CSE 101: Introduction to Computational Thinking

Unit 1: What is Computational Thinking?

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
- Although computer programming is an important aspect of computer science, it would be wrong to say that "computer science equals computer programming"
- Rather, computer programs often provide (parts of) the solutions to challenging technological problems
- Computer science is also not:
  - computer literacy
  - computer maintenance/repair
  - a fast track to becoming a nerd

Are You a Good Fit for CS?

- You are a good fit for computer science if:
  - You are naturally curious and inquisitive.
  - You feel compelled to solve problems and puzzles.
  - You have a creative spirit and like making things.
  - You think in a logical, step-by-step manner.
  - You approach issues from unconventional angles.
  - You are willing to evolve and learn new things every day.
  - You are self-driven and have enough grit to endure long periods of frustration.
  - You know how to search the web for answers.
- List courtesy http://www.makeuseof.com/tag/what-is-computer-science

A Modern Computing Problem

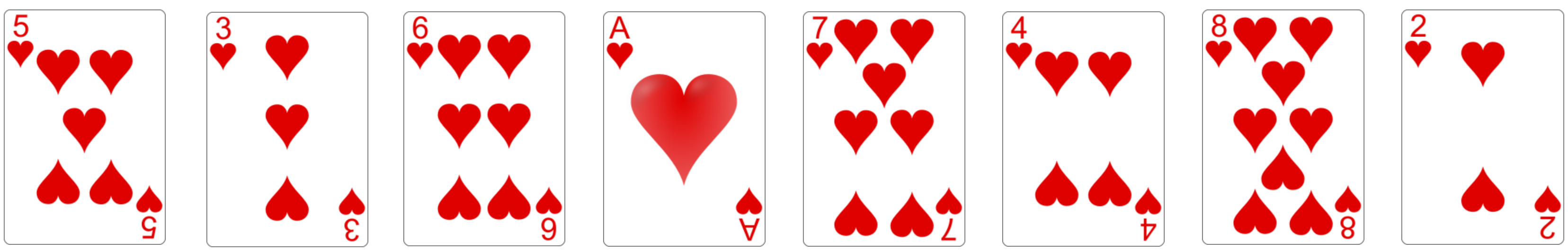
- Electronic health records are becoming increasingly important as time goes on
- Consider some of the issues (technical and otherwise) that would arise in solving the problem of providing a hardware/software system to medical professionals and other people who need access to digital medical records:
  - 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**

What is Computational Thinking?

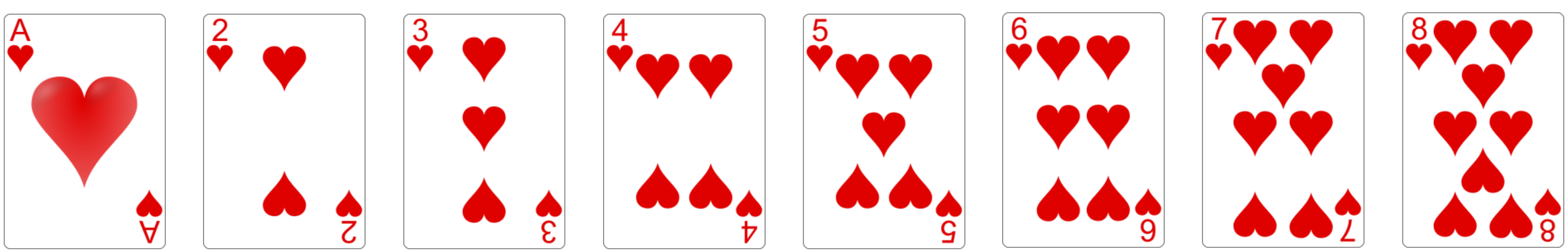
- Computational thinking refers to how computer scientists think – how they reason and work through problems
- Computer science encompasses many sub-disciplines that support the general goal of solving problems:
  - Computer theory areas: algorithms, data structures – these are the heart and soul of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

A Classical Problem: Sorting Data

- Suppose we have a deck of cards we want to put in order
- This is the important problem of **sorting** that arises very frequently in computer science
- To keep things simple, let’s just use the Ace thru 8 of Hearts
- We are given:

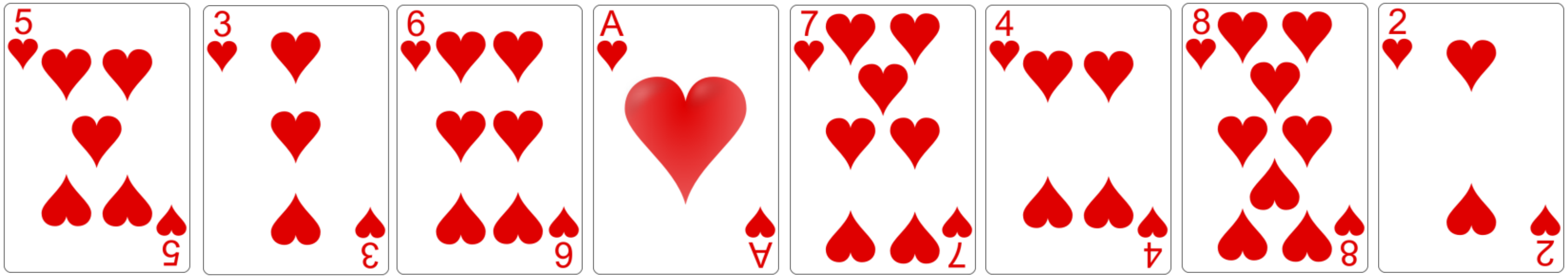


- But we want:



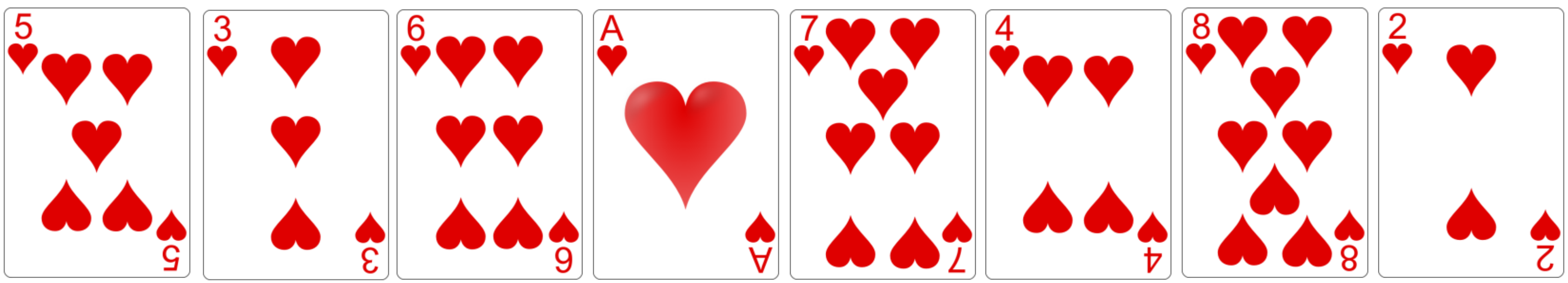
A Classical Problem: Sorting Data

- Imagine you wanted to explain to a young child how to put the cards in order. What steps would you give?



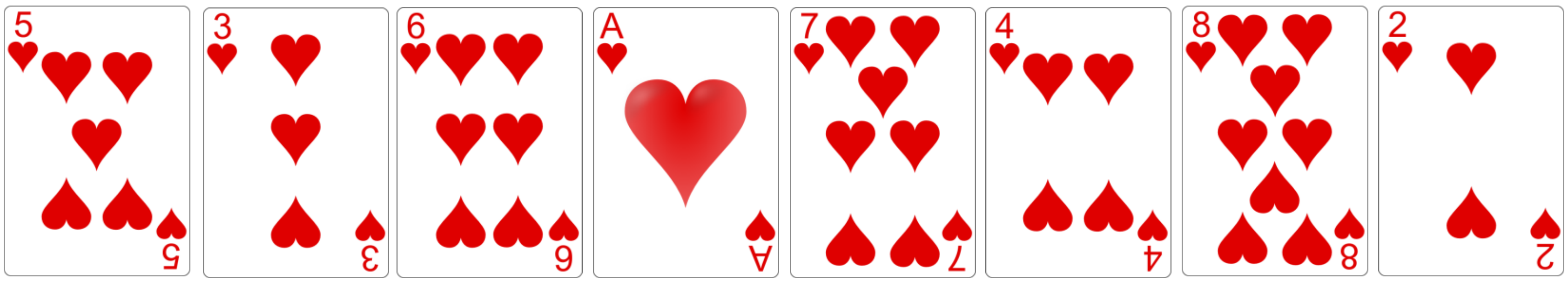
A Classical Problem: Sorting Data

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



A Classical Problem: Sorting Data

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



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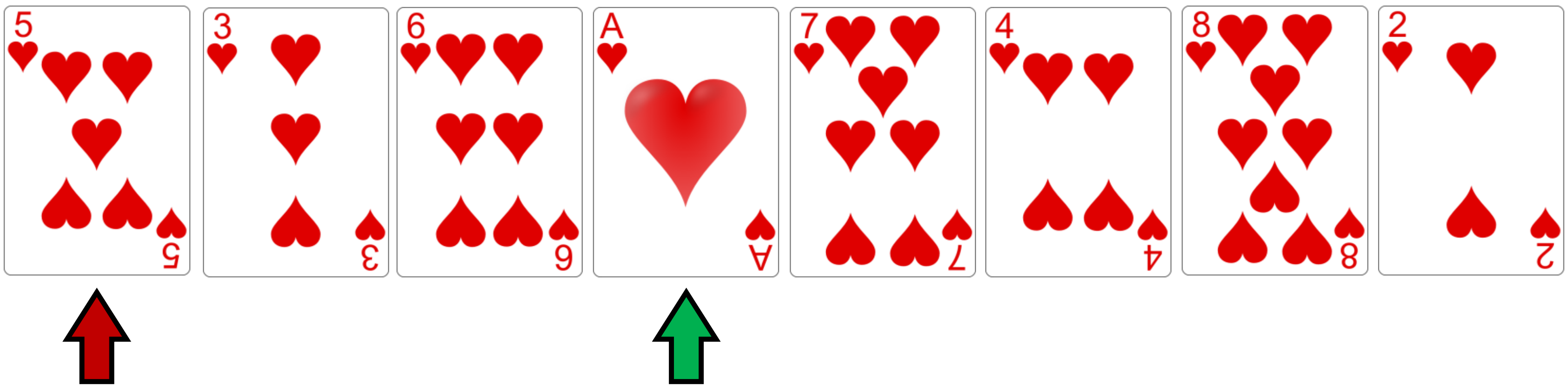

