokerchips.io

$ db_get 123
raymondxu.io

$ cat database
123,raymondxu.io
456,pokerchips.io
```

Source: Martin Kleppmann, Designing Data-Intensive Applications

Databases

Real databases use data structures and algorithms for efficiency

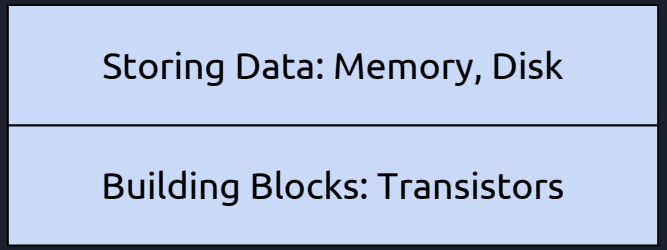
Data modeling is representing the data requirements of an application in a useful and efficient manner

Layering

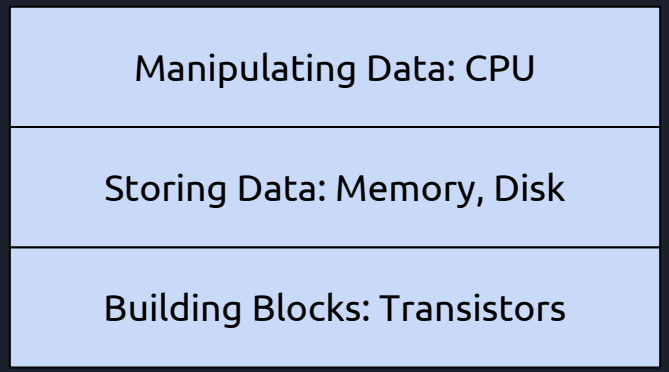
Layering

Building Blocks: Transistors

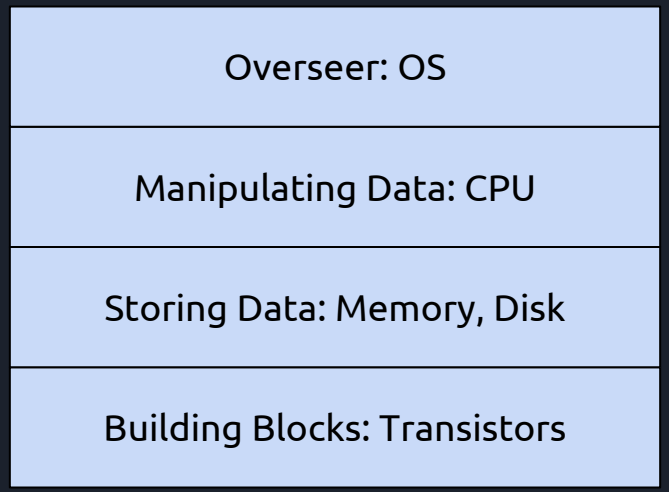
Layering



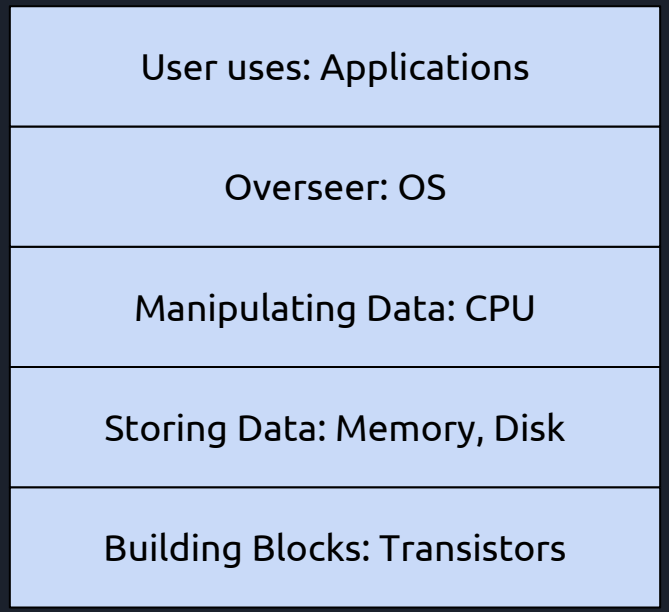
Layering


Manipulating Data: CPU
Storing Data: Memory, Disk
Building Blocks: Transistors

Layering


Overseer: OS
Manipulating Data: CPU
Storing Data: Memory, Disk
Building Blocks: Transistors

Layering


User uses: Applications
Overseer: OS
Manipulating Data: CPU
Storing Data: Memory, Disk
Building Blocks: Transistors

Computers store and manipulate data.

Networks transfer data.

Computers store and manipulate data.

Networks transfer data.

Networks

So we can store and manipulate data within one computer

Networks

So we can store and manipulate data within one computer

How do we transfer data between computers?

Networks

So we can store and manipulate data within one computer

How do we transfer data between computers?

- First let’s prepare the data for transmission...

