CSMC 417

Computer Networks
Prof. Ashok K Agrawala

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General

• Instructor - Ashok K. Agrawala
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• TA – Andrew Pachulski
  – Office Hours –

• Class Meets – Tu Th 9:30 – 10:45 CSIC3117
Prerequisite

• **Required Background**
  – must have 351 and 330 (412 or 430 would be helpful)

• **Expectations**
  – Understand the basics of Computer Architecture
  – Experience in implementing non-trivial systems-type projects
  – Should know
    • Processor
    • Memory
    • Kernel vs. user process
  – Familiar with basic probability
Expectations – After the course

• Understand the fundamentals of networking protocols, including protocol layering, basic medium access including wireless protocols, routing, addressing, congestion control

• Understand the principles behind the Internet protocols and some application layer protocols such as http, ftp, and DNS, and a few peer-to-peer systems/protocols such as Gnutella and Chord.

• Understand some of the limitations of the current Internet and its service model

• Understand the causes behind network congestion, and explain the basic methods for alleviating congestion

• Design, implement, and test substantial parts of network protocols
Announcements

• **Required Work**
  – will require about the same amount of effort as 412
    • 412 a (slightly) harder project to debug
    • 417 project is (by design) more ambiguous

• **Required Texts**
Other Material

• Recommended Texts

• RFCs
Grading

• Final 25%
• In-Term Exam(s) 25%
• Programming Assignments 35%
• Class Participation 15%
  – Pop Quizzes
  – ...

Fall 2018
POP Quizzes

• Unannounced
• Frequent
• In the **beginning** of the class
  – If you come late you miss
  – Missing pop quizzes **will** impact your grade
• Mostly question(s) from the book
What is this course all about?

- Computer Networking
  - ???

![Diagram showing computer network with users, computers, and internet connection]
Block Diagram of Typical Laptop/desktop

Motherboard (~1998)

Backplane (~1998)

Some CPU chips

Are these the only computers?

We use a large number and variety of devices with computing capabilities

- Laptops
- Pads
- Smart phones
- Wearables
  - Watches
- Cars
- Appliances
- Speakers
- Light bulbs
- Locks
- Webcams
- Internet of Things (IoT)
What about Cloud?
DIGITAL AROUND THE WORLD IN 2018

KEY STATISTICAL INDICATORS FOR THE WORLD’S INTERNET, MOBILE, AND SOCIAL MEDIA USERS

TOTAL POPULATION 7.593 BILLION
INTERNET USERS 4.021 BILLION
ACTIVE SOCIAL MEDIA USERS 3.196 BILLION
UNIQUE MOBILE USERS 5.135 BILLION
ACTIVE MOBILE SOCIAL USERS 2.958 BILLION

URBANISATION: 55%
PENETRATION: 53%
PENETRATION: 42%
PENETRATION: 68%
PENETRATION: 39%

SOURCES: POPULATION: UNITED NATIONS; U.S. CENSUS BUREAU; INTERNET: INTERNET WORLDSTAT; ITU; EUROSTAT; INTERNET DEVELOPMENT STATISTICS; CIA WORLD FACTBOOK; MID EAST MEDIA ORC; FACEBOOK; GOVERNMENT OFFICIALS; REGULATORY AUTHORITIES; REPUTABLE MEDIA; SOCIAL MEDIA; ACTIVE SOCIAL MEDIA: FACEBOOK; TWITTER; VKONTAKTE; YAHOO; NAVER; QING; TECHRASA; SIMILARWEB; KEPIS ANALYSIS; MOBILE: GSMA INTELLIGENCE; GOOGLE; ERICSSON; KEPIS ANALYSIS. NOTE: PENETRATION FIGURES ARE FOR TOTAL POPULATION (ALL AGES).
Internet Statistics 2018

