

Introduction to Computational and Algorithmic Thinking

LECTURE 1 – COMPUTATIONAL THINKING

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Announcements

This lecture: Computational Thinking

Reading: Read Chapter 1 of Conery

Acknowledgement: These slides are extended version of slides prepared by Prof. Arthur Lee, Prof. Tony Mione for earlier CSE101 classes.

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What is Computer Science

- **Computer science** is all about using computers and computing technology to solve challenging, real-world problems in science, medicine, business and society
- Computer science = computer programming ← Not true
 - Computer programming is an important aspect of computer science
 - Computer programs often provide (parts of) the solutions to challenging technological problems
- Computer science is also not:
 - computer literacy
 - computer maintenance/repair

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A modern computing problem

ELECTRONIC HEALTH RECORDS ARE BECOMING INCREASINGLY IMPORTANT AS TIME GOES ON

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A modern computing problem

- Electronic health records are becoming increasingly important as time goes on
- Consider issues (technical + others) that arise providing a hw/sw system to medical professionals and others who need access to digital medical records:
 - What data will be stored? How? In what format?
 - How will the data be accessed and displayed?
 - Who will have access? How will the data be secured?
 - How will the data be backed up and preserved?
- Answering these questions requires **computational thinking**

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Computing systems

Let's take a tour of modern computing systems

A computing system consists of two major parts: the **hardware** and the **software**

Some hardware elements of a computer:

- Screen, keyboard, mouse
- Central processing unit (CPU), main memory
- Hard drives and other storage units

Types of software:

- Applications software, like office productivity programs, video games, web browsers
- Systems software, like operating systems, database systems

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Computing systems

Can hardware exist without software?

- Sure, but is it useful? → It depends
 - General Purpose CPUs [Intel x86, core i5, i7, etc.] Not really
 - Specialized hardware [FPGAs, ASICs with functionality built into hardware] – Yes. Although functionality was developed with software based tools

Can software exist without hardware?

- In a literal sense, no – hardware is needed to execute software
- But, the underlying problem-solving techniques employed by the programmer to create the software do exist separately from the hardware and software

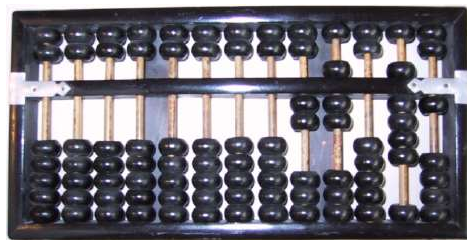
One more part to a computer system: data

- The software needs some kind of data to process: numbers, text, images, sound, video

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A quick history of computing

- We think of computers as modern inventions
- Computing devices
 - go back thousands of years
 - have many of the same basic features of digital computers
- **Abacus** – an early device to record numeric values and do basic arithmetic (16th century B.C.)



- <https://www.youtube.com/watch?v=GF6nCmcQ5es>
- What does an abacus have to do with laptops, smartphones and tablet computers???

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A quick history of computing

Modern computers borrow four important concepts from the abacus:

1. Storage
2. Data Representation
3. Calculation
4. User Interface

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A quick history of computing

1. Storage

- An abacus stores numbers, which are the most fundamental type of data in modern computing.
- In a modern computer, all data – text, images, audio, video – is represented using binary numbers (1s and 0s)

2. Data Representation

- The abacus represents numbers using beads on spindles.
- Modern computers employ a variety of techniques for representing data on storage media:
 - Magnetic
 - Optical
 - Electrical

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A quick history of computing

3. Calculation

- By moving beads on abacus spindles, user can perform addition, subtraction, multiplication, and division
- Modern computers contain powerful central processing units that perform calculations at astonishing speeds

4. User Interface

- The beads and spindles on the abacus
- Modern computers provide a wide variety of input and output devices for the user

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A quick history of computing



- In the 17th century people began tinkering with physical devices that could do computations and calculations
- Blaise Pascal
 - the French mathematician and philosopher
 - one of a few to design and build a physical calculator
- Calculator could only do addition and subtraction
 - Input is given using dials
 - Output is read on small windows above each dial

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Programmable devices

- Pascal's calculator and other similar devices of that time were not programmable
- One of the first programmable devices in history was a loom
- Joseph Marie Jacquard's loom (1804) could be programmed by feeding in a set of punched cards
- This is not all that different from quitting a program that's running on your computer and starting another one!