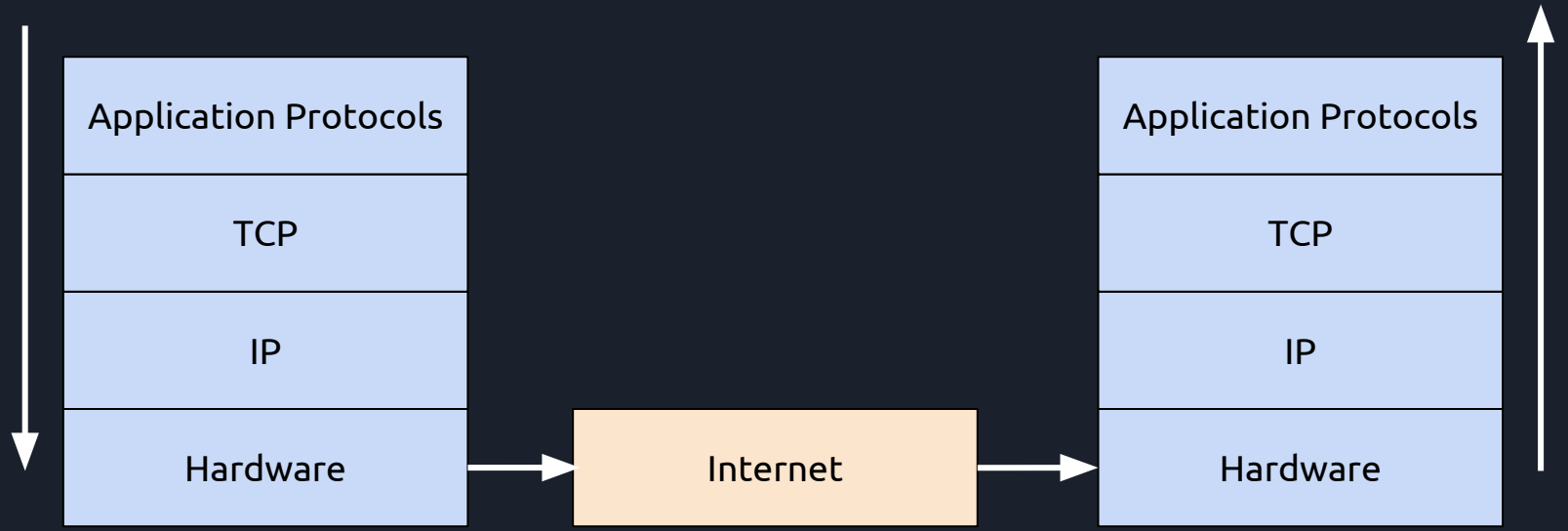
Protocols

Standardized procedures for communication

Can’t just send your raw data into a network

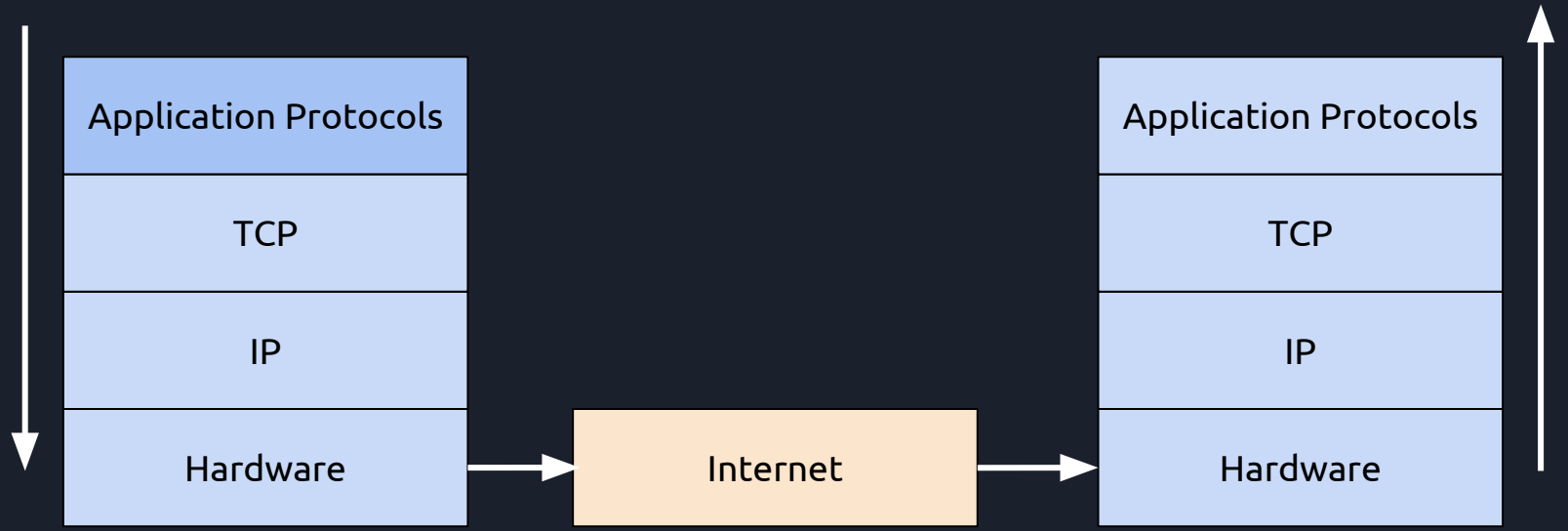
- Where does it go?
- What is the data?
- What if some of the data is lost?
- How do you know it was sent?