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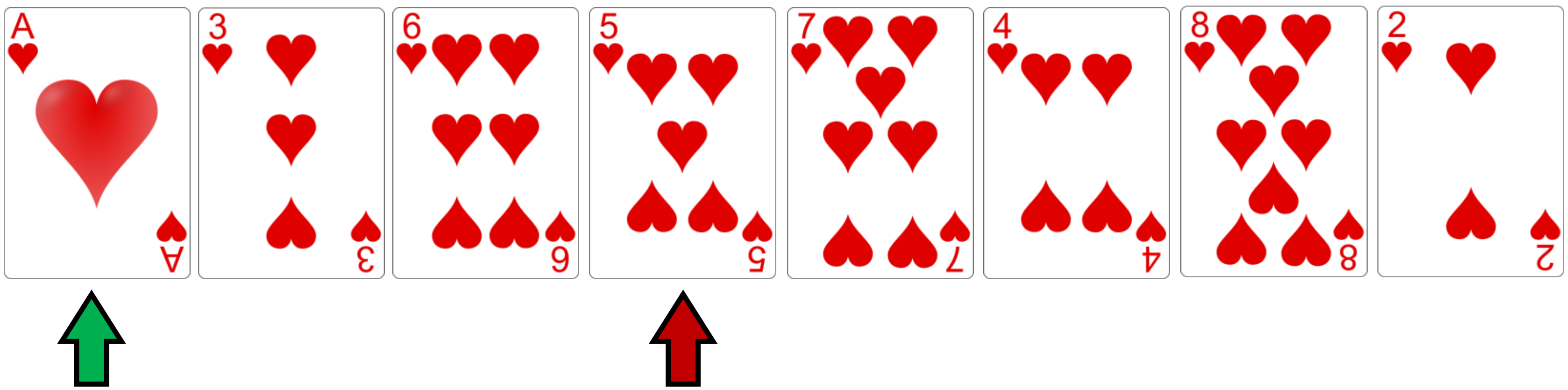
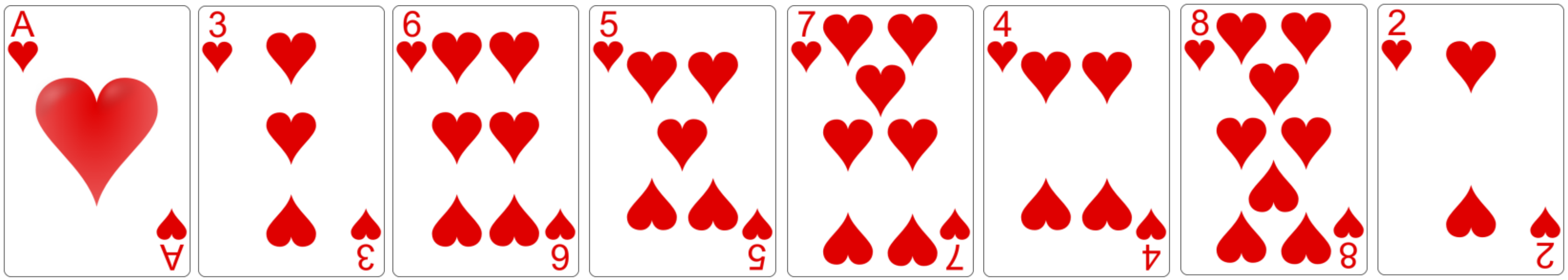


A Classical Problem: Sorting Data

- Now, find the second-smallest item and exchange it with the card in the second position



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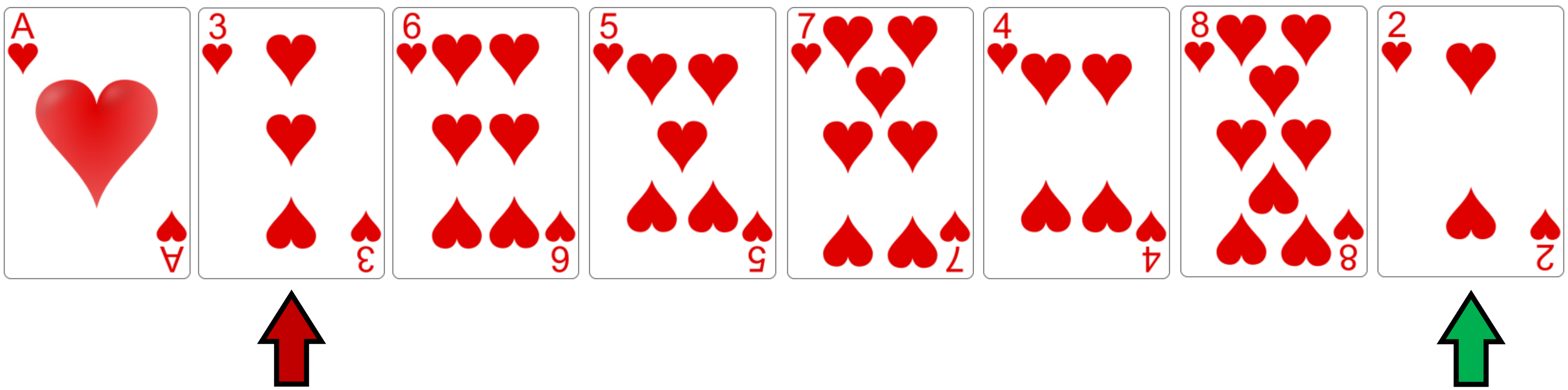

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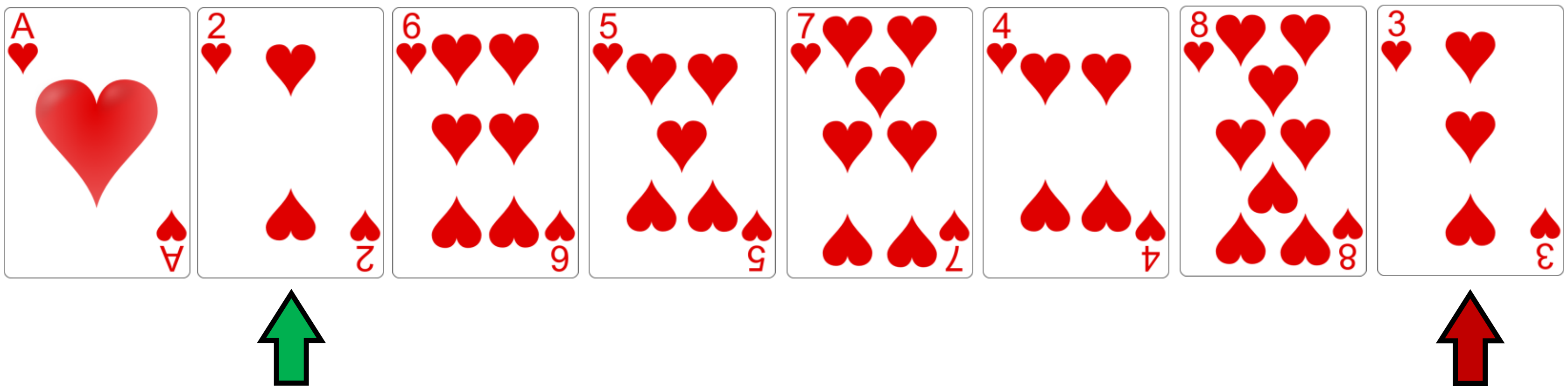
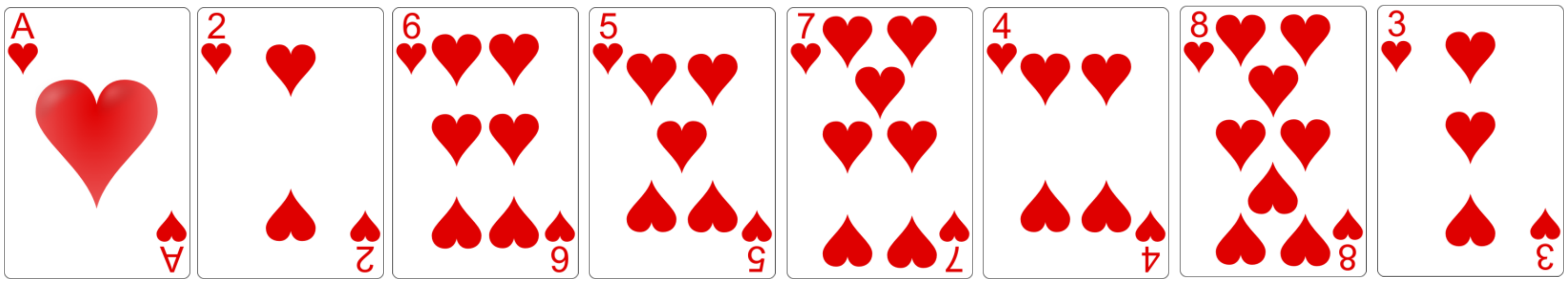


A Classical Problem: Sorting Data

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



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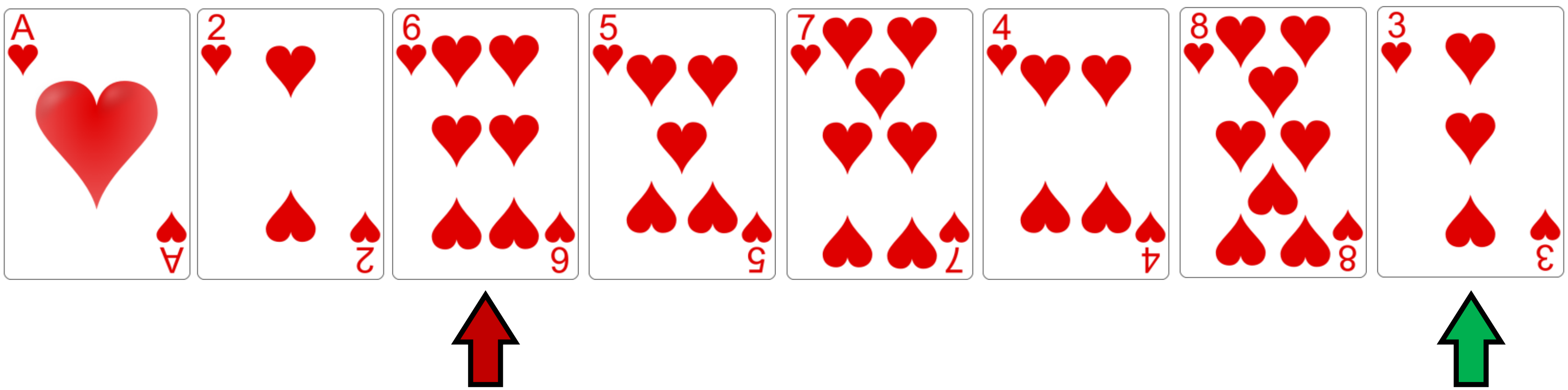