• <https://www.youtube.com/watch?v=MQzpLLhN0fY>

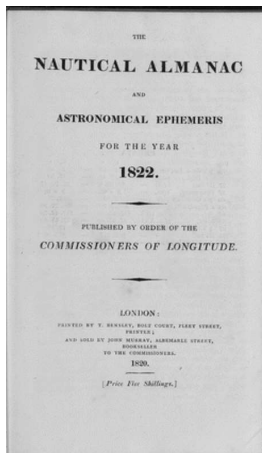


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Rise of Analytical Engine



- Summer of 1821 – Mathematician Charles Babbage and astronomer John Herschel were working on creating a book of mathematical tables.
- Almanac contains tables denoting positions of the Moons, planets and stars – which are used by navigators to determine location at the sea.
- Manual work caused a number of errors.
- Babbage showed his frustration with the large number of errors by exclaiming, “I wish to God these calculations had been executed by steam!”
- What made Babbage think steam engines could help him solve mathematical problems?

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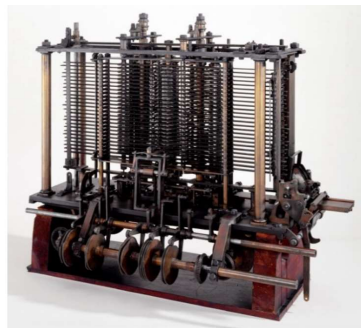
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2022 MAY 10, 11, 12 (FRI., SAT., SUN.)														2022 MAY 10, 11, 12 (FRI., SAT., SUN.)													
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10 10	01 21 21.7	02 11 57.3	03 03 06.9	04 00 24.4	05 00 00.0	06 00 00.0	07 00 00.0	08 00 00.0	09 00 00.0	10 00 00.0	11 00 00.0	12 00 00.0	13 00 00.0	14 00 00.0	15 00 00.0	16 00 00.0	17 00 00.0	18 00 00.0	19 00 00.0	20 00 00.0	21 00 00.0	22 00 00.0	23 00 00.0	24 00 00.0	25 00 00.0	26 00 00.0	

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Programmable devices

- Charles Babbage designed the Analytical Engine, a mechanical, programmable computer in 19th Century
 - It was never built in Babbage's time due to a lack of manufacturing capabilities (ahead of his time!)
 - Design called for punched cards to be fed into the machine to program it to perform mathematical calculations
 - Output would go to a printer or punched cards
 - See for details: <https://www.thoughtco.com/first-computer-charles-babbages-1221836>



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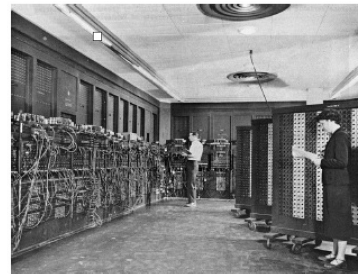
Programmable computers

- Many others
- Now, move forward to the 20th and 21st centuries
- A modern computer has three basic requirements:
 1. Must be electronic and not exclusively mechanical.
 2. Must be digital, not analog
 - Uses discrete values (digits), not a continuous range of values to represent data. (i.e. digital vs mercury-based thermometer)
 3. Must employ the **stored-program concept**
 - the device can be reprogrammed by changing the instructions stored in the memory of the computer

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Programmable computers

- ENIAC (Electronic Numerical Integrator and Computer)
 - Built in the 1940s
 - Among the first computers to employ the stored-program concept
- A modern computer has four major kinds of components:
 - Input device(s) – examples?
 - Output device(s) – examples?
 - Memory – for data storage, both temporary & permanent
 - Processor – for doing computations



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Programmable computers

- Again, the **stored-program concept** is the idea that programs (software) along with their data are *stored* (saved) in the memory of a computer
 - Not referring to storage on hard drives, flash drives or CDs
 - Referring to **main memory** of the computer, sometimes called the **RAM** (random access memory)
- A modern processor
 - reads the **machine instructions** stored as 1s and 0s in the main memory
 - executes those instructions in sequence
 - Key point: these instructions can be changed to easily reprogram the computer to do new tasks

A typical processor has a thousand or more different machine instructions.

