CS 2461
Computer Architecture 1
i.e., Introduction to Computer Systems

https://cs2461-2020.github.io/
Fall 2020
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What is CS 2461 about?!

- Look 'under the hood' to see how a computer works
  - Explore the interface between hardware and software
  - Understand the components in a processor
  - Bottom up approach: from transistors on up to algorithm design
    - i.e., the hardware stack
- With this knowledge you can
  - Understand the link between hardware and software
  - Write better, more efficient software
  - Design better hardware
    - Link between hardware and software
  - Appreciate the abstractions that are built on top of these foundations

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Pre-requisites

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  - CS 1112 – Data structures and algorithms
  - CS 1311 – Discrete Math 1
- Co-requisite: CS 2113
  - Knowledge of C programming language
  - I will be synchronizing with instructor
- Programming practice…system skills
  - Practice, practice,…and more practice

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Course Objectives

- To understand the structure and operation of a modern computer system from the ground up.
  - Understand basic hardware concepts and build simple circuits
    - digital circuits -gates, bits, bytes, number representation
  - Understand the Von Neumann architecture/computing model
    - structure and operation, (assembly language)
  - Basic "system" concepts
    - runtime stack, simple I/O devices, Unix OS
    - Software security Introduction – stack smashing attacks
- How high level languages are implemented on the machine (using the C language)
  - How are C programs translated to assembly and implemented on a machine
  - Proficiency in the C programming language
- Understand how software/program performance is linked to program and machine properties

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Two recurring themes in Computer Sci.

- Abstraction: Productivity Enhancer
  - You don't need to worry about the details
    - You can drive a car without knowing about the internal combustion engine….until something goes wrong: where is that smoke coming from !!
  - The notion that we can concentrate on one "level" of the big picture at a time, with confidence that we can then connect with other levels.
  - Framing abstraction appropriately is a very important skill
    - THIS is the whole point of mathematical modeling in Engineering/CS fields
- Hardware and Software
  - abstraction does *not* mean being clueless about HW or SW
  - In particular, hardware and software are inseparably connected, especially at the level we will be studying
    - Even if you specialize in one, you must understand the capabilities of the other

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What are Computers meant to do ?

- Solve problems that are described in English (or Greek or French or Hindi or Chinese or ...) and use a box filled with electrons and magnetism to accomplish the task.*
  - This is accomplished using a system of well defined (sometimes) transformations that have been developed over the last 50+ years.
  - As a whole the process is complex, examined individually the steps are simple and straightforward
  - *Definition from the textbook*
- *So how do you get the electrons to run around and do our task ?*

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Two Big Ideas in Computing

- Universal Computational Devices
  - Turing's Thesis: every computation can be performed by some "Turing Machine" - a theoretical universal computational device
    - You will see this in the Foundations course CS 3313
- Problem Transformation (Abstraction!)
  - The ultimate objective is to transform a problem expressed in natural language into electrons running around a circuit (using a succession of transformations)
    - That's what Computer Science and Computer Engineering are all about: a continuum that embraces software & hardware.
    - Note the role of compilers/translators

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Big Idea #1: Universal Computing Device

- All computers, given enough time and memory, are capable of computing exactly the same things
  - Smartphone, laptop, supercomputer
    - Limited only by time and memory (and energy)
- Anything that can be computed, can be computed by a computer
  - If you can describe something in terms of computation, it can be done by a computer
- Formal (mathematical) model of computing = Turing Machine

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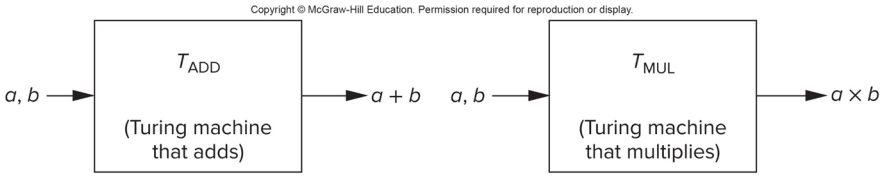
Turing Machine

- Mathematical model of a device that can perform any computation – Alan Turing (1937)
  - Ability to read/write symbols on an infinite 'tape'
  - State transitions: based on current state and input symbol
- Every computation can be performed by some Turing machine (*Turing's thesis*)



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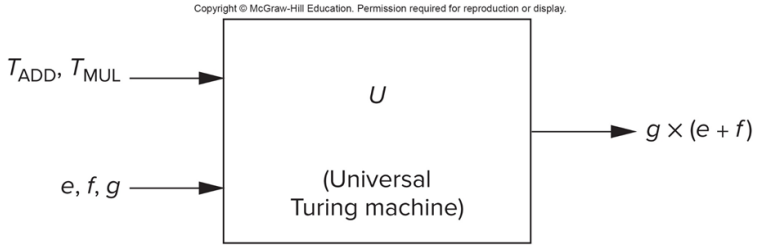
Universal Turing Machines

- A machine that can implement all Turing machines
  - This is also a Turing machine !
  - Inputs: data, plus a description of computation (other TMs)
- U is programmable – so is a computer !
  - Instructions are part of the input data
  - A computer can emulate a universal Turing machine



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Turing machines, Computers,….so which one do we use ?