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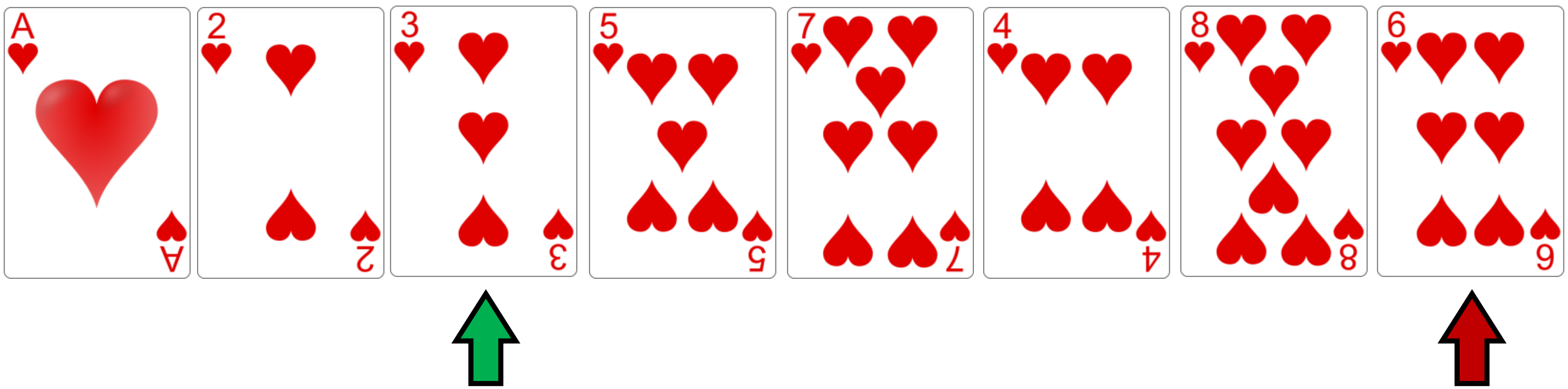

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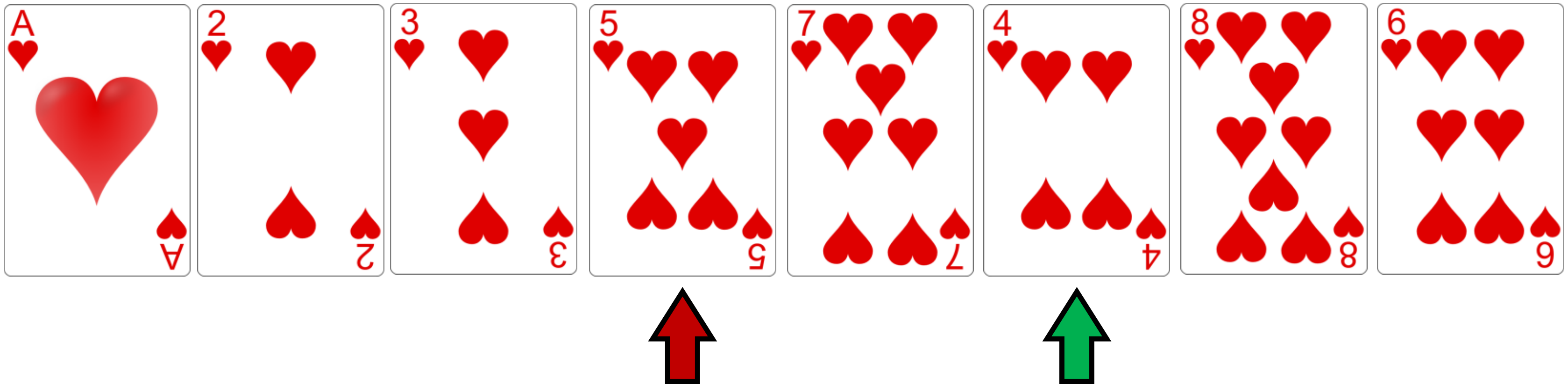

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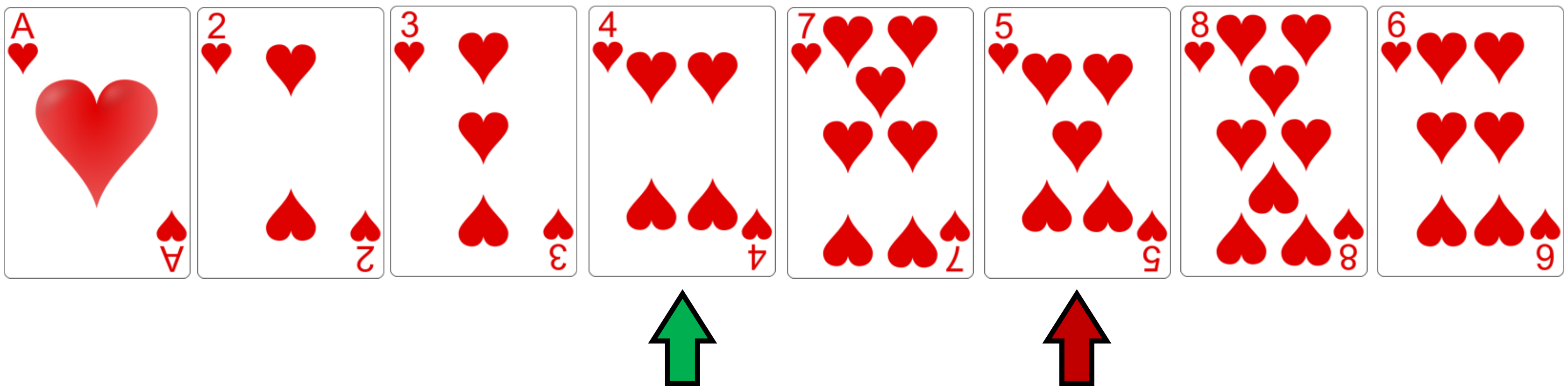

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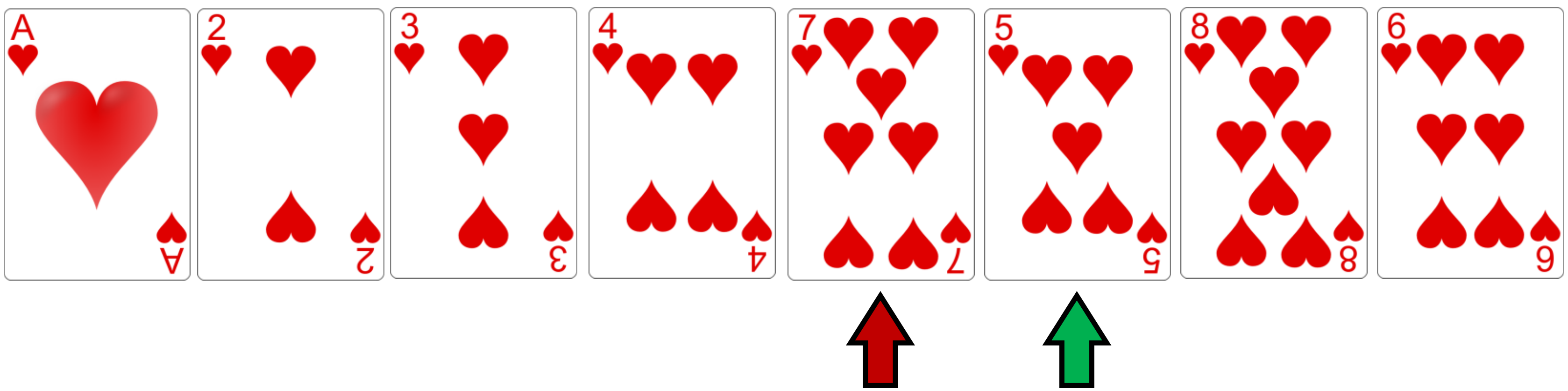

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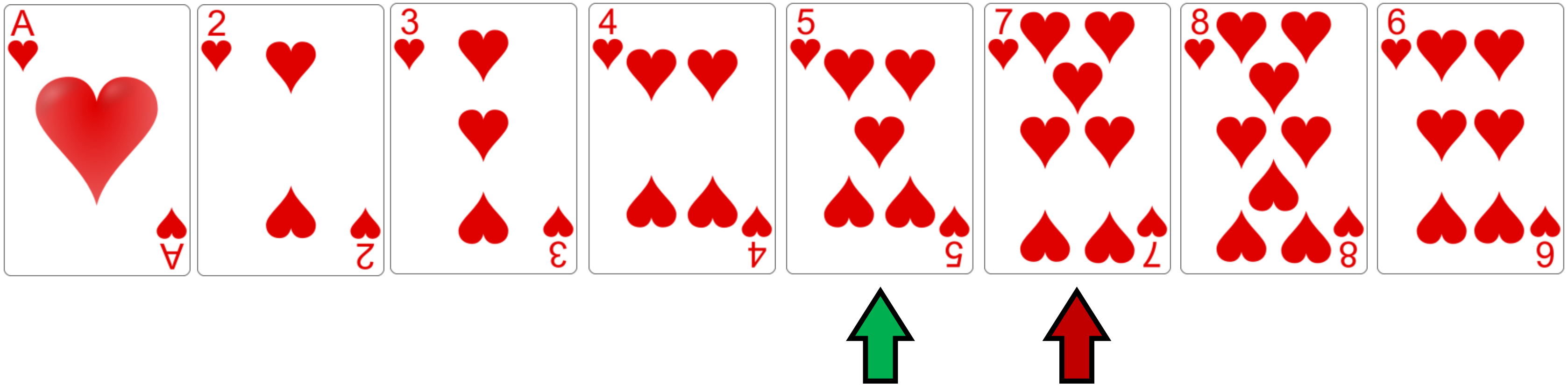