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Transistors



- A variety of devices have been used to represent digits and to control the operation of computing machines
- In the 1940s:
 - Bardeen, Brattain, and Shockley invented the **transistor**, which is an electronic switch with no moving parts
- In the 1950s and 1960s:
 - Kilby, Noyce, and others used transistors to develop **integrated circuits**
 - Devised a way to manufacture thousands – later, millions and billions – of transistors on a single wafer of silicon
- A single **chip** contains:
 - an integrated circuit
 - a ceramic or plastic case
 - external pins to attach it to a **circuit board**

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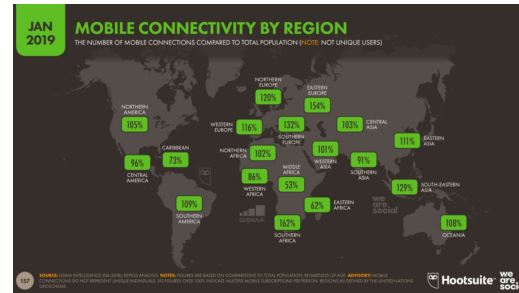
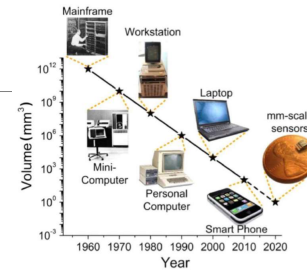
The information explosion in 21st century



<https://www.internetlivestats.com/>

Figure 1 source: <https://www.visualcapitalist.com/what-happens-in-an-internet-minute-in-2019/>

Figure 2 source: <https://wearesocial.com/global-digital-report-2019>



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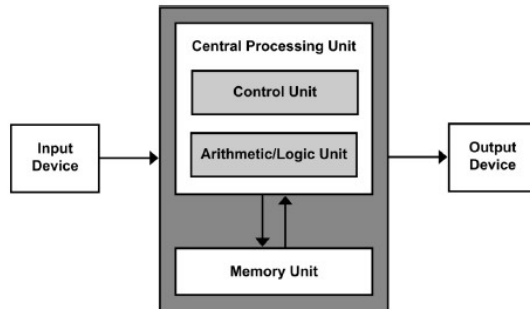
Computing systems

- A computing system consists of two major parts: the **hardware** and the **software**
- Some hardware elements of a computer
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 - Central processing unit, main memory
 - Hard drives and other storage units
- Type of software in use
 - Applications software, like office productivity programs, video games, web browsers
 - Systems software, like operating systems, database systems

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Modern computer architecture

- The stored program approach used today is implemented using **von Neumann architecture**, named after U.S. mathematician John von Neumann
- This architecture contains input devices, output devices, a processor and a memory unit



- Will now look at how they work together to form a functioning computer

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Modern computer architecture

- In modern computers (PCs), the major components in a von Neumann machine reside physically in a circuit board called the **motherboard**
 - The CPU, memory, expansion cards and other components are plugged into slots so they can be replaced
 - Hard drives, CD drives, and other storage devices are connected to the motherboard through cables
- The central processing unit is the “brain” of the machine
 - its **arithmetic/logic unit (ALU)** performs millions or billions of calculations per second
 - The **control unit** is the main organizing force of the computer and directs the operation of the ALU

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Modern computer architecture



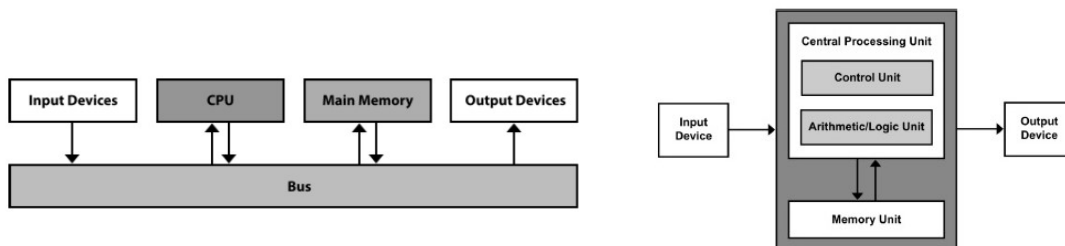
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Modern computer architecture

- The memory unit in this diagram refers to the main memory, not hard drives and other forms of **external storage**
- CPU, main memory, and I/O devices communicate over a shared set of wires known as the **system bus**



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The fetch-decode-execute cycle