• There are **3.812 billion internet users** as at January 20018;
• Approx 40% of the world population has an internet connection in 2018. It was less than 1% in 1995
• **Asia, as a continent, has the most internet users.** It accounts for 49.7% of global internet users.
• **China, as a country, has the most internet users;** with an estimated 738 million internet users,
• US has 287 million, Russia 110 million.
• North America has the highest penetration rate 88.1% followed by Europe (80.2%) Australia (69.6%)
• **China has the highest percentage of internet users (21.97%),** followed by the U.S. (9.58%) and India (8.33%).
• **Falkland Island and Iceland have the highest penetration with 96.9% and 96.5%**.
• Google processes 6.586 billion searches a day.
• 56% of all internet traffic is from automated sources such as hacking tools, scrapers and spammers, impersonators, and bots.
• 332.4 million domain names are registered by Jan 2018. .Com has 131.9 million and .CN has 21.4 million.

**DEVICE USAGE**

Percentage of the adult population that currently uses each kind of device [survey-based]

- **Mobile Phone (Any Type)**: 95%
- **Smart Phone**: 75%
- **Laptop or Desktop Computer**: 57%
- **Tablet Computer**: 20%
- **Television (Any Kind)**: 97%
- **Device for Streaming Internet Content to TV**: 10%
- **E-Reader Device**: 1%
- **Wearable Tech Device**: 4%

*SOURCES: Google Consumer Barometer, January 2018. Figures based on responses to a survey. *Note*: Data represents adult respondents only. Please see the notes at the end of this report for more information on Google’s methodology and their audience definitions.
INTERNET PENETRATION BY COUNTRY
NATIONAL INTERNET PENETRATION FIGURES

JAN 2017

SOURCES: INTERNET WORLDSTAT, INTERNATIONAL TELECOMMUNICATION UNION (ITU), INTERNETSTOSS, CSW, WORLD BIZ, BDO, ONF, FACEBOOK, NATIONAL REGULATORY AUTHORITIES.
Average Fixed Internet Connection Speeds

Average speed of fixed internet connections by country, in Mbps

- South Korea: 26.3 Mbps
- Hong Kong: 20.1 Mbps
- Singapore: 18.2 Mbps
- United States: 18.0 Mbps
- Norway: 16.3 Mbps
- Sweden: 14.9 Mbps
- Germany: 14.5 Mbps
- Canada: 13.8 Mbps
- Australia: 13.7 Mbps
- France: 11.6 Mbps
- Thailand: 11.7 Mbps
- Poland: 10.7 Mbps
- United Arab Emirates: 8.8 Mbps
- Italy: 8.7 Mbps
- Mexico: 7.5 Mbps
- Turkey: 6.7 Mbps
- Morocco: 6.4 Mbps
- Global: 6.3 Mbps
- Vietnam: 6.0 Mbps
- South Africa: 5.7 Mbps
- India: 5.5 Mbps
- Japan: 5.0 Mbps
- Saudi Arabia: 4.9 Mbps
- Philippines: 4.2 Mbps
- Italia: 4.1 Mbps
- Nigeria: 3.8 Mbps

SOURCES: Akamai State of the Internet Report 1Q 2017
Global Internet Users = Slowing Growth @ +7% vs. +12% Y/Y
Global Internet Users = 3.6B @ >50% of Population (2018)
E-COMMERCE DETAIL: CONSUMER GOODS
AN OVERVIEW OF THE E-COMMERCE MARKET FOR CONSUMER GOODS, WITH VALUES IN UNITED STATES DOLLARS

TOTAL NUMBER OF PEOPLE PURCHASING CONSUMER GOODS VIA E-COMMERCE

1.77 BILLION
YEAR-ON-YEAR CHANGE: +8%

PENETRATION OF CONSUMER GOODS E-COMMERCE (TOTAL POPULATION)

23%

VALUE OF THE CONSUMER GOODS E-COMMERCE MARKET (TOTAL ANNUAL SALES REVENUE)

$1.474 TRILLION
YEAR-ON-YEAR CHANGE: +16%

AVERAGE ANNUAL REVENUE PER USER OF CONSUMER GOODS E-COMMERCE (ARPU)