- If all of them can do your work which one do you choose and what is the difference ?

- Performance
  - Speed/Latency (how long to solve your single program)
  - Throughput (how many tasks at a time can the server handle)
- Cost
- Energy/Power
  - Particularly important in smartphones, embedded systems,..
    - Because energy source is a battery

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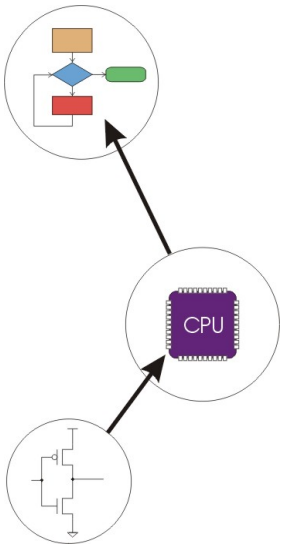
Big Idea #2: Transformation between layers (Abstraction!): Putting the electrons to work!



- **Problems**
- **Algorithms**
- **Program**
- **Instruction Set Architecture**
- **Microarchitecture**
- **Circuits**
- **Devices**

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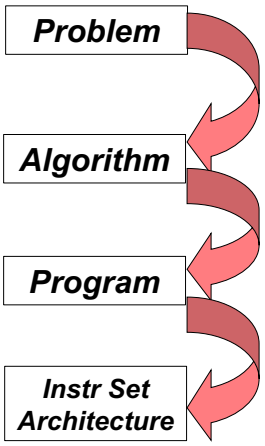
How do we solve a problem using a computer?

A systematic sequence of transformations between abstraction layers.

Example: Problem = Sort a set of numbers

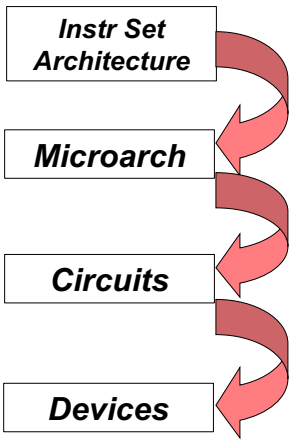


Software Design: choose algorithms and data structures. Bubble Sort

Programming: use language to express design and implement algorithm. C lang.

Compiling/Interpreting: convert language to machine instructions. Use gcc compiler (to compile to ARM ISA)

…and even more layers…

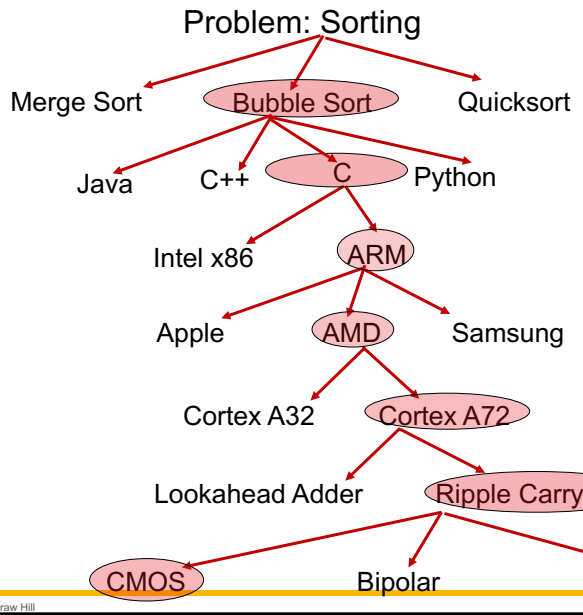


Processor Design: choose structures to implement ISA. Choose ARM ISA

Logic/Circuit Design: gates and circuits to implement components of AMD ARM processor

Process Engineering & Fabrication: develop and manufacture transistors, wires, etc.

