The Hardware/Software Interface

CSE 351 Autumn 2023

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Justin Hsia

Teaching Assistants:
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Bhavik Soni         Naama Amiel
Cassandra Lam       Nayha Auradkar
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Dawit Hailu         Renee Ruan
Ellis Haker         Simran Bagaria
Eyoel Gebre         Will Robertson
Joshua Tan          

An x64 processor is screaming along at billions of cycles per second to run the XNU kernel, which is frantically working through all the POSIX-specified abstraction to create the Darwin system underlying OS X, which in turn is straining itself to run Firefox and its Gecko renderer, which creates a flash object which renders dozens of video frames every second.

Because I wanted to see a cat jump into a box and fall over.

I am a God.

http://xkcd.com/676/
Quarter Specifics
Course Staff

❖ Instructor: just call me Justin
  ▪ CSE Associate Teaching Professor
  ▪ Raising a toddler takes up energy and dictates my schedule

❖ TAs:
  Afifah  Bhavik  Cassandra  Connie  David  Dawit  Ellis  Eyoel
  Joshua  Malak  Naama  Nayha  Nikolas  Pedro  Renee  Simran  Will

❖ More than anything, we want you to feel...
  ✓ Comfortable and welcome in this space
  ✓ Able to learn and succeed in this course
  ✓ Comfortable reaching out if you need help or want change
Bookmarks

❖ Website: https://courses.cs.washington.edu/courses/cse351/23au/
  ▪ Schedule, policies, materials, tutorials, assignment specs, etc.

❖ Ed Course: https://edstem.org/us/courses/41511
  ▪ Discussion: announcements, ask and answer questions
  ▪ Lessons: lessons, practice problems, homework

❖ Linked from website and Ed
  ▪ Canvas: surveys, grade book, Zoom links
  ▪ Gradescope: lab submissions, take-home exams
  ▪ Panopto: lecture recordings
Grading

- **Lesson Problems:** 6%  
  - Can reveal solution after one attempt (completion)

- **Homework:** 20% total  
  - Unlimited submission attempts (autograded correctness)

- **Labs:** 40% total  
  - Last submission graded (correctness)

- **Exams:** Midterm (16%) and Final (16%)  
  - Take-home; individual, but some discussion permitted

- **EPA:** Effort, Participation, and Altruism (2%)
Support Hours

- Check Weekly Calendar on website for scheduled support hours:
  - In-person or virtual, but NOT hybrid
  - Zoom meeting links found in Zoom tab within Canvas

- *All* support hours will use a Google Sheets queue:
  - Fill out first 3 columns to enter queue:

- We encourage you to chat with other students if the TAs are busy!
In-Person Support Hours

- Allen 3rd floor breakout
  - Up the stairs in the CSE Atrium (Allen Center, not Gates)
  - At the top of two flights, the open area with the whiteboard wall is the 3rd floor breakout!
To-Do List

❖ Admin
  ▪ Explore/read the course website *thoroughly*, especially the syllabus
  ▪ Check that you can access Ed Discussion & Lessons
  ➢ **Get your machine set up to access the CSE Linux environment (attu or seaside) as soon as possible**
  ▪ Optionally, sign up for CSE 391: System and Software Tools

❖ Assignments
  ▪ Pre-Course Survey and hw0 due Friday (9/29)
  ▪ HW1 and Lab 0 due Monday (10/2)
  ▪ Lessons quiz questions due 11:59 pm *after* the associated lecture
Binary and Numerical Representation
Lesson Summary (1/2)

❖ Humans think about numbers in decimal; computers think about numbers in binary
  ▪ Base conversion to go between them
  ▪ Hexadecimal is more human-readable than binary

❖ All information on a computer is binary

❖ Binary encoding can represent anything!
  ▪ Computer/program needs to know how to interpret the bits
  ▪ Encodings aren’t “neutral”; priorities are baked in
Lesson Summary (2/2)

❖ Terminology:
  ▪ numeral, digit, base, symbol, digit position, leading zeros
  ▪ binary, bit, nibble, byte, hexadecimal
  ▪ numerical representation, encoding scheme

❖ Learning Objectives:
  ▪ Convert between binary, decimal, and hexadecimal number representations.
  ▪ Given an encoding scheme, decode and encode binary to/from its intended representation.
  ▪ Identify limitations of given encoding schemes.