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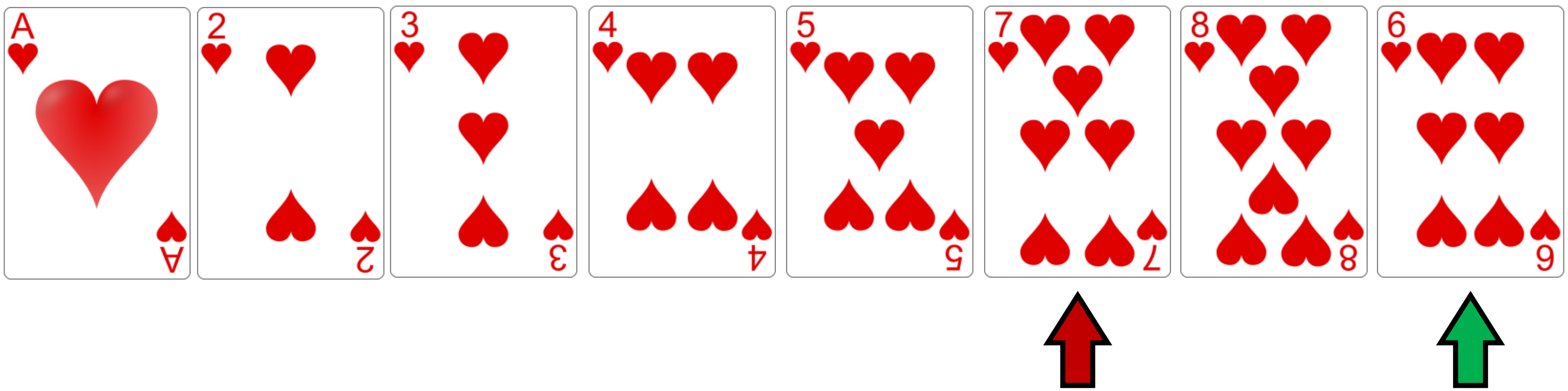

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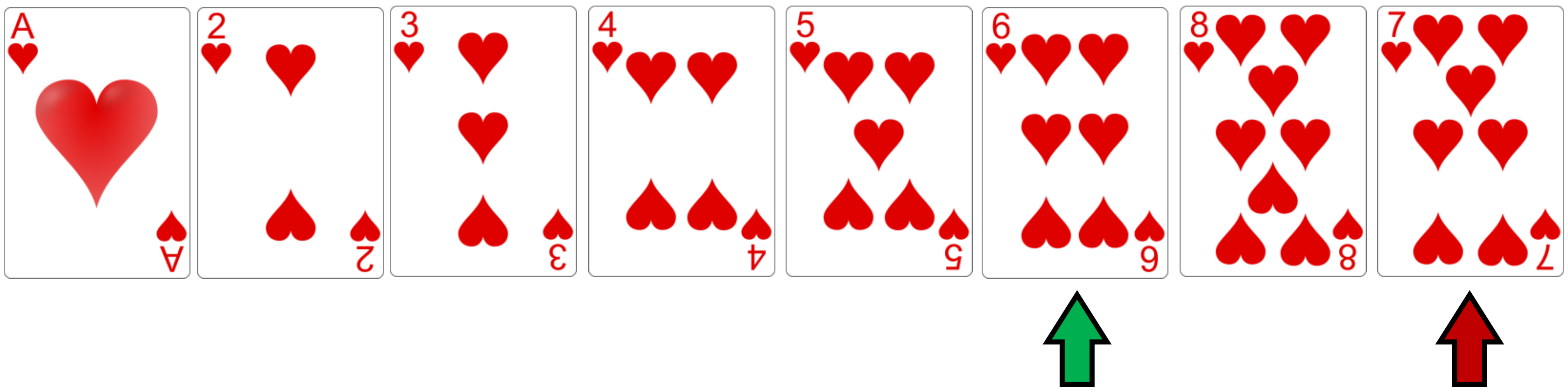

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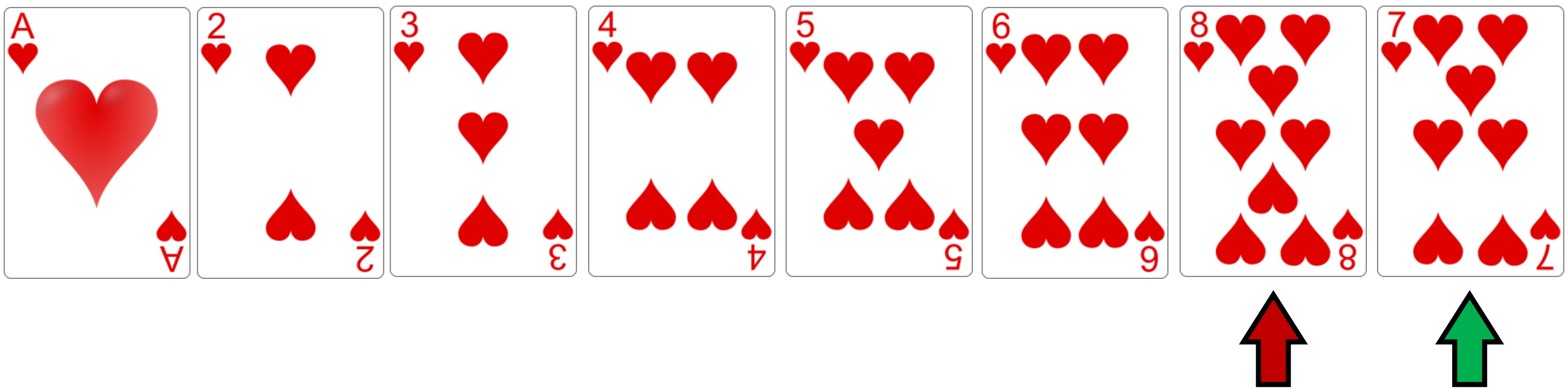

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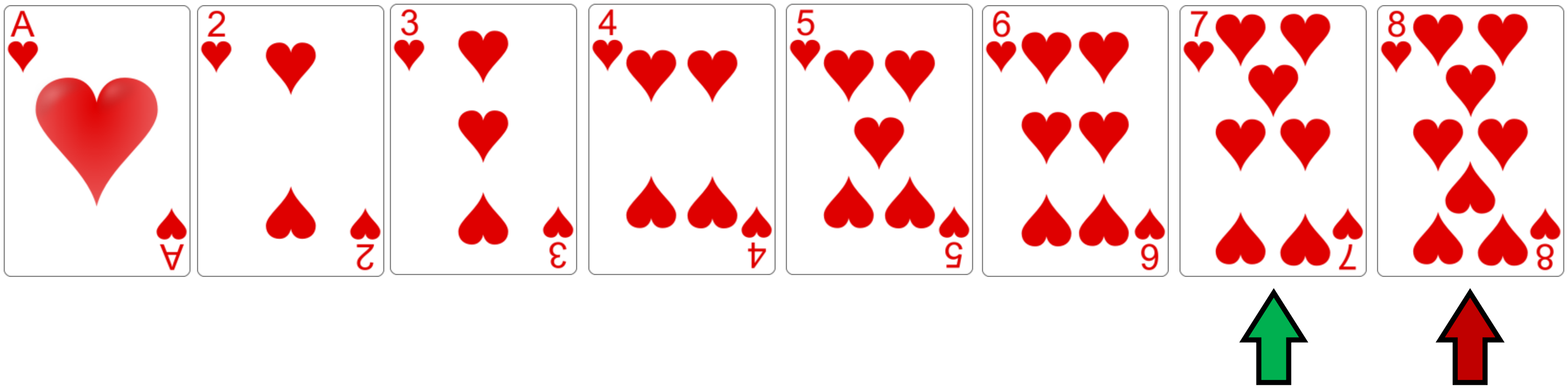

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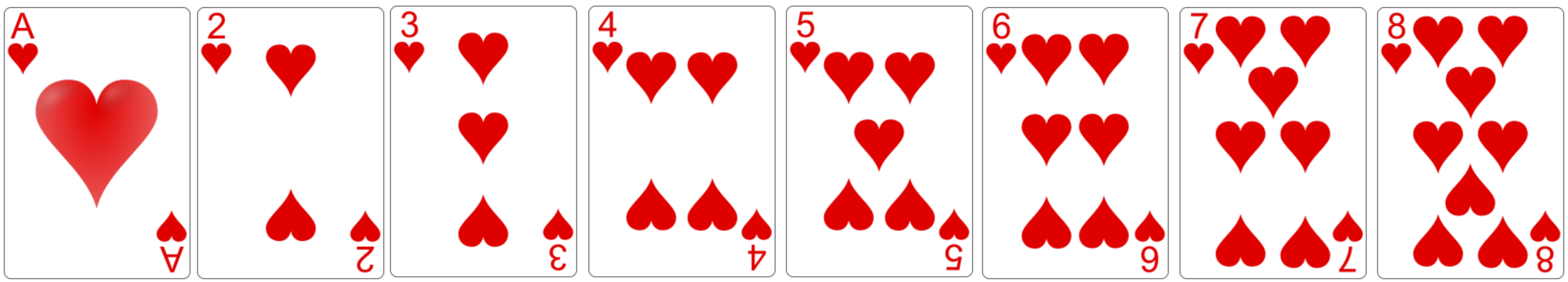
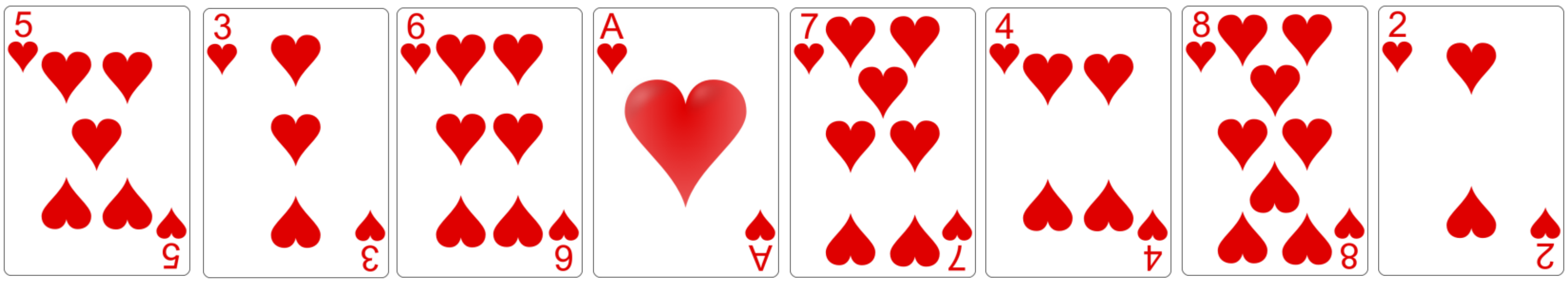


Finished!