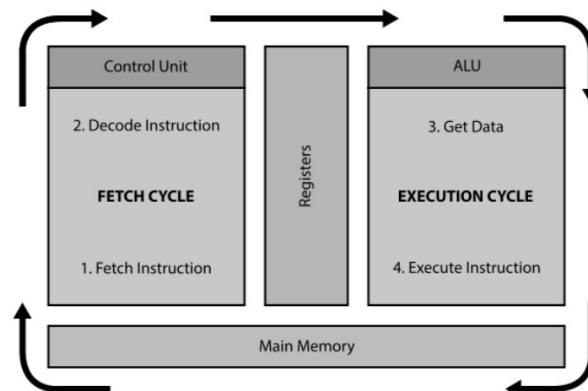
- The system bus carries electrical signals that encode machine instructions and data
 - The CPU **fetches** the instructions and data from memory as needed
 - The control unit **decodes** each instruction to figure out what it is (an addition, subtraction, whatever)
 - Data values (e.g., numbers to be added and their resultant sum) are stored temporarily in memory cells called **registers** within the CPU
 - The ALU **executes** the instruction, saving the result in the registers and main memory
- This whole process is known as the **fetch-decode-execute cycle**
- Illustration
https://chortle.ccsu.edu/java5/Notes/chap04/ch04_4.html

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The fetch-decode-execute cycle



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What about the software?

- Software consists of instructions for the CPU to execute
 - CPUs “understand” something called **machine language**, which consists of 0s and 1s
 - A single instruction for a modern computer might consist of some combination of 32 or 64 0s and 1s!
- Most programming now done using **high-level programming languages**, which consist of English and English-like words with some mathematical notation thrown in
- Will look into the basics of Python, a popular, easy-to-learn, high-level programming language

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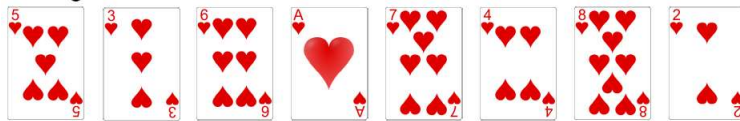
What is computational thinking?

- **Computational Thinking:**
 - How computer scientists think – how they reason and work through problems
- Computer science encompasses many sub-disciplines that support the goal of solving problems:
 - Computer theory areas → these are the heart and soul of computer science
 - algorithms
 - data structures
 - Computer systems areas
 - hardware design
 - operating systems
 - networks
 - Computer software and applications
 - software engineering
 - programming languages
 - Databases
 - Simulation
 - artificial intelligence
 - computer graphics
- A major goal of this course is to help you develop your computational thinking and problem solving skills

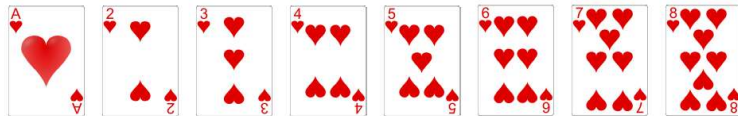
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A classical problem: Sorting data

- Suppose we have a deck of cards we want to put in order
- **Sorting:** important problem – arises frequently in computer science
- Example: Use the Ace thru 8 of Hearts
- Given:



- Want the following:



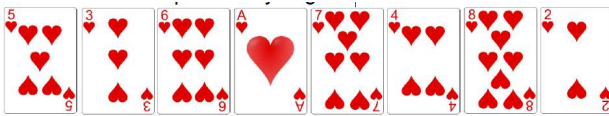
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A classical problem: Sorting data

- You want to explain to a young child how to put the cards in order
 - What steps would you give?



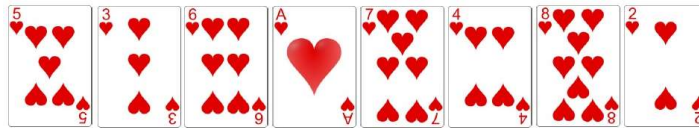
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A classical problem: Sorting data

- One sorting technique is called **selection sort**
- It repeatedly searches for and swaps cards in the list



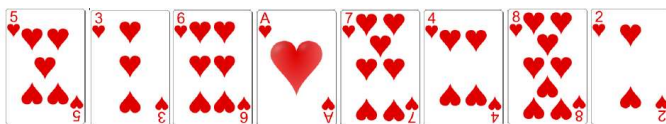
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Selection sort

- First, find the smallest item and exchange it with the card in the first position



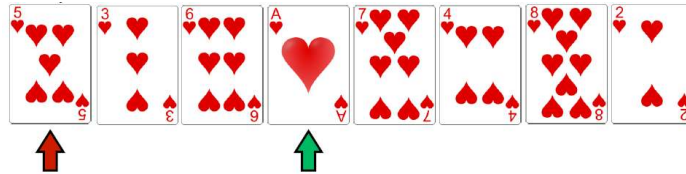
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Selection sort

- **Select** the smallest item and exchange it with the card in the first position