❖ What lingering questions do you have from the lesson?
Binary and Numerical Representation — Context
Why Base 2?

- Electronic implementation
  - Easy to store with bi-stable elements
  - Reliably transmitted on noisy and inaccurate wires

![Diagram of voltage levels between 0 and 3.3V]

- Other bases possible, but not yet viable:
  - DNA data storage (base 4: A, C, G, T) is hot @UW
  - Quantum computing
Binary Encoding – Colors

❖ RGB – Red, Green, Blue
  ▪ Additive color model (light): byte (8 bits) for each color
  ▪ Commonly seen in hex (in HTML, photo editing, etc.)
  ▪ Examples: Blue→0x0000FF, Gold→0xFFD700, White→0xFFFFFFF, Deep Pink→0xFF1493
Binary Encoding – Characters/Text

❖ ASCII Encoding (www.asciitable.com)

- American Standard Code for Information Interchange

<table>
<thead>
<tr>
<th>Dec</th>
<th>Hex</th>
<th>Oct</th>
<th>Ch</th>
<th>ASCII Encoding (<a href="http://www.asciitable.com">www.asciitable.com</a>)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>000</td>
<td>0</td>
<td>&quot; &quot;</td>
<td>Space</td>
</tr>
<tr>
<td>1</td>
<td>001</td>
<td>1</td>
<td>&quot; &quot;</td>
<td>Start of heading</td>
</tr>
<tr>
<td>2</td>
<td>002</td>
<td>2</td>
<td>&quot; &quot;</td>
<td>Start of text</td>
</tr>
<tr>
<td>3</td>
<td>003</td>
<td>3</td>
<td>&quot; &quot;</td>
<td>End of text</td>
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<tr>
<td>4</td>
<td>004</td>
<td>4</td>
<td>&quot; &quot;</td>
<td>End of transmission</td>
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<td>5</td>
<td>005</td>
<td>5</td>
<td>&quot; &quot;</td>
<td>Inquiry</td>
</tr>
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<td>6</td>
<td>006</td>
<td>6</td>
<td>&quot; &quot;</td>
<td>Acknowledgment</td>
</tr>
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<td>7</td>
<td>007</td>
<td>7</td>
<td>&quot; &quot;</td>
<td>Bell</td>
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<td>8</td>
<td>008</td>
<td>8</td>
<td>&quot; &quot;</td>
<td>Backspace</td>
</tr>
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<td>9</td>
<td>009</td>
<td>9</td>
<td>&quot; &quot;</td>
<td>Horizontal tab</td>
</tr>
<tr>
<td>10</td>
<td>010</td>
<td>10</td>
<td>&quot; &quot;</td>
<td>LF line feed, new line</td>
</tr>
<tr>
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<td>011</td>
<td>11</td>
<td>&quot; &quot;</td>
<td>Vertical tab</td>
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<td>12</td>
<td>012</td>
<td>12</td>
<td>&quot; &quot;</td>
<td>Form feed, new page</td>
</tr>
<tr>
<td>13</td>
<td>013</td>
<td>13</td>
<td>&quot; &quot;</td>
<td>Carriage return</td>
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<tr>
<td>14</td>
<td>014</td>
<td>14</td>
<td>&quot; &quot;</td>
<td>Shift out</td>
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<td>15</td>
<td>&quot; &quot;</td>
<td>Shift-in</td>
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<td>&quot; &quot;</td>
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<td>&quot; &quot;</td>
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<td>18</td>
<td>&quot; &quot;</td>
<td>Operation code</td>
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<td>019</td>
<td>19</td>
<td>&quot; &quot;</td>
<td>End of transmission block</td>
</tr>
<tr>
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<td>020</td>
<td>20</td>
<td>&quot; &quot;</td>
<td>Acknowledgment</td>
</tr>
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<td>021</td>
<td>21</td>
<td>&quot; &quot;</td>
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<td>022</td>
<td>22</td>
<td>&quot; &quot;</td>
<td>Reserved</td>
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<td>023</td>
<td>23</td>
<td>&quot; &quot;</td>
<td>Monitor information</td>
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<td>024</td>
<td>24</td>
<td>&quot; &quot;</td>
<td>Cancel</td>
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<td>025</td>
<td>25</td>
<td>&quot; &quot;</td>
<td>Substitute</td>
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<td>026</td>
<td>26</td>
<td>&quot; &quot;</td>
<td>Escape</td>
</tr>
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<td>027</td>
<td>27</td>
<td>&quot; &quot;</td>
<td>File separator</td>
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<td>28</td>
<td>028</td>
<td>28</td>
<td>&quot; &quot;</td>
<td>Group separator</td>
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<td>029</td>
<td>29</td>
<td>&quot; &quot;</td>
<td>Record separator</td>
</tr>
<tr>
<td>30</td>
<td>030</td>
<td>30</td>
<td>&quot; &quot;</td>
<td>Unit separator</td>
</tr>
</tbody>
</table>