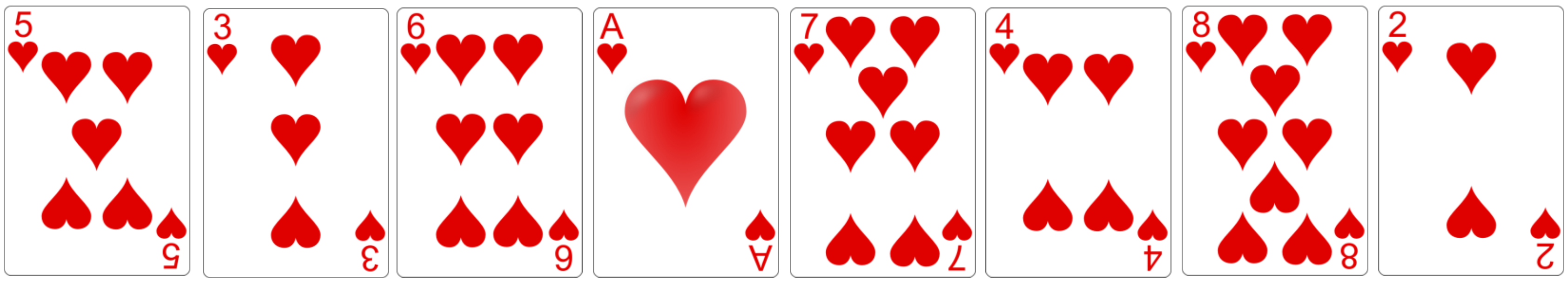
A Classical Problem: Sorting Data

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



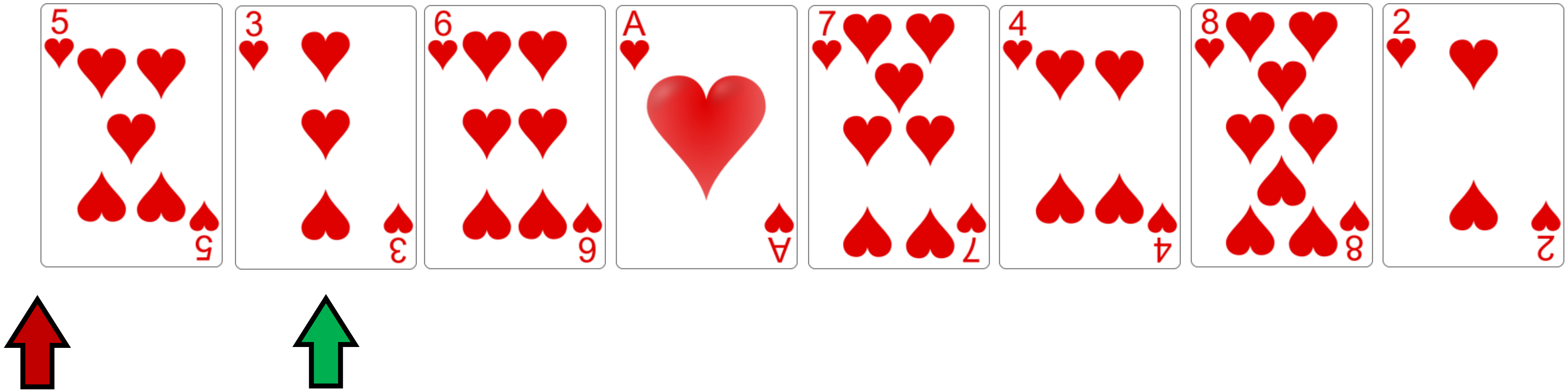
A Classical Problem: Sorting Data

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



A Classical Problem: Sorting Data

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



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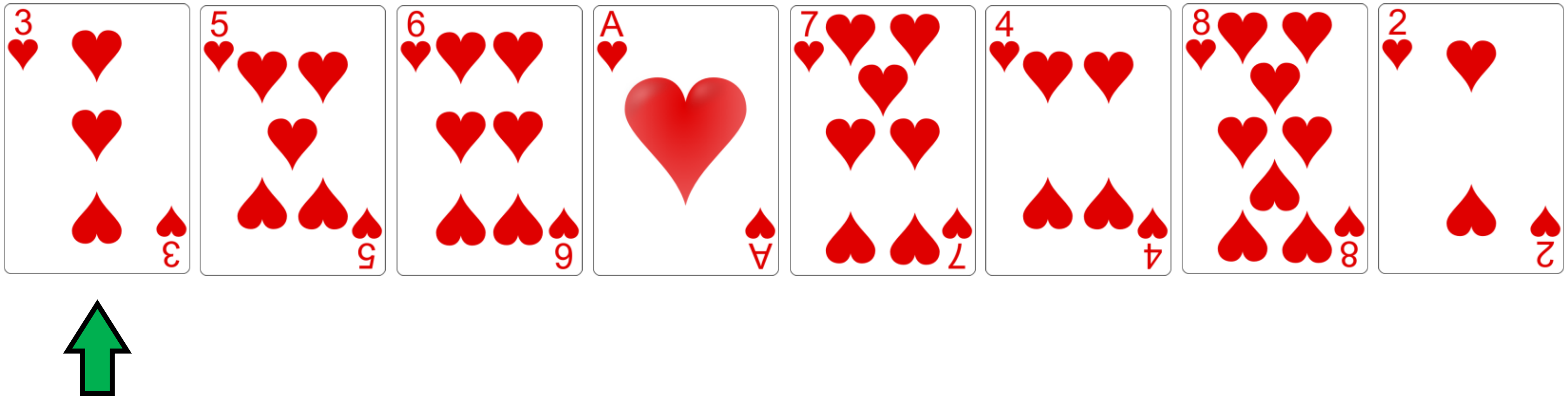
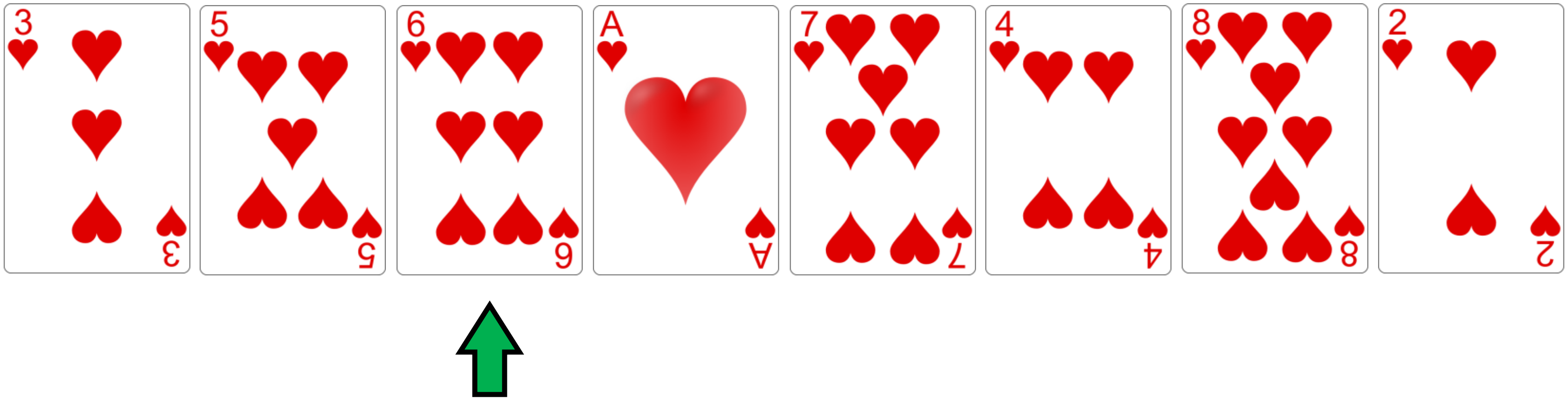