Protocol Stack



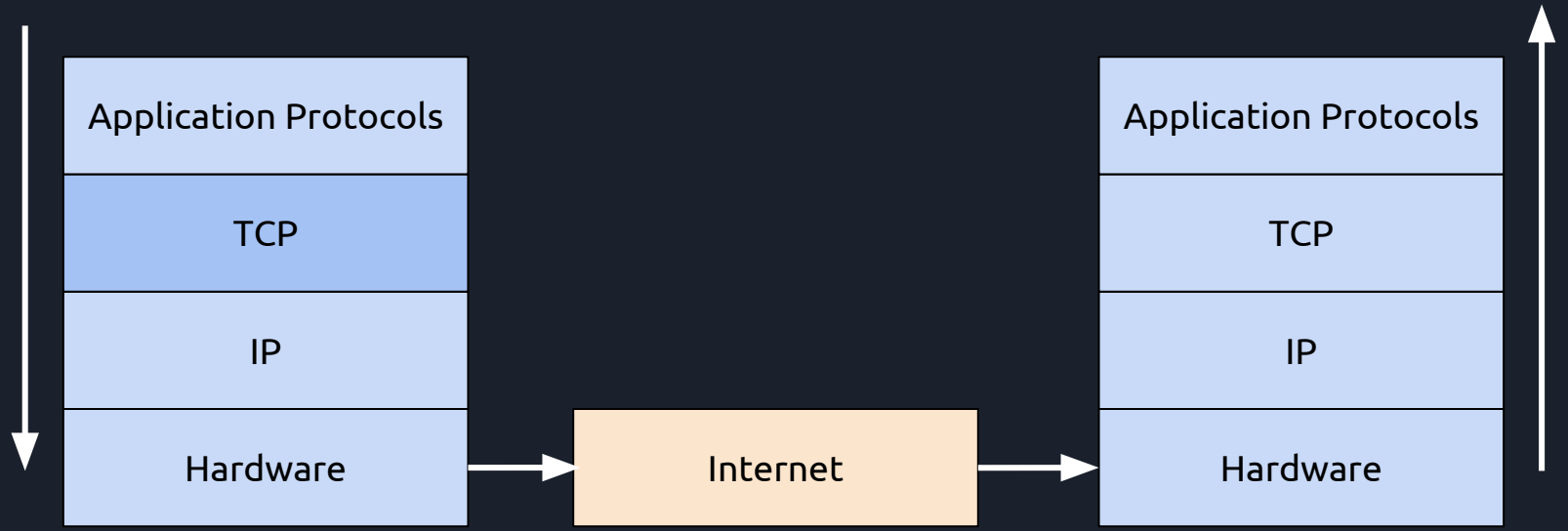
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



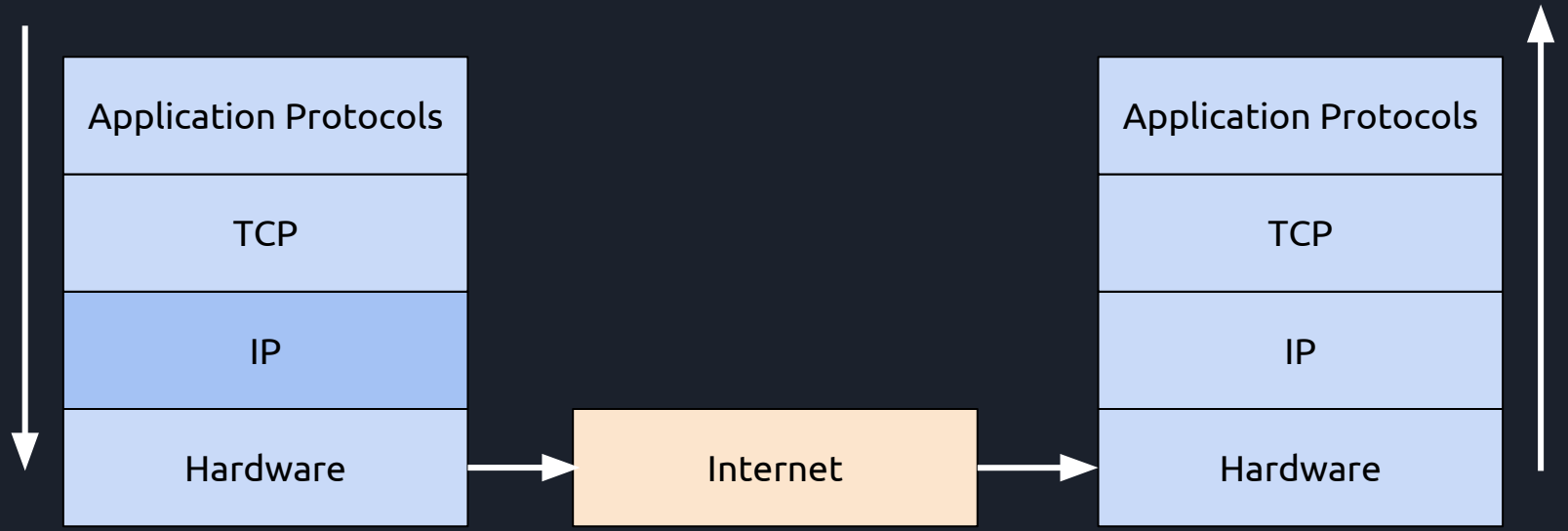
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



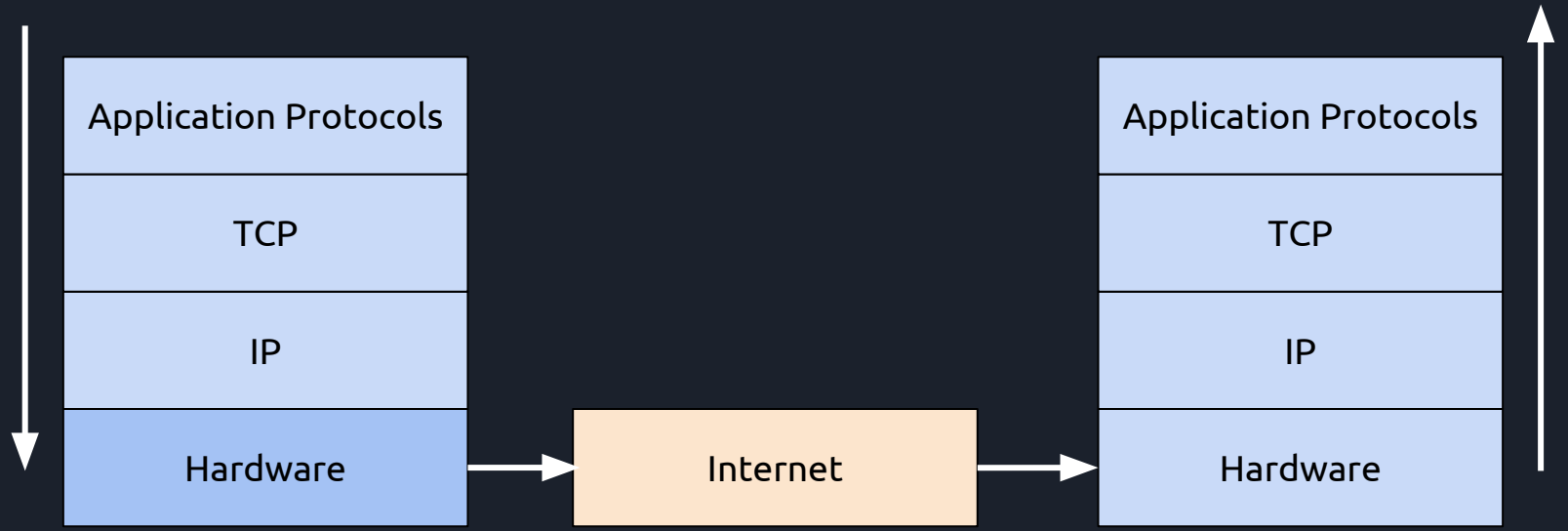