What’s Missing?
Binary Encoding – Characters/Text

❖ ASCII Encoding (www.asciiutable.com)
  ▪ American Standard Code for Information Interchange

❖ Created in 1963
  ▪ Memory was expensive, 32KB in brand new machines
  ▪ Economic incentive to use fewer bits for encoding

❖ Design Goals:
  ▪ Represent everything on an American typewriter as efficiently as possible
  ▪ Organize similar characters together
    • Numbers, uppercase, lowercase, then other stuff
Binary Encoding – Unicode & Emoji

❖ Unicode Standard is managed by the Unicode Consortium
  ▪ “Universal language” that uses 1-4 bytes to represent a much larger range of characters/languages, including emoji
  ▪ Adds new emojis every year, though adoption often lags: 🎉
    • https://emojipedia.org/new/

❖ Emojipedia demo: http://www.emojipedia.org
  ▪ Desktop Computer: 🖥️
  ▪ Code points: U+1F5A5, U+FE0F
  ▪ Display: 🌐💻🖥️イヤホン・耳型 🎂 🧀 🍎 🍏 🍊 🍒 🍓 🍒 🍓 🍂 🍃 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 🍄 🍅 🍆 🍇 🍈 🍉 🍊 🍋 🍌 🍍 🍎 🍏 🍐 🍑 🍒 🍓 ⚛️
Binary Encoding – Files and Programs

❖ At the lowest level, all digital data is stored as bits!

❖ Layers of abstraction keep everything comprehensible
  - Data/files are groups of bits interpreted by program
  - Program is actually groups of bits being interpreted by your CPU

❖ Computer Memory Demo
  - Linux tool: `xxd`
Discussion Question

❖ Discuss the following question(s) in groups of 3-4 students
  ▪ I will call on a few groups afterwards so please be prepared to share out
  ▪ Be respectful of others’ opinions and experiences

http://xkcd.com/1953/
Discussion Question

❖ Discuss the following question(s) in groups of 3-4 students
  ▪ I will call on a few groups afterwards so please be prepared to share out
  ▪ Be respectful of others’ opinions and experiences

❖ The Unicode Consortium publicly solicits proposals from the public for new emoji to add to future standards
  ▪ What do you think some of the decision factors are (or should be) in how many and which ones to add?
  ▪ Voting is done by a combination of paid members consisting of companies, institutions, and individuals – how do you feel about who has control and how they gained that control?
  • https://home.unicode.org/membership/members/
Binary and Numerical Representation – Practice
Group Work Time

❖ During this time, you are encouraged to work on the following:
  1) If desired, continue your discussion
  2) Work on the lesson problems (solutions at the end of class)
  3) Work on the homework problems

❖ Resources:
  ▪ You can revisit the lesson material
  ▪ Work together in groups and help each other out
  ▪ Course staff will circle around to provide support
Practice Problems

❖ What is the decimal value of the numeral 107₈?

A. 71
B. 87
C. 107
D. 568

❖ Represent 0b100110110101101 in hex.

16 = 2⁴
1 hex digit ↔ 4 bits

❖ What is the decimal number 108 in hex?

A. 0x6C
B. 0xA8
C. 0x108
D. 0x612

❖ Represent 0x3C9 in binary.

0b 0011 1100 1001

Possible drop leading zeros