$833
YEAR-ON-YEAR CHANGE: +7%

SOURCE: STATISTA DIGITAL MARKET OUTLOOK, E-COMMERCE INDUSTRY, ACCESSED JANUARY 2018. NOTES: FIGURES REPRESENT SALES OF PHYSICAL GOODS VIA DIGITAL CHANNELS ON ANY DEVICE TO PRIVATE END USERS, AND DO NOT INCLUDE DIGITAL MEDIA, DIGITAL SERVICES SUCH AS TRAVEL OR SOFTWARE, KG PRODUCTS AND SERVICES, RESALE OF USED GOODS, OR SALES BETWEEN PRIVATE PERSONS (P2P COMMERCE). PENETRATION FIGURE REPRESENTS PERCENTAGE OF TOTAL POPULATION, REGARDLESS OF AGE.
SHARE OF WEB TRAFFIC BY DEVICE

Based on each device's share of all web pages served to web browsers.

**Laptops & Desktops:**
- Share: 41%
- Year-on-year change: -18%

**Mobile Phones:**
- Share: 54%
- Year-on-year change: +21%

**Tablet Devices:**
- Share: 5%
- Year-on-year change: -7%

**Other Devices:**
- Share: 0.14%
- Year-on-year change: +27%

Sources: StatCounter, August 2017.
PERSPECTIVE: MOBILE USERS vs. CONNECTIONS

Comparing the number of unique individuals using mobile phones to the number of mobile subscriptions in use.

**GSMA INTELLIGENCE DATA**

- Total Number of Mobile Users (Unique Individuals): 5.052 Billion
- Total Number of Mobile Connections: 8.228 Billion

**ERICSSON MOBILITY REPORT DATA**

- Total Number of Mobile Users (Unique Individuals): 5.200 Billion
- Total Number of Mobile Connections: 7.600 Billion

Sources: GSMA Intelligence, Q4 2017; Ericsson Mobility Report, June 2017.
MOBILE CONNECTIONS BY DEVICE

BASED ON GLOBAL SMARTPHONE CONNECTIONS COMPARED TO TOTAL GLOBAL MOBILE CONNECTIONS

TOTAL GLOBAL CONNECTIONS (ALL DEVICES)*

8.05 BILLION

CONNECTIONS USED ON SMARTPHONE DEVICES

4.42 BILLION

SHARE OF SMARTPHONE CONNECTIONS vs. TOTAL CONNECTIONS

55%

CONNECTIONS USED ON FEATUREPHONE DEVICES

3.38 BILLION

SHARE OF FEATUREPHONE CONNECTIONS vs. TOTAL CONNECTIONS

42%
GLOBAL MOBILE DATA GROWTH

TOTAL MONTHLY GLOBAL MOBILE DATA TRAFFIC (UPLOAD & DOWNLOAD), IN EXABYTES (BILLIONS OF GIGABYTES)

MONTHLY MOBILE DATA USED BY THE AVERAGE SMARTPHONE WORLDWIDE: 1.9GB
Global New Smartphone Unit Shipments = No Growth @ 0% vs. +2% Y/Y

New Smartphone Unit Shipments vs. Y/Y Growth

Source: Katy Huberty @ Morgan Stanley (3/18), IDC.
Digital Media Usage @ +4% Growth...
5.9 Hours per Day (Not Deduped)