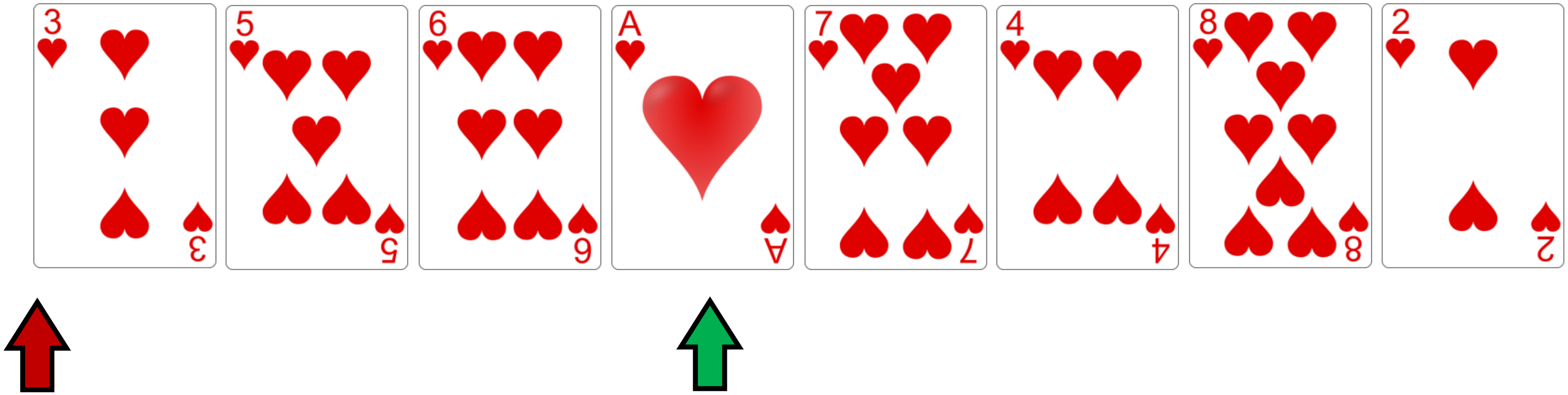
A Classical Problem: Sorting Data

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



A Classical Problem: Sorting Data

- 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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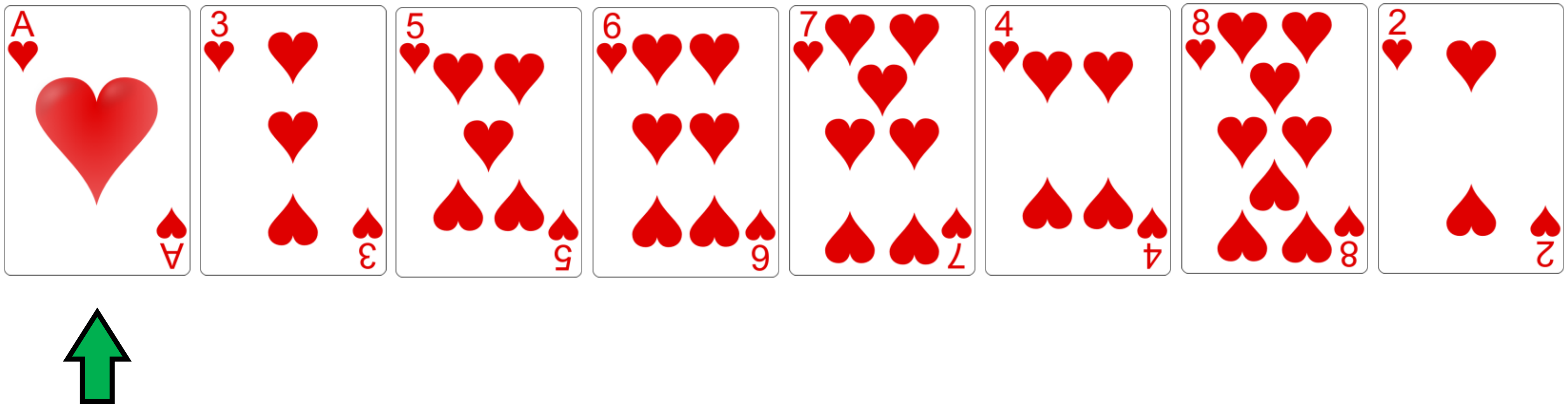
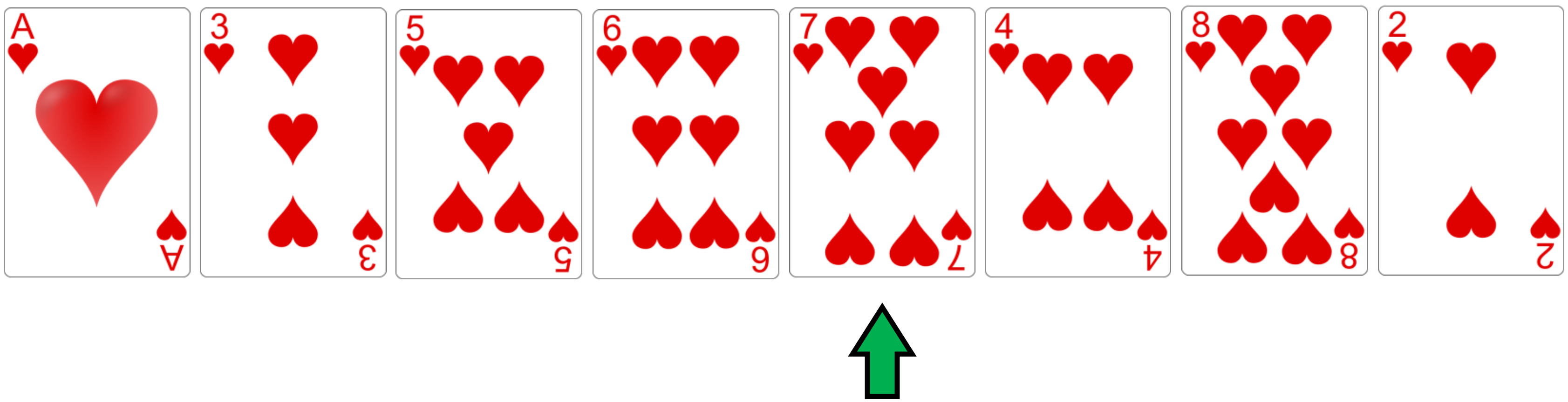


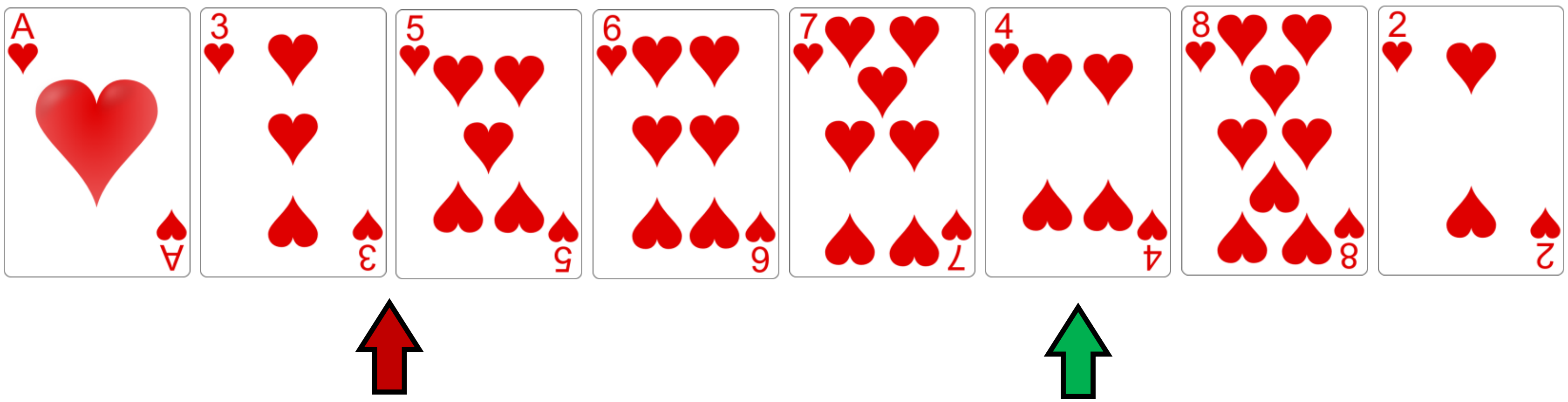
A Classical Problem: Sorting Data

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



A Classical Problem: Sorting Data

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



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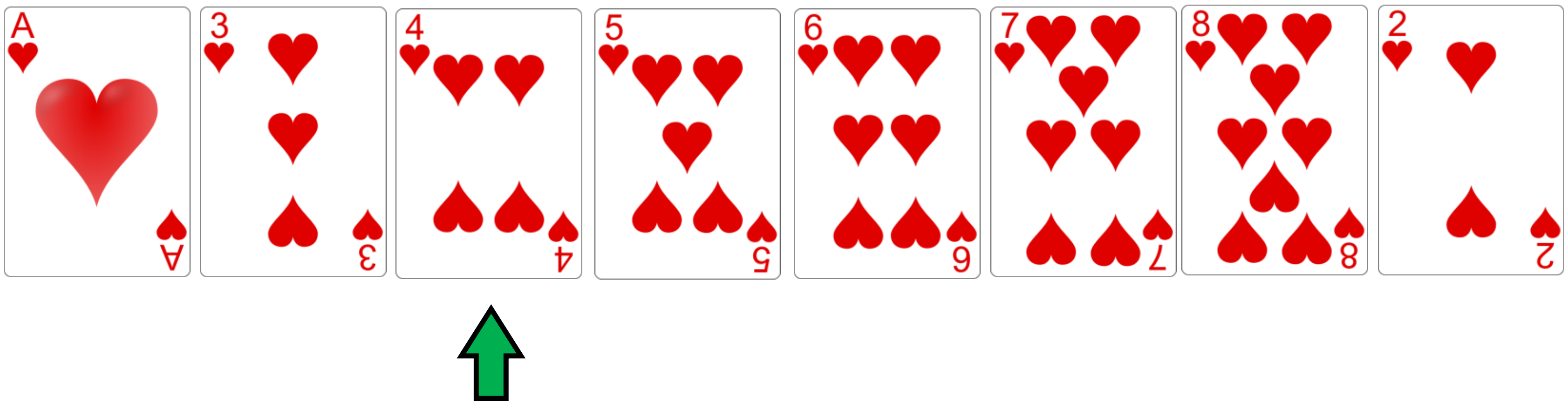
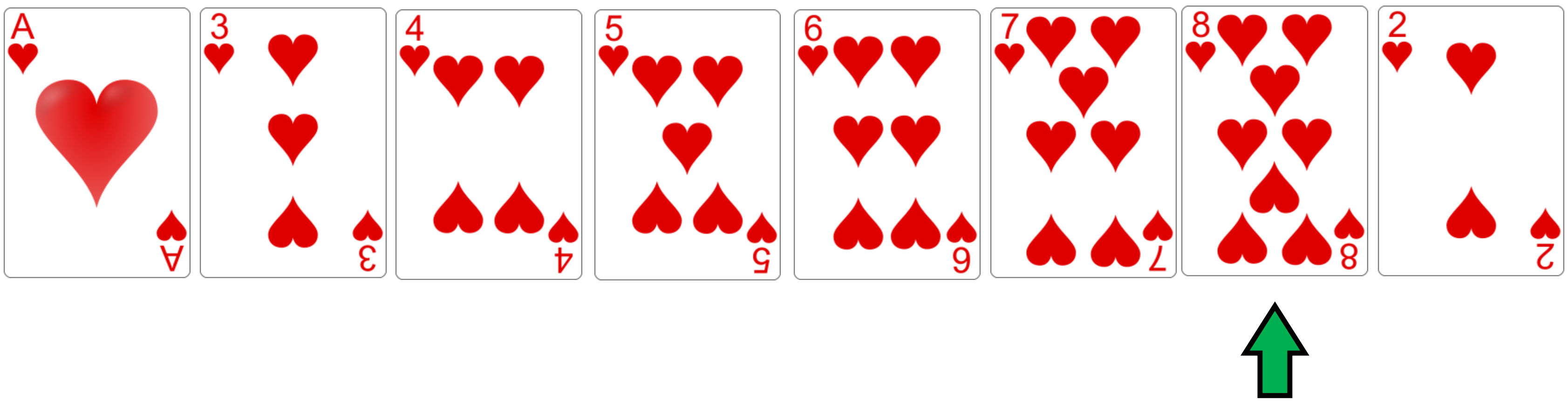