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



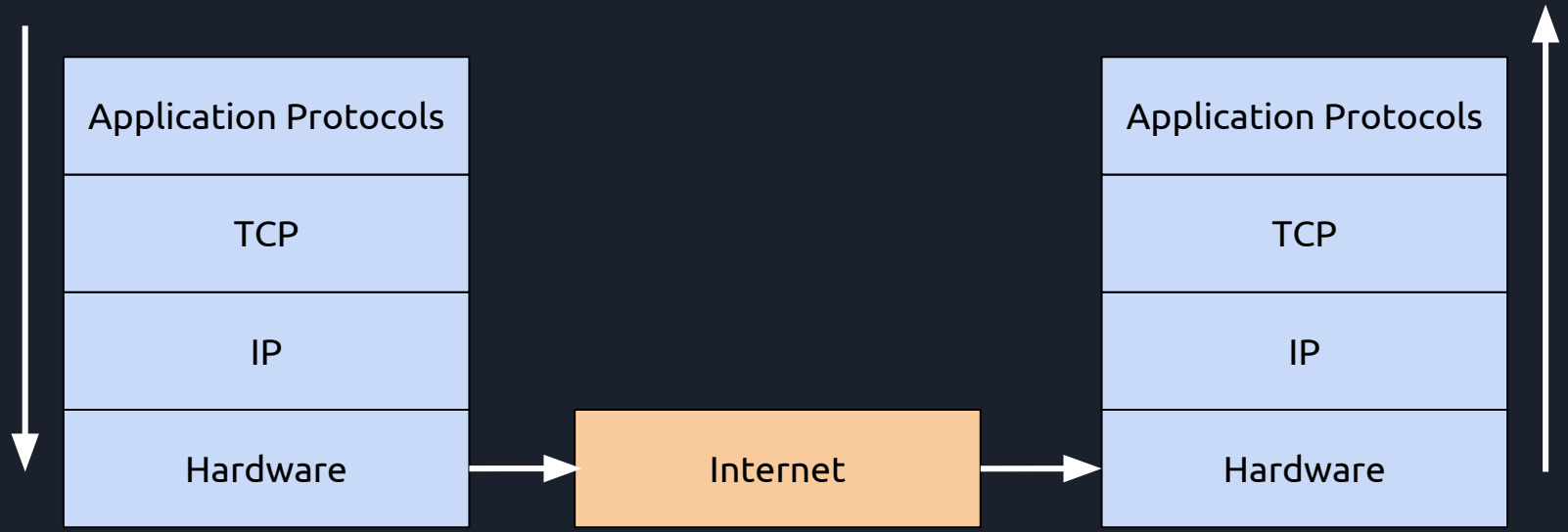
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



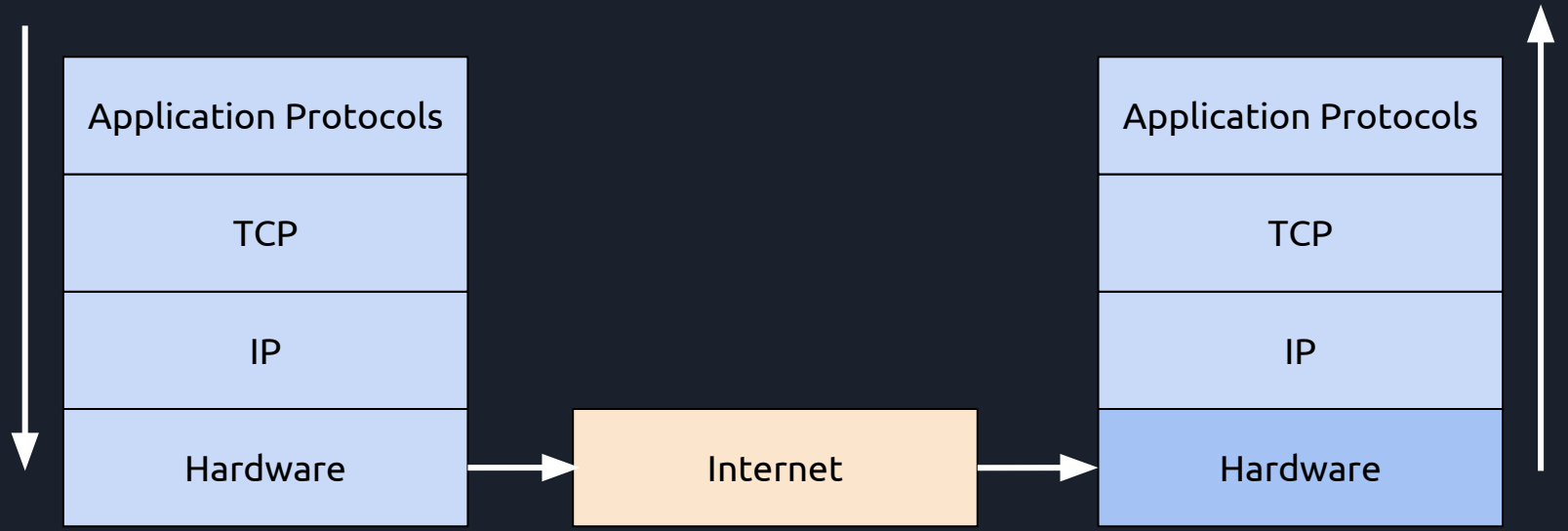
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