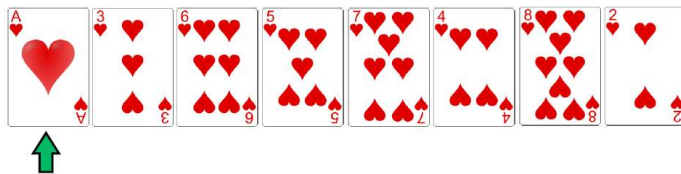
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Selection sort

- Collection after the exchange



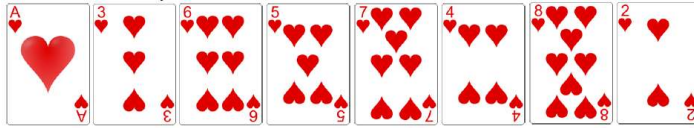
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Selection sort

- Next, **select** the second-smallest item and exchange it with the card in the second position



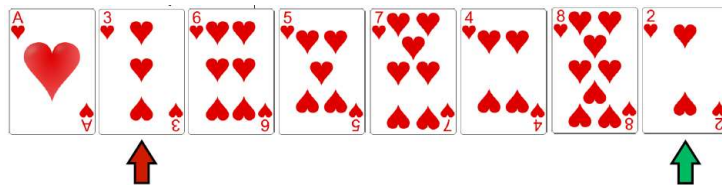
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Selection sort

- **Select** the second-smallest item and exchange it with the card in the second position



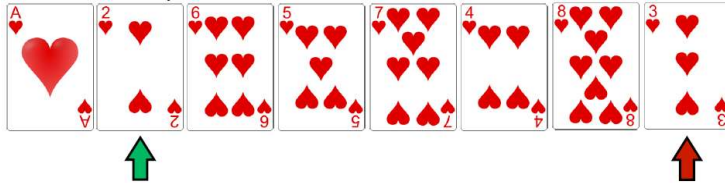
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Selection sort

- Collection after the exchange



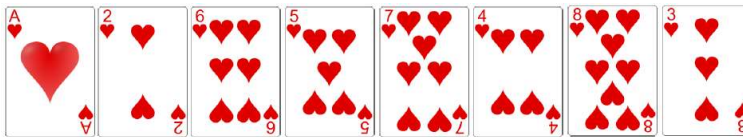
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Selection sort

- Continue in this fashion, *selecting* the third-smallest, fourth-smallest, etc., until the list is sorted