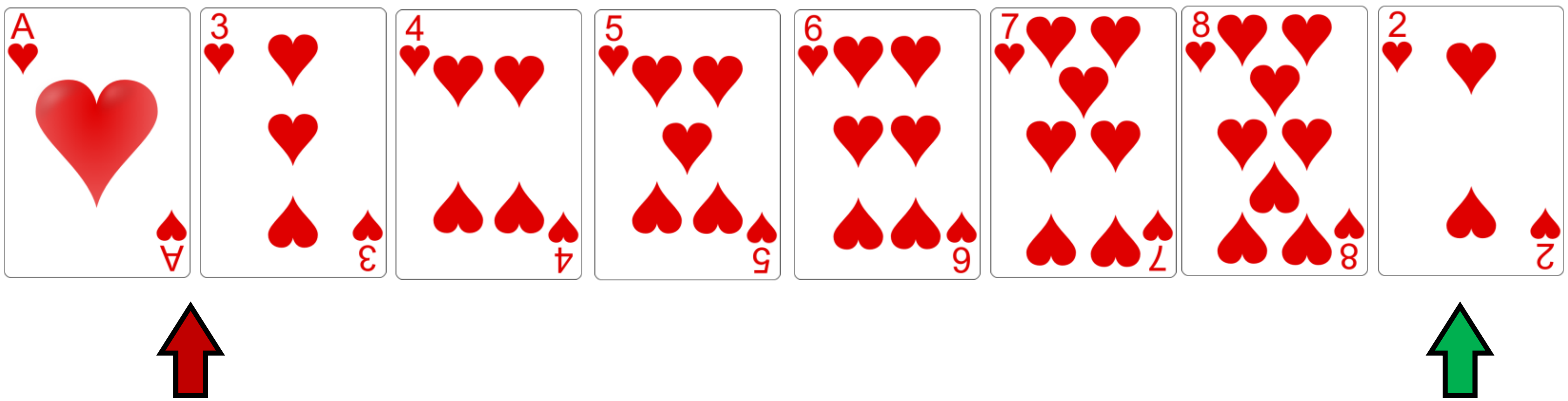
A Classical Problem: Sorting Data

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



A Classical Problem: Sorting Data

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



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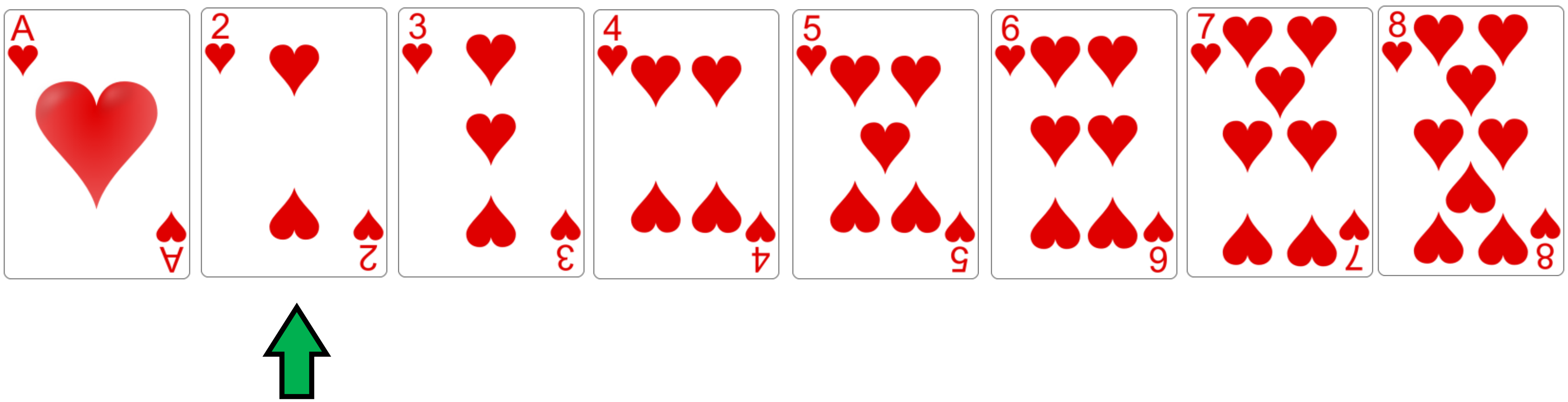

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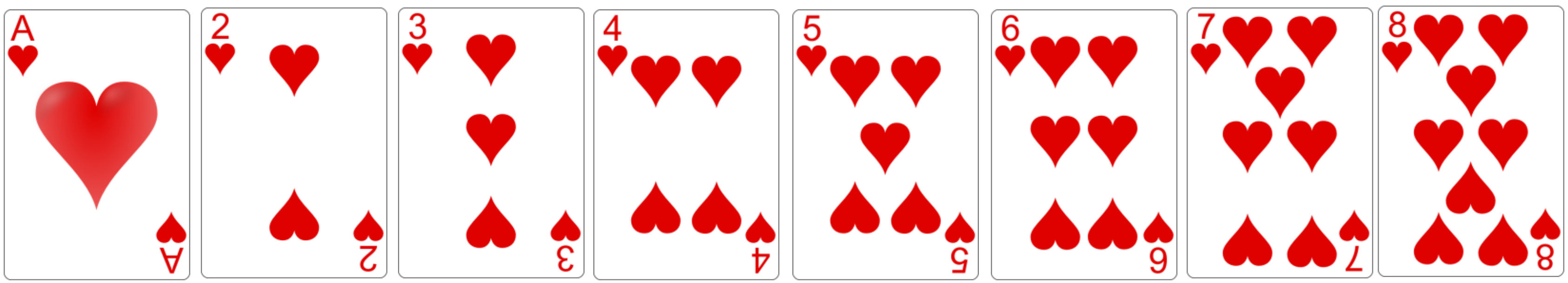


Finished!

Algorithms for Sorting

- We have just confirmed is that there can be different ways to solve the same computational problem
- That is, we could derive many different **algorithms** for solving the sorting problem
- An algorithm is a set of concrete steps that solve a problem or accomplish some task in a finite amount of time
- For example, the Selection Sort and Insertion Sort algorithms are just two ways of sorting a list of values
- Suppose we wanted to sort a list of student records by the students' GPAs. Would both of these algorithms work?
- Yes! A hallmark of a good algorithm is that it is general and can work to solve a wide variety of similar problems

Computing Systems

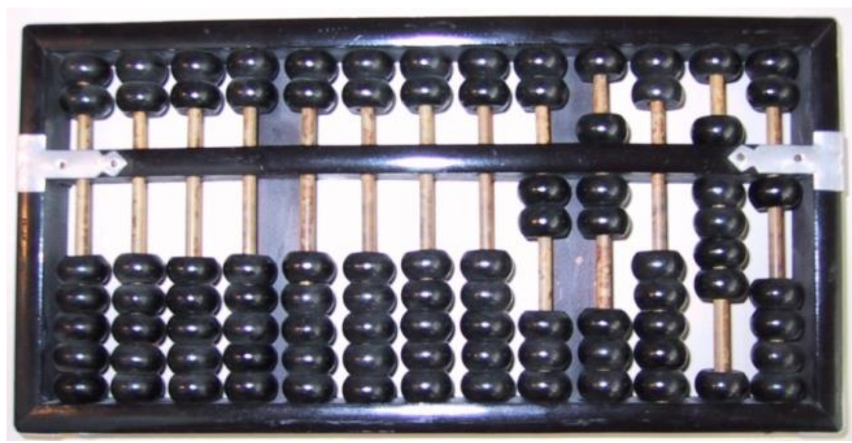
- Let's take a tour of modern computing systems
- A computing system consists of two major parts: the **hardware** and the **software**
- What are some of the hardware elements of a computer?
  - Screen, keyboard, mouse
  - Central processing unit, main memory
  - Hard drives and other storage units
- What kinds of software exist?
  - Applications software, like office productivity programs, video games, web browsers
  - Systems software, like operating systems, database systems

Computing Systems

- Can hardware exist without software?
  - Sure, but it's not very useful, is it!
- 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
- We can throw in one more part to a computer system: data
  - The software needs some kind of data to process: numbers, text, images, sound, video

A Quick History of Computing

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



- What does an abacus have to do with laptops, smartphones and tablet computers???

A Quick History of Computing

- Modern computers borrow four important concepts from the abacus:
  1. Storage
  2. Data Representation
  3. Calculation
  4. User Interface

1. Storage: an abacus can store only numbers, but numbers are the most fundamental kinds of **data** we deal with in modern computing.

- In a modern computer, all data – text, images, audio, video – is represented using binary numbers (ones and zeros)

A Quick History of Computing

2. Data Representation: the abacus represents numbers using beads on spindles.

- Modern computers employ a variety of techniques – magnetic, optical, electrical – for representing data on a variety of storage media

3. Calculation: by moving beads on the abacus's spindles, the 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

A Quick History of Computing

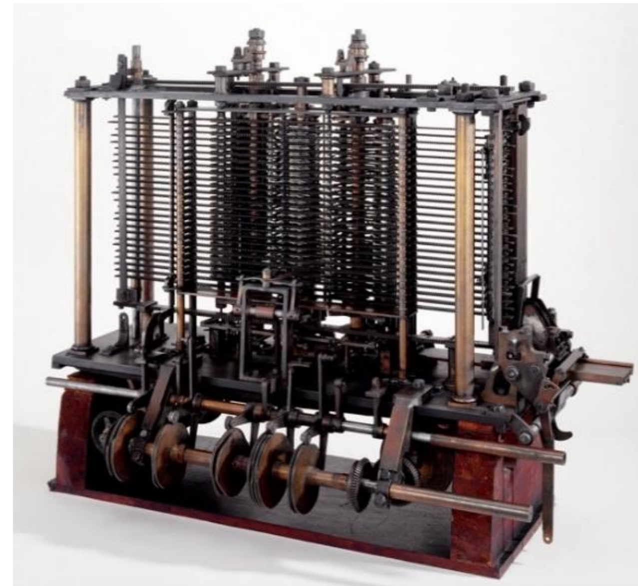
- In the 17th century people began tinkering with physical devices that could do computations and calculations
- Blaise Pascal – the French mathematician and philosopher – was one of a few people to design and build a physical calculator

- His calculator could do only addition and subtraction
- Input is given using dials, and output is read on small windows above each dial

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!