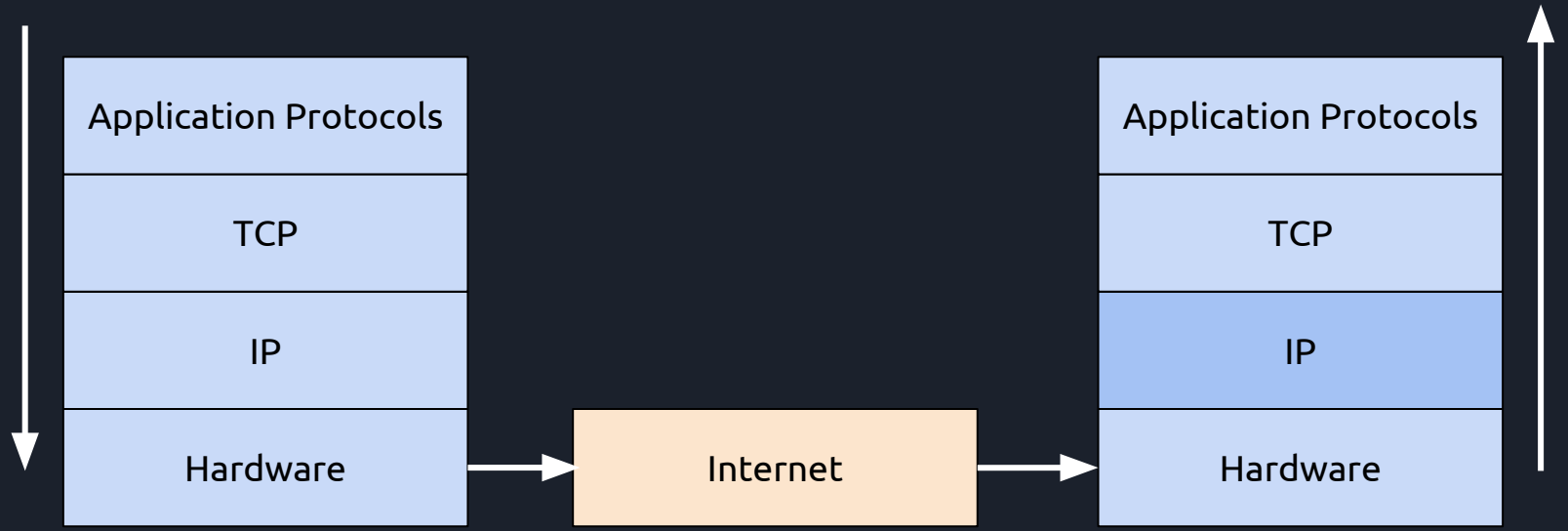
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



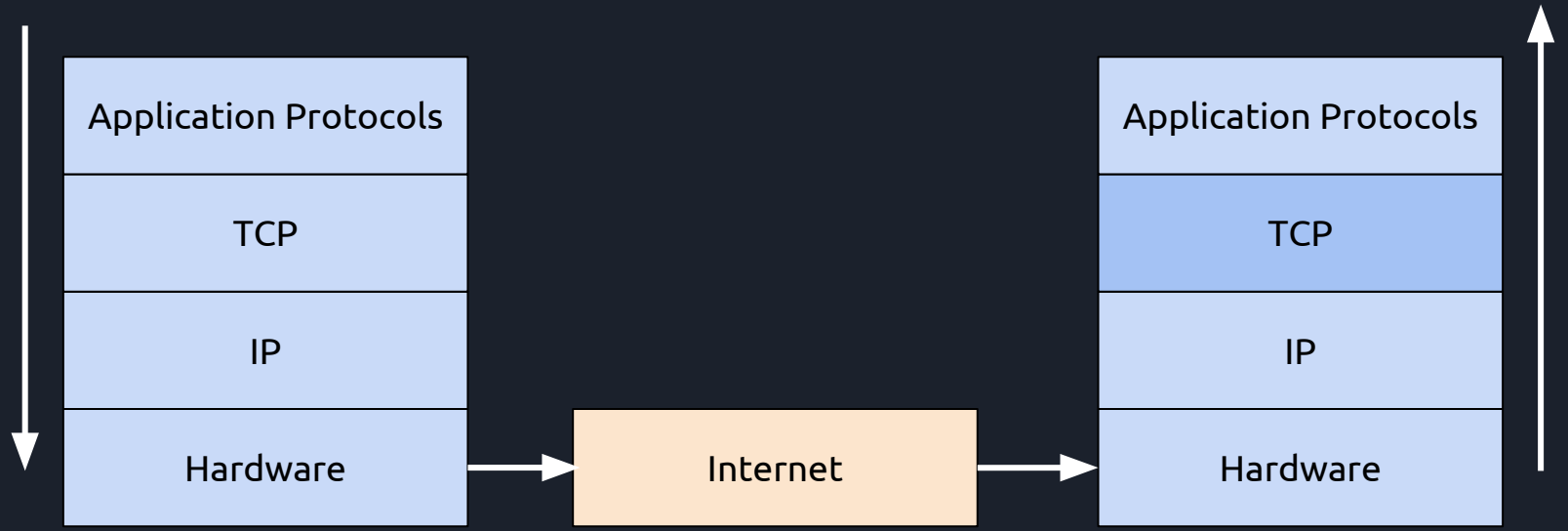
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



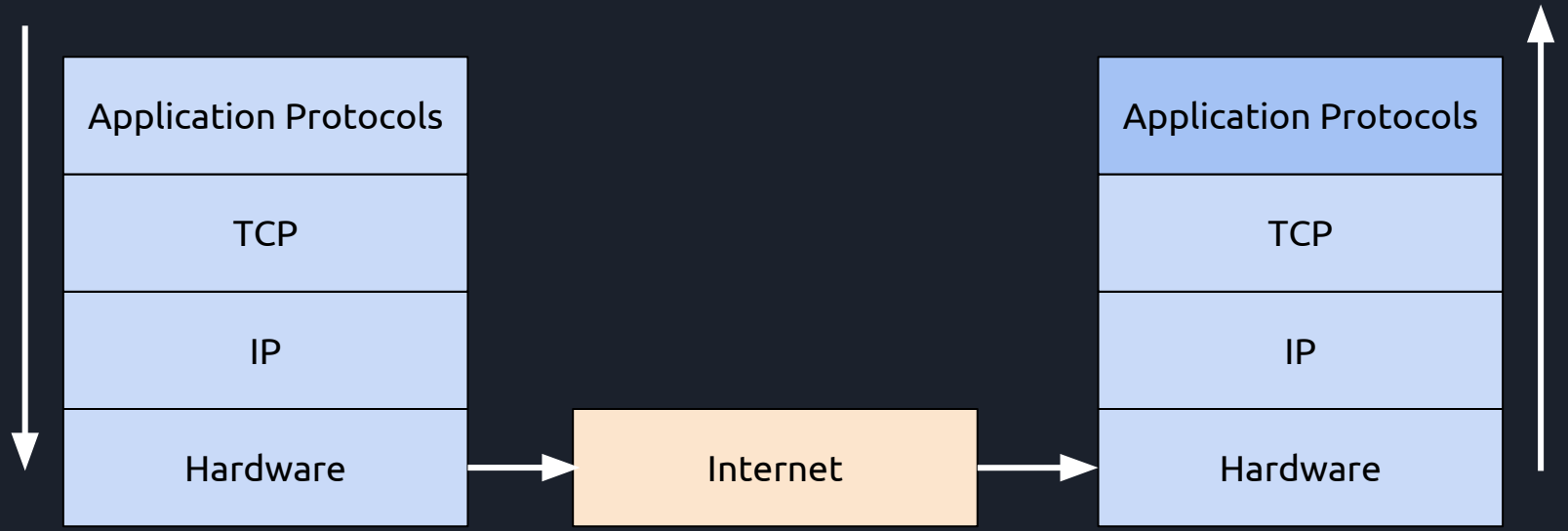