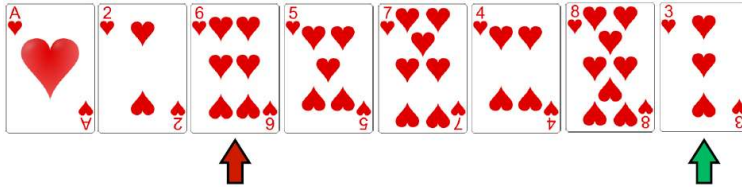
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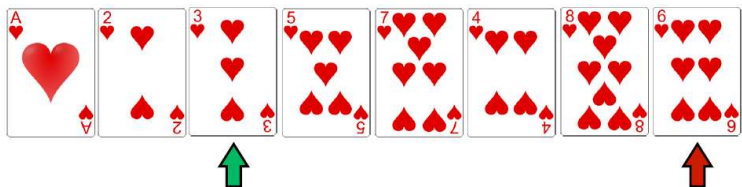
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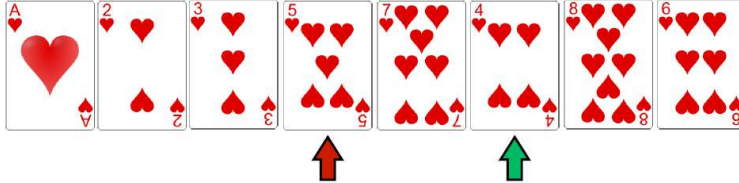
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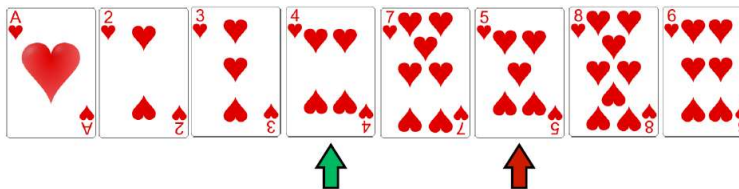
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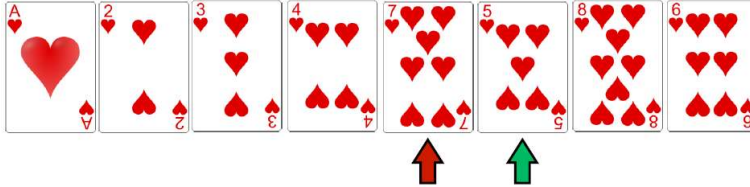
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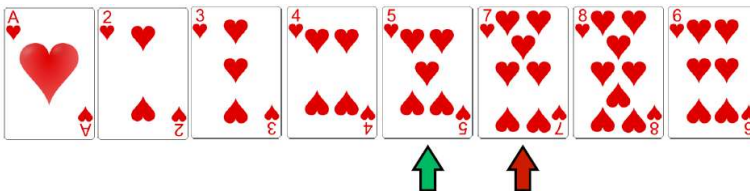
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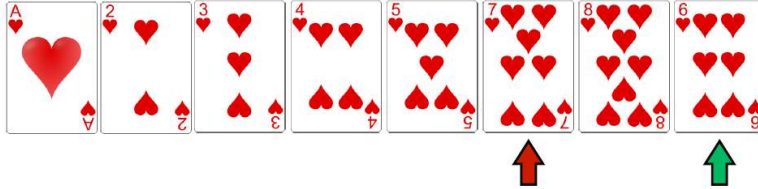
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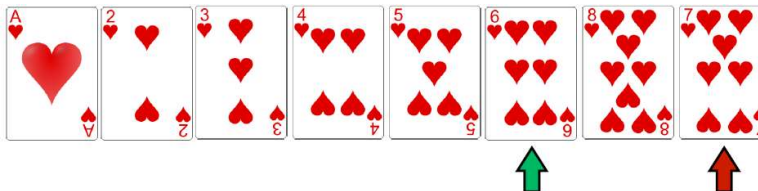
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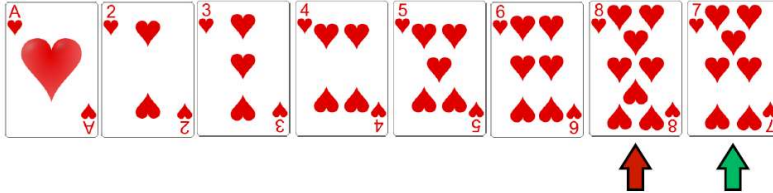
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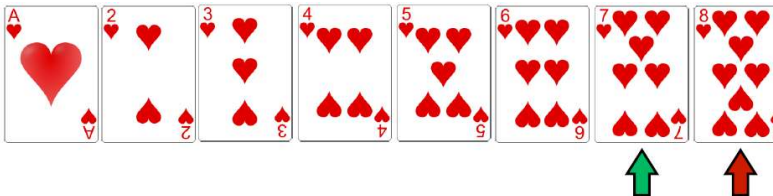
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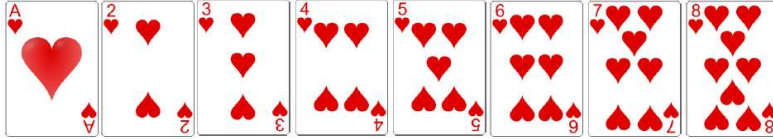
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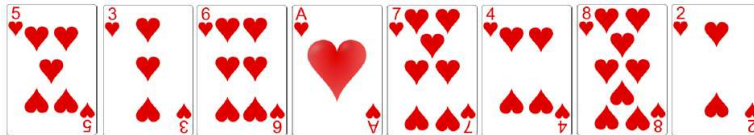


Finished!

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A classical problem: sorting data (2)

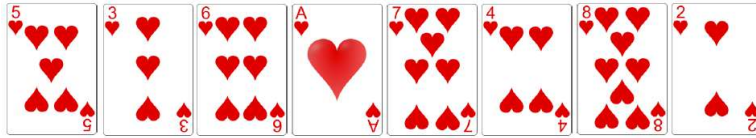
- Another sorting technique is **insertion sort**
- It repeatedly inserts the “next” card into its correct spot



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Insertion sort

- We begin by leaving the first card (#5) where it is



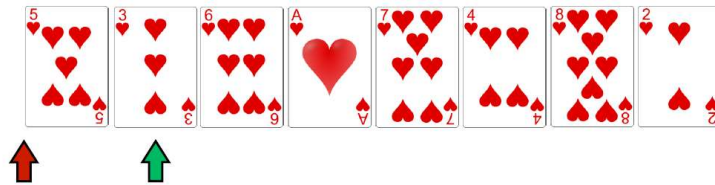
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Insertion sort