Daily Hours Spent with Digital Media per Adult User

<table>
<thead>
<tr>
<th>Year</th>
<th>Other Connected Devices</th>
<th>Desktop / Laptop</th>
<th>Mobile</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>0.2</td>
<td>2.2</td>
<td>0.3</td>
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<tr>
<td>2009</td>
<td>0.3</td>
<td>2.3</td>
<td>0.3</td>
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<tr>
<td>2010</td>
<td>0.4</td>
<td>2.4</td>
<td>0.3</td>
</tr>
<tr>
<td>2011</td>
<td>0.8</td>
<td>2.6</td>
<td>0.3</td>
</tr>
<tr>
<td>2012</td>
<td>1.6</td>
<td>2.5</td>
<td>0.3</td>
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<tr>
<td>2013</td>
<td>2.3</td>
<td>2.3</td>
<td>0.3</td>
</tr>
<tr>
<td>2014</td>
<td>2.6</td>
<td>2.2</td>
<td>0.3</td>
</tr>
<tr>
<td>2015</td>
<td>2.8</td>
<td>2.2</td>
<td>0.4</td>
</tr>
<tr>
<td>2016</td>
<td>3.1</td>
<td>2.2</td>
<td>0.4</td>
</tr>
<tr>
<td>2017</td>
<td>3.3</td>
<td>2.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Devices = Better / Faster / Cheaper

Apple iPhone

2016
- ‘Portrait’ Photos
- Water Resistant

2017
- Face Tracking
- Full Device Display
- Wireless Charging

Google Android

2016
- Google Assistant
- ‘AI-Assisted’ Photo Editing

2017
- ‘Lens’ Smart Image Recognition
- Always-On Display

New Smartphone Shipments – ASP

Source: Apple, Google, Katy Huberty @ Morgan Stanley, IDC. *ASP Based on Morgan Stanley’s new smartphone shipment breakdown by taking the midpoint of each $50 price band & assuming a $1,250 ASP for smartphones over $1,000. Note: Deloitte estimates that 120MM used smartphones were traded in 2016 and 80MM in 2015 which may further reduce smartphone costs to consumers as the ratio of used to new devices rises. Apple 2016 = iPhone 7 Plus, 2017 = iPhone X. Google 2016 = Pixel, 2017 = Pixel 2.
Access = WiFi Adoption Rising

WiFi Networks

Source: WiGLE.net as of 5/29/18. Note: WiGLE.net is a submission-based catalog of wireless networks that has collected >6B data points since launch in 2001. Submissions are not paired with actual people, rather 'name / password' identifies which people use to associate their data.
Messaging = Extensibility Expanding

**Messaging**
Tencent (2000 → 2018)

**Messenger MAUs**

![Graph of Messenger MAUs](image)

Source: Facebook, WhatsApp, Tencent, Instagram, Twitter, Morgan Stanley Research. Note: 2013 data for Instagram & Facebook Messenger are approximated from statements made in early 2014. Twitter users excludes B2B (Business-to-Business) users. MAUs (Monthly Active Users) are defined as users who log into a messenger on the web or through an application.
Video = Mobile Adoption Climbing...

Mobile Video Usage

Source: Zenith Online Video Forecasts 2017 (7/17). Note: Based on a study across 63 countries. The historical figures are taken from the most reliable third-party sources in each market including Nielsen and comScore. The forecasts are provided by local experts, based on the historical trends, comparisons with the adoption of previous technologies, and their judgement.
...Voice = Product Lift Off

Amazon Echo Installed Base

Amazon Echo Skills

Source: Consumer Intelligence Research Partners LLC (Echo install base, 2/18). Various media outlets including Geekwire, TechCrunch, and Wired (Echo skills, 3/18)
Voice =
Technology Lift Off…

Google Machine Learning Word Accuracy

Source: Google (5/17). Note: Data as of 5/17/17 & refers to recognition accuracy for English language. Word error rate is evaluated using real world search data which is extremely diverse & more error prone than typical human dialogue.
Domain Name Statistics 2016

• **There are currently 123.78 million registered .com domain names**, making the .com TLD the top domain name extension. This is followed by the .tk TLD with 27.7 million registered domain names.