Programmable Devices



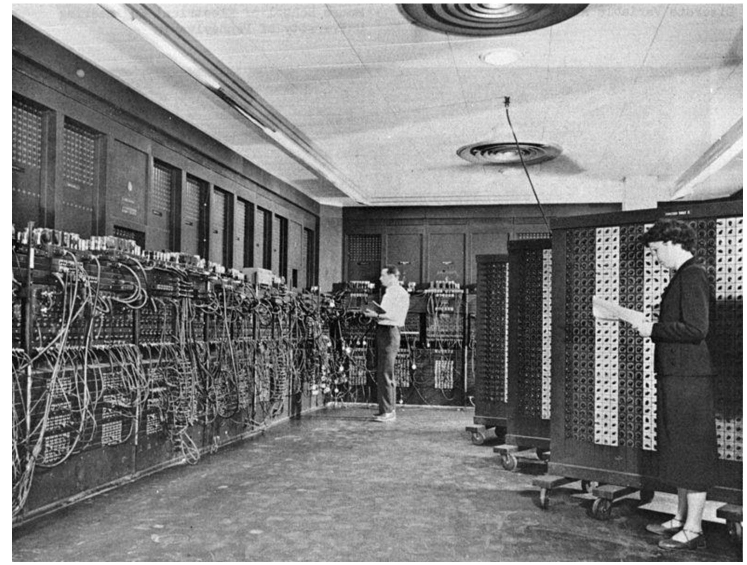
- Another leap forward came in the 19th century with Charles Babbage's design of the Analytical Engine, a mechanical, programmable computer
- It was never built in Babbage's time due to a lack of manufacturing capabilities (ahead of his time!)
- The design called for punched cards to be fed into the machine to program it to perform mathematical calculations
- Output would go to a printer or punched cards

Programmable Computers

- We could go on and on with the history of computing, so let's move forward to the 20th and 21st centuries
- A modern computer has three basic requirements:

1. It must be electronic and not exclusively mechanical.
2. It must be digital, not analog. This means that it uses discrete values (digits) and not a continuous range of values to represent data. (Contrast a digital thermometer with an alcohol-based or mercury-based one.)
3. It must employ the **stored-program concept**: the device can be reprogrammed by changing the instructions stored in the memory of the computer.

Programmable Computers



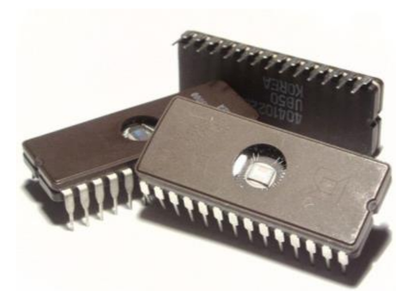
- The ENIAC (Electronic Numerical Integrator and Computer) of the 1940s was among the first computers to employ the stored-program concept
- Note that a modern computer has four major kinds of components:
  - Input device(s) – examples?
  - Output device(s) – examples?
  - Memory – for data storage,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

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
- We're not talking about storing data on hard drives, flash drives or CDs – we're talking about the **main memory** of the computer, sometimes called the **RAM** (random access memory)
- A modern processor reads the **machine instructions** *stored* as ones and zeroes in the main memory and then executes those instructions in sequence
- The key point here is that these instructions can be changed to easily reprogram the computer to do new tasks

Transistors

- Over time, a variety of devices was used to represent the 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**
- They 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, and external pins to attach it to a **circuit board**

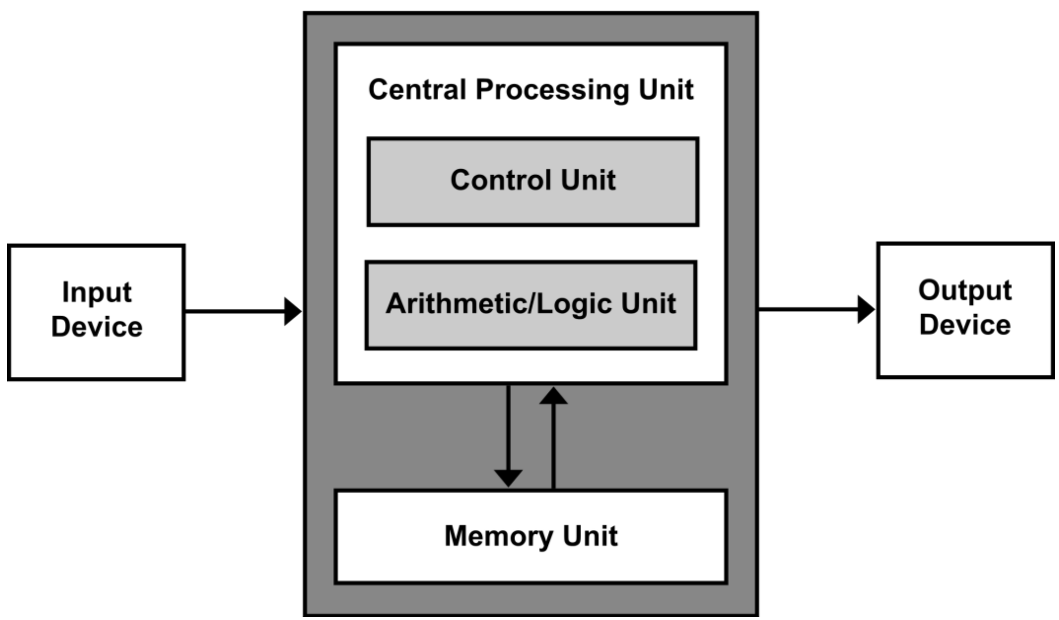


Transistors

- Noyce and businessman Gordon Moore commercialized this technology by co-founding Intel Corporation in 1968
- As manufacturing technologies improved in the 1950s and 1960s, engineers were able to pack many more transistors per unit area on silicon wafers
- **Moore's law:** Moore observed that the number of components within an integrated circuit was doubling every 18 months, a trend which has continued pretty steadily since then. But transistors can be only so small!
- To combat miniaturization challenges, manufacturers like Intel and AMD (Advanced Micro Devices) now make processors that feature multiple processing **cores** that perform calculations in parallel with each other

Modern Computer Architecture

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



- We'll see now how they work together to form a functioning computer

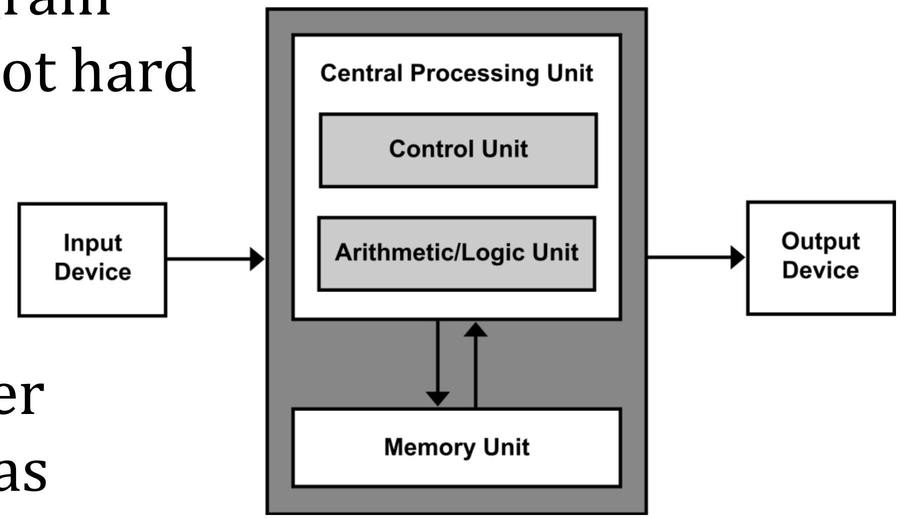
Modern Computer Architecture

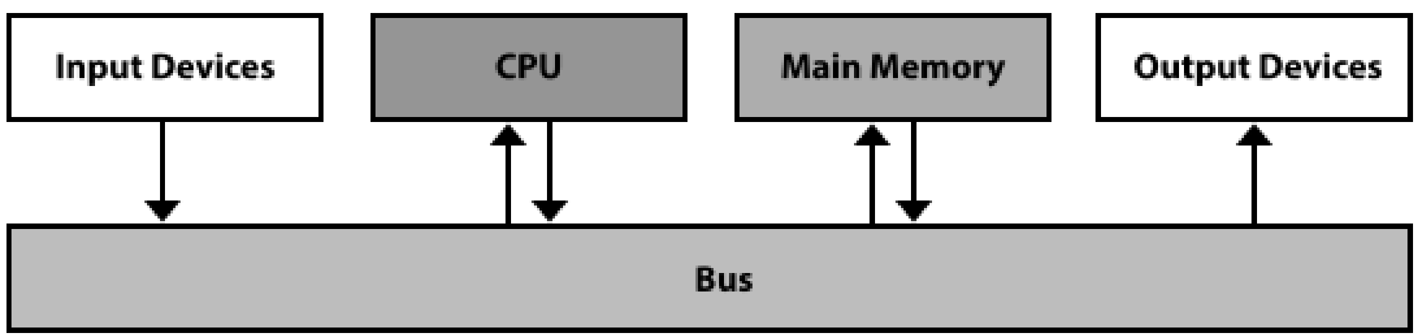
- In a modern computer, the major components in a von Neumann machine reside physically in a circuit board called the **motherboard**
- The CPU, memory, expansion cards and other components are plugged into slots so that they can be replaced
- Hard drives, CD drives and other storage devices are connected 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 CPU's **control unit** is the main organizing force of the computer and directs the operation of the ALU


MSI
TRUEPOWER TRIO

Modern Computer Architecture

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