- The second card (#3) is smaller than the first card
- **Insert** it in front of the first card



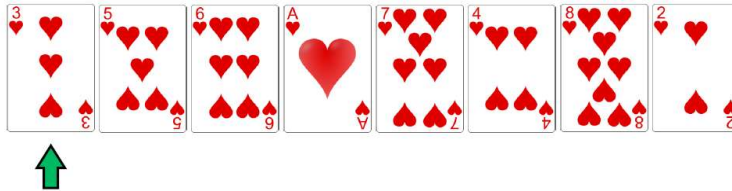
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- The second card (#3) is smaller than the first card
- **Insert** it in front of the first card



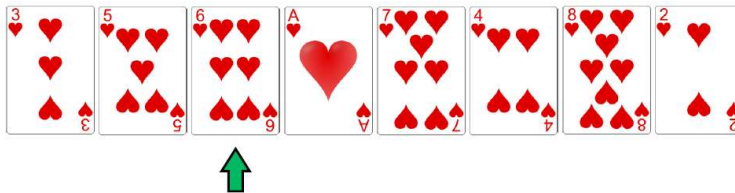
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Insertion sort

- The third card (#6) is larger than the first two cards
- So, we don't need to move it



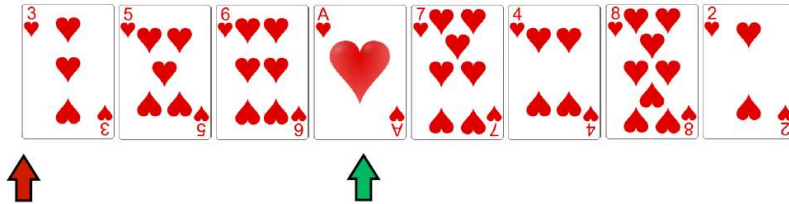
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Insertion sort

- The fourth card (#1) is smaller than the first three cards
- **Insert** it in front of the first card, shifting the others



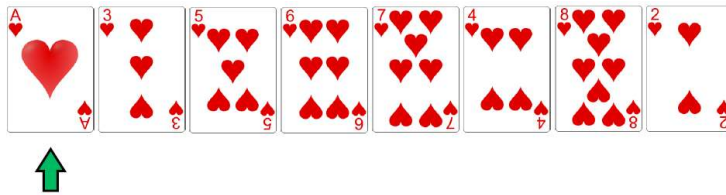
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Insertion sort

- The fourth card (#1) is smaller than the first three cards
- **Insert** it in front of the first card, shifting the others



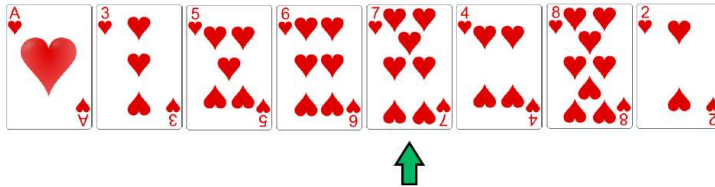
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Insertion sort

- The fifth card (#7) is larger than the first four cards
- So, we don't need to move it



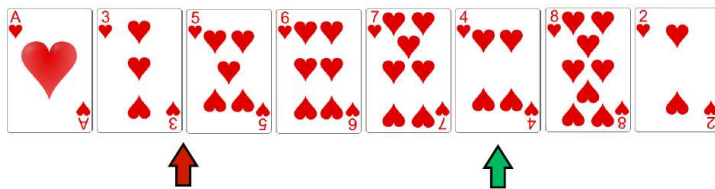
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Insertion sort

- The sixth card (#4) should be **inserted** in between the second (#3) and third (#5) cards



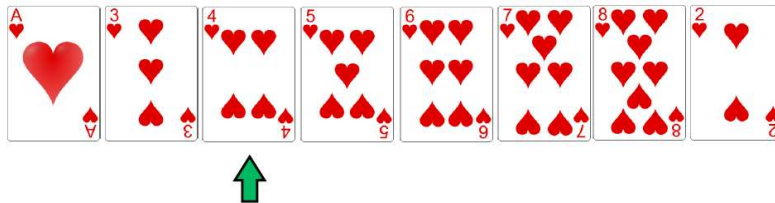
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Insertion sort

- The sixth card (#4) should be **inserted** in between the second (#3) and third (#5) cards