Why do we need 'experts' at each layer – Choices at each layer



Tradeoffs: Cost, Performance, Power, …

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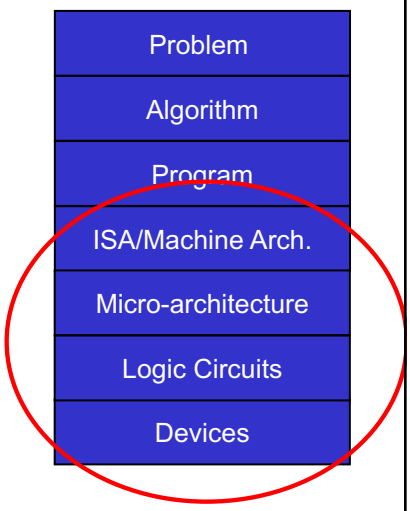
Recap: Our Computing Technology Stack & transformation between layers

- The problem..in words
- The algorithm..still in words but formalized
- The program…captures algorithm in specific HLL syntax (C, Java,..)
- The ISA…an instruction set architecture that specifies what operations processor can perform
- The micro-architecture…potentially many ways to implement processor with given ISA
- The logic circuits…implement various components of microarchitecture as assemblies of logic gates
- The devices…logic gates built from transistors fabricated using technologies (CMOS, GaAs,..)



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Focus of this course: The Machine/Hardware Level

This is going to be 'all new' material for most of you…

- Machine Architecture
  - This is the formal specification of all the functions a particular machine can carry out, known as the *Instruction Set Architecture* (ISA).
    - We will study the ISA, and Assembly Language programming of a simple computer LC3 – why select a simple "unrealistic" computer?
- Microarchitecture
  - The implementation of the ISA in a specific CPU - i.e. the way in which the specifications of the ISA are actually carried out.
    - We give an overview of the microarchitecture; CS 3462 covers this topic

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The Machine Level –contd.

- Logic Circuits
  - Each functional component of the microarchitecture is built up of circuits that make "decisions" based on simple rules
    - We will study the basic building blocks of logic circuits
    - You will learn to implement hardware logic circuits in the labs
- Devices
  - Finally, each logic circuit is actually built of electronic devices such as CMOS or NMOS or GaAs (etc.) transistors.
    - Device electronics – not in this course

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Approach

- Bottom-up: from bits to C
  - Establish link between hardware and software
  - Learn C in context of hardware
    - Used for systems programming & misused by many!
    - Learn what actually happens when your programs run
    - If you understand the hardware the language loses a lot of its mystery!
- Why C: the ultimate high-level, low-level language
  - High level enough that you can write large scale programs in It
  - Low level enough that you can reach down and twiddle the bits.

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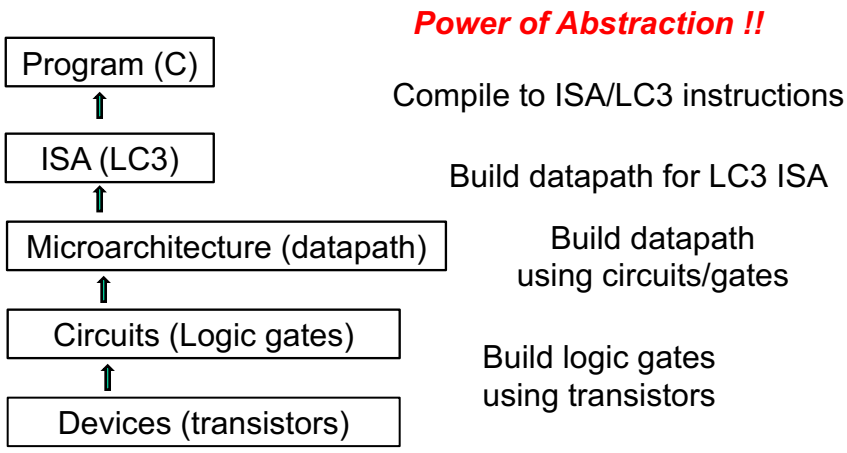
Bottom up Approach….Power of Abstraction



Our starting point is "how to represent data"

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How does this course "interface" with other courses ?

- CS2113 Software Engineering: learn C, learn software development, testing, debugging,…
- CS 3410 Systems Programming:
  - HW: use a CPU board and sensors to deploy a system to solve a problem (parking assist in a car)
  - SW: systems programming (in C) to process data gathered from sensors
- CS 3411 Operating systems:
  - How does software 'manage' the HW resources
    - CS2461 barely touches the tip of the iceberg when it comes to systems concepts!
  - A lot more programming in C
- CS 3313 Foundations:
  - Mathematical foundations of computing devices

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Your Initial To-do List

1. Get your "reading resources" - textbook
2. Go to the course web page.
   - Lecture videos and notes will be posted
3. Prepare for class:
   - Read notes/slides, textbook and watch any videos that are posted for the next class/topic.
     - There are going to be in-class exercises during class!!

4. Submit the "Feedback Questions" survey by 1pm before each class

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