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



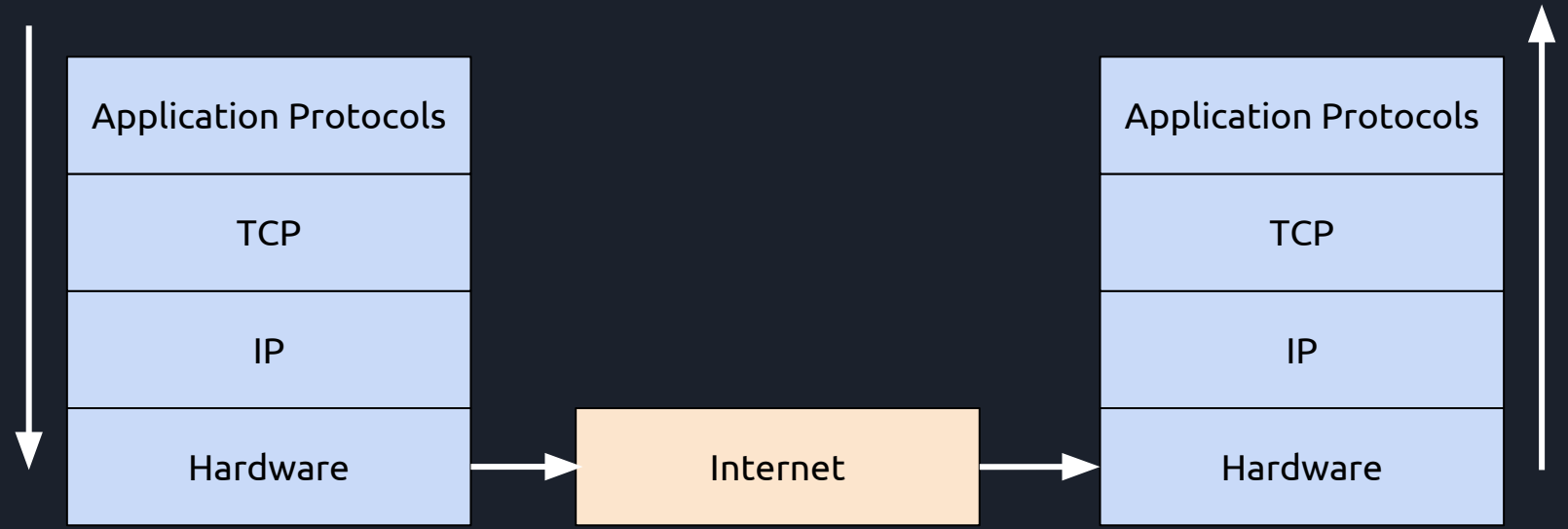
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



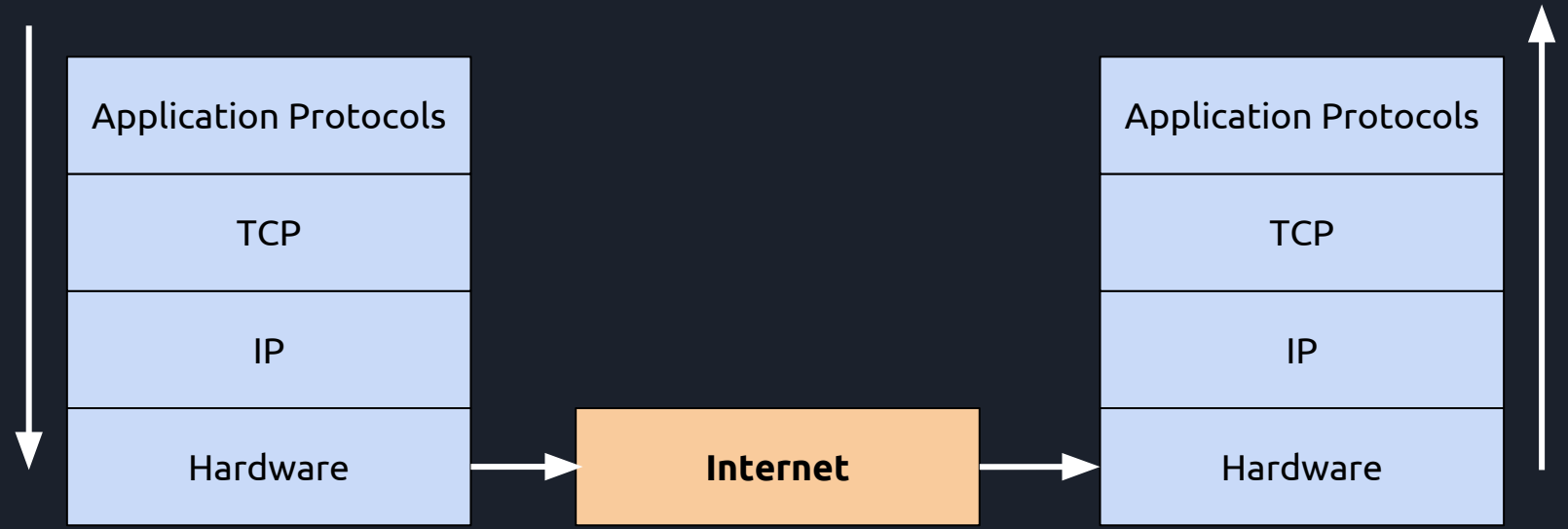
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

Protocol Stack



Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm


Internet

Internet

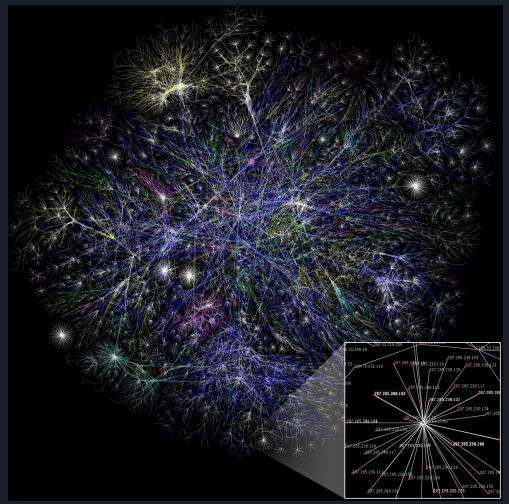
So we have prepared our data for transmission and can accept transmitted data

What’s inside the “Internet” box?