• **The .com TLD accounts for 50% of all registered TLDs.**

• **As of November 2015, there are a total of 1096 TLDs.**

• **The most expensive domain name ever sold is Insurance.com, for $35.6 million in 2010.**
Web Hosting and Website 2016

- There are currently 966 million websites in the world today.
Web Hosting and Website 2016

• The highest number of websites connected to internet was 1 billion; this happened in September 2014, but the number eventually declined and is expected to be achievable again by mid 2016.
• The world’s first website was published on August 6, 1991 by British physicists Tim Berners-Lee.
• Only 44% of web traffic is from humans; a massive 56% of web traffic is from bots, impersonators, hacking tools, scrapers and spammers.
• 39% of web servers are hosted on Apache.
• Google is the #1 most popular website in the world, followed by Facebook and YouTube.
• The average e-commerce site takes 7.12 seconds to load in Internet Explorer 9, an average of 7.15 seconds to load in Firefox 7 and an average of 7.5 seconds to load in Google Chrome.
• Google uses site speed as a ranking factor.
• The most popular CMS is WordPress, powering 25.4% of all websites in the world and responsible for over 76.5 million blogs.
• An estimated 37,000 websites are hacked every day.
SOCIAL MEDIA USE
TOTAL ACTIVE ACCOUNTS ON THE TOP SOCIAL NETWORK IN EACH COUNTRY, COMPARED TO POPULATION

- NORTH AMERICA: 59%
- CENTRAL AMERICA: 40%
- SOUTH AMERICA: 50%
- WEST EUROPE: 48%
- EAST EUROPE: 6%
- EAST ASIA: 48%
- CENTRAL ASIA: 11%
- SOUTHEAST ASIA: 37%
- SOUTHWEST ASIA: 11%
- MIDDLE EAST: 26%
- AFRICA: 11%
- OCEANIA: 45%

GLOBAL AVERAGE: 31%

Sources: Facebook; Tencent; VKontakte, LiveInternet.ru, Nikkei, VentureBeat, Nik Agha; UN, US Census Bureau for population data.
GLOBAL FACEBOOK REACH & ENGAGEMENT

AVERAGE POST REACH COMPARED TO TOTAL PAGE LIKES, AND ENGAGEMENT RATES BASED ON ACTUAL POST REACH

**Average Monthly Change in Page Likes:** +0.20%

**Average Post Reach vs. Page Likes:** 10.7%

**Average Organic Reach vs. Page Likes:** 8.0%

**Percentage of Pages Using Paid Media:** 22.1%

**Average Paid Reach vs. Total Reach:** 26.8%

**Average Engagement (All Post Types):** 4.20%

**Average Video Post Engagement:** 5.23%

**Average Photo Post Engagement:** 4.42%

**Average Link Post Engagement:** 3.90%

**Average Status Post Engagement:** 3.70%

**Source:** Locowise, January 2018. Data represents average figures for full-year 2017. Notes: Reach figures compate the number of times a post was served in users' newsfeeds to the total number of "fans" (i.e., users that had liked the page) at the time the post was published. Engagement rates compare the number of people who interacted with a post to the total number of unique users to whom that post was served, regardless of whether those users were fans of the page at that time.
GLOBAL E-COMMERCE REVENUES
TOTAL VALUE OF THE CONSUMER (B2C) E-COMMERCE MARKET, AND AVERAGE E-COMMERCE REVENUE PER USER

- NUMBER OF PEOPLE PURCHASING VIA E-COMMERCE: 1.61 BILLION
- E-COMMERCE PENETRATION (NUMBER OF PURCHASERS vs. TOTAL POPULATION): 22%
- TOTAL VALUE OF GLOBAL E-COMMERCE MARKET IN 2016 (IN US$): $1.915 TRILLION
- AVERAGE ANNUAL E-COMMERCE REVENUE PER USER IN 2016 (IN US$): $1,189
E-commerce and Conversion Statistics 2016

• 40% of global internet users, or more than 1 billion people, have bought products or goods online.
• The U.S. e-commerce economy is worth $349 billion while China’s e-commerce economy is worth $562.66 billion.
• A single second delay in your website loading time can result in a 7% loss in conversion, and 40% of web users will abandon a website if it takes longer than 3 seconds to load.
• Slow loading websites cost the U.S. e-commerce market more than $500 billion annually.
• Online retail sales in the U.K. reached an estimated £52.25 billion in 2015, with the average shopper spending £1,174.
• Worldwide B2C e-commerce sales reached $1.7 trillion in 2015, and it is estimated to reach $2.35 trillion by 2018.
• 8 out of 10 consumers will shop online if offered free shipping.
E-commerce and Conversion Statistics 2016