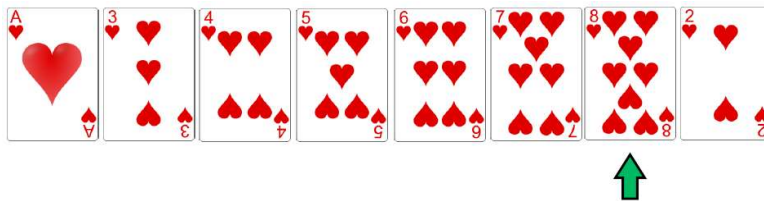
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Insertion sort

- The seventh card (#8) is larger than the first six cards
- So, we don't need to move it



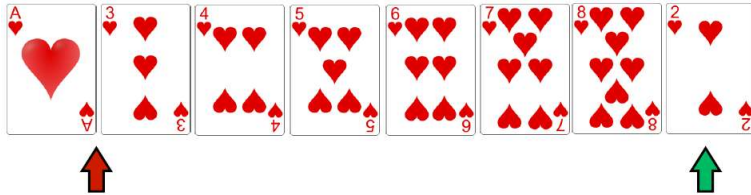
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Insertion sort

- The eighth card (#2) should be **inserted** in between the first (#1) and second (#3) cards



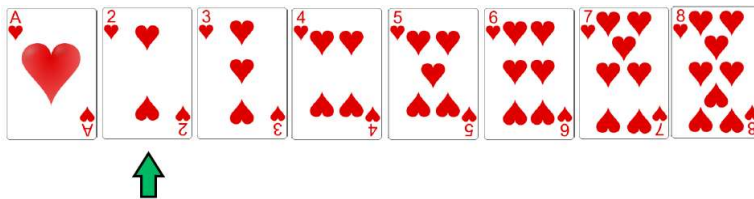
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Insertion sort

- The eighth card (#2) should be **inserted** in between the first (#1) and second (#3) cards



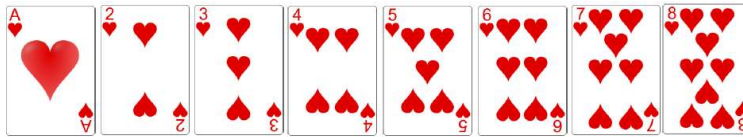
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Insertion sort

- The eighth card (#2) should be **inserted** in between the first (#1) and second (#3) cards



Finished!

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Sorting algorithms

- We have just confirmed there can be different ways to solve the same computational problem
 - can derive many different **algorithms** for solving the sorting problem
- Algorithm:
 - A set of concrete steps
 - Steps solve a problem or accomplish some task
 - Solve in a finite amount of time
 - The earliest algorithm known as Euclid's algorithm dates from 300 BC and used to find the Lowest Common Denominator of two numbers.
- The **Selection Sort** and **Insertion Sort** algorithms are only two ways of sorting a list of values
- New problem: Wish to sort a list of student records by their GPAs.
 - Would both of these algorithms work?
 - Yes! A hallmark of a good algorithm is that it is **general** → can solve a wide variety of similar problems

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Limits of Computation

What computer can do?	What computer cannot do?
Send email to a person if email address is known.	Find email of a person we met at a coffee shop.
Calculate difference investment options based on historical data.	Choose a perfect investment or predict success and future of companies.
Find information about colleges offering computer science course.	Make a perfect decision on the best school to attend.
Solve well defined problems.	Solve ambiguous problems.

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Unsolvable Problems

If a computer tries to analyze every possible sequence of moves in response to this opening in a game of chess, it will have to consider over 10^{43} different games.

Computer solving one trillion combinations per second will compute the perfect game of chess if we are patient enough to wait 10^{21} years, so it is only unsolvable in a practical sense.



Rise of Quantum Computers: <https://www.youtube.com/watch?v=WVv5OAR4Nik>

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To sum up...

- Computer science is the discipline of how to solve problems using computers
- We strive for efficient, general solutions that will work on a wide variety of problem types
- Although computer science has existed as a field for about 70 years, its roots in mathematics and computation go back thousands of years!
- CS is a very peculiar field
 - it relies partly on old mathematical ideas
 - it advances in development of new techniques at an extraordinary pace
- The semester you will be exposed to many of the modern topics in CS and also to some of the older mathematical content that is still very relevant today
- Watch BBC documentary exploring the development of computer:
https://www.youtube.com/watch?v=ApJSz_OrkiA

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Questions?

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