Internet Backbone

A core web of fiber optic cables

- Light transmission



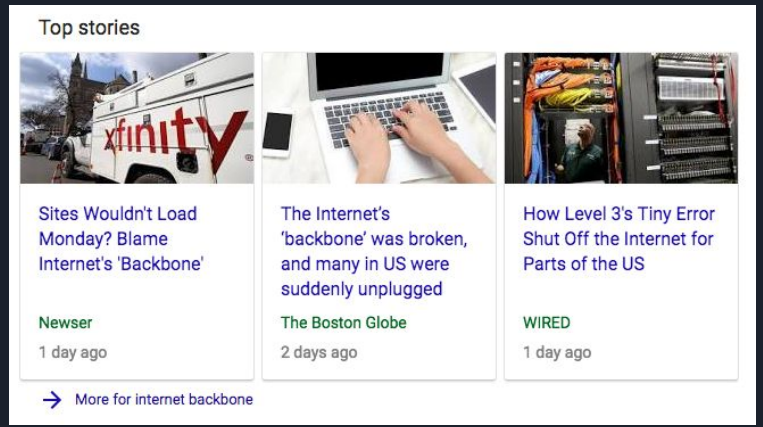
Source: https://en.wikipedia.org/wiki/Internet_backbone

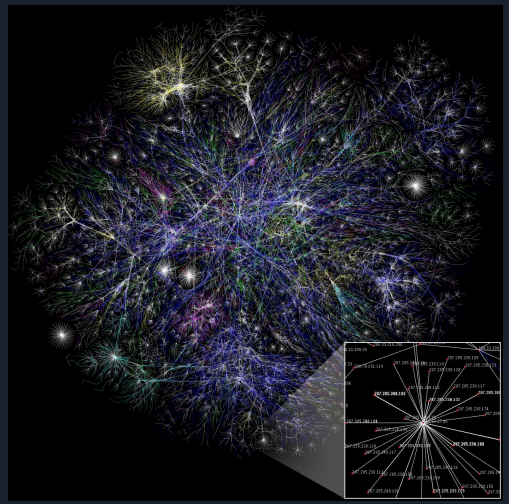
ISPs, NAPs

Internet Backbone

A core web of fiber optic cables

- Light transmission





Source: https://en.wikipedia.org/wiki/Internet_backbone

ISPs, NAPs

Routers

Routers are devices that forwards data packets

Routing tables make sure we get to the destination IP address

- Another protocol

Physical and wireless transmission

- WiFi uses radio signals (electromagnetic wave modulation)

Routers

Routers are devices that forwards data packets

Routing tables make sure we get to the destination IP address

- Another protocol

Physical and wireless transmission

- WiFi uses radio signals (electromagnetic wave modulation)

Routers use IP addresses — what’s the IP for google.com?

Domain Name System (DNS)

Converts web URLs into IP addresses

Distributed database that tracks names and IP addresses

Domain Name System (DNS)

Converts web URLs into IP addresses

Distributed database that tracks names and IP addresses

```
$ host google.com

google.com has address 172.217.6.238
google.com has IPv6 address 2607:f8b0:4006:805::200e
google.com mail is handled by 40 alt3.aspmx.l.google.com.
google.com mail is handled by 30 alt2.aspmx.l.google.com.
google.com mail is handled by 50 alt4.aspmx.l.google.com.
google.com mail is handled by 10 aspmx.l.google.com.
google.com mail is handled by 20 alt1.aspmx.l.google.com.
```

Authoritative name servers, DNS caching, Domain name registration

Vertical

Computer

- Applications
- Operating System
- Hardware
- Physics

Google

Computer

x 1,000,000

+ Distributed Systems

Networks

- Protocols
- Infrastructure
- Physics

Key Takeaways

1. Computers store and manipulate data. Networks transfer data.

Key Takeaways

1. Computers store and manipulate data. Networks transfer data.
2. All data is bits. Bits are electricity.

Key Takeaways

1. Computers store and manipulate data. Networks transfer data.
2. All data is bits. Bits are electricity.
3. Computing is theoretical. Computers are machines that model computing.

Key Takeaways

1. Computers store and manipulate data. Networks transfer data.
2. All data is bits. Bits are electricity.
3. Computing is theoretical. Computers are machines that model computing.
4. Layering and black boxes reduce the complexity of understanding systems.

Key Takeaways

1. Computers store and manipulate data. Networks transfer data.
2. All data is bits. Bits are electricity.
3. Computing is theoretical. Computers are machines that model computing.
4. Layering and black boxes reduce the complexity of understanding systems.
5. “Systems in 60 Seconds” alliterates better but wouldn’t be as educational.

Resources

What happens when: https://github.com/alex/what-happens-when

How Does the Internet Work?: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

From NAND to Tetris: http://nand2tetris.org/

Systems in 60 Minutes

Raymond Xu
raymondxu.io