• Personalized recommendations can increase conversion rates by up to 5.5 times.
• 51% of U.S. online shoppers cite slow site loading times as the top reason they abandon a purchase.
• 34% of British consumers cite a store’s reputable brand name for being their reason for shopping with a brand, while 38% cite social media interaction as their reason for visiting a retailer’s website.
• 40% of shoppers consult 3 or more channels, often in the process of shopping, before making a purchase; that’s a massive increase from 10% in 2002, and it goes to show the increasing importance of having an online presence in as many places as possible.
• While mobile internet usage is high, desktop and tablet internet usage still leads for conversions; an estimated 8.52% of desktop users add to cart and an estimated 2.78% convert to sales. This is much higher than Smartphone conversion rates with an estimated 4.70% add to cart rate and an estimated 0.80% sales conversion rate. The number is much higher when you consider conversion rates from tablets and other mobile devices, but desktop still leads when it comes to actual sales.
• An increase in site speed from 8 to 2 seconds can boost your conversion rate by 74% (this is based on data monitoring real user activity from 33 major retailers).
E-commerce and Conversion Statistics 2016

• Increasingly shrinking attention span keeps influencing e-commerce; in 2010, a page that took 6 seconds to load suffered a 40% loss in conversion. Today, a page that takes 6 seconds to load will experience a 50% loss in conversion.

• The abandonment rate for mobile shopping cart is higher (at 97%) than that of desktop shopping carts (at 70 – 75%).

• E-commerce sales from social media grew by 202% in 2014, and is expected to further increase.

• The average human attention span has declined from 12 seconds in the year 2000 to 8 seconds now. This is much shorter than the attention span of a goldfish (at 9 seconds). This was revealed by a recent study by Microsoft Corp. that surveyed 2,000 people and monitored brain activity of 112 others using electroencephalograms (EEGs).
JAN 2017

TIME SPENT ON THE INTERNET
AVERAGE NUMBER OF HOURS SPENT USING THE INTERNET PER DAY, SPLIT BY COMPUTER USE AND MOBILE PHONE USE (SURVEY BASED)

NOTE THAT TIMES CAN BE ADDED TOGETHER TO FIND TOTAL INTERNET TIME BY COUNTRY; RANKINGS ARE IN ORDER OF TOTAL TIME SPENT USING THE INTERNET EACH DAY

ACCESS THROUGH LAPTOP / DESKTOP
ACCESS THROUGH MOBILE DEVICE

SOURCES: GLOBALWEBINDEX 2017 BASED ON A SURVEY OF INTERNET USERS AGED 16+1
2016 What happens in an Internet Minute?

- Facebook: 20.8 million+ messages
- YouTube: 2.78 million video views
- Tinder: 972,222 swipes
- Google: 2.4 million search queries
- Spotify: 1.04 million Vine loops
- Instagram: 38,052 hours of music
- Twitter: 38,194 posts to Instagram
- LinkedIn: 150 million emails sent
- Netflix: 701,389 Facebook logins
- Uber: 69,444 hours watched
- Snapchat: 527,760 photos shared
- Amazon: 51,000 app downloads from Apple
- vine: 120+ new LinkedIn accounts
- Vine: 347,222 new tweets
- App Store: $203,596 in sales

60 seconds
GROWTH IN THE INTERNET OF THINGS

THE NUMBER OF CONNECTED DEVICES WILL EXCEED 50 BILLION BY 2020

BILLIONS OF DEVICES

1992 1M
1996 0.5B
2000 22.9B
2004 14.2B
2008 11.2B
2012 8.7B
2015 18.2B
2016 22.9B
2017 28.4B
2018 34.8B
2019 42.1B
2020 50.1B

INCEPTION

Source: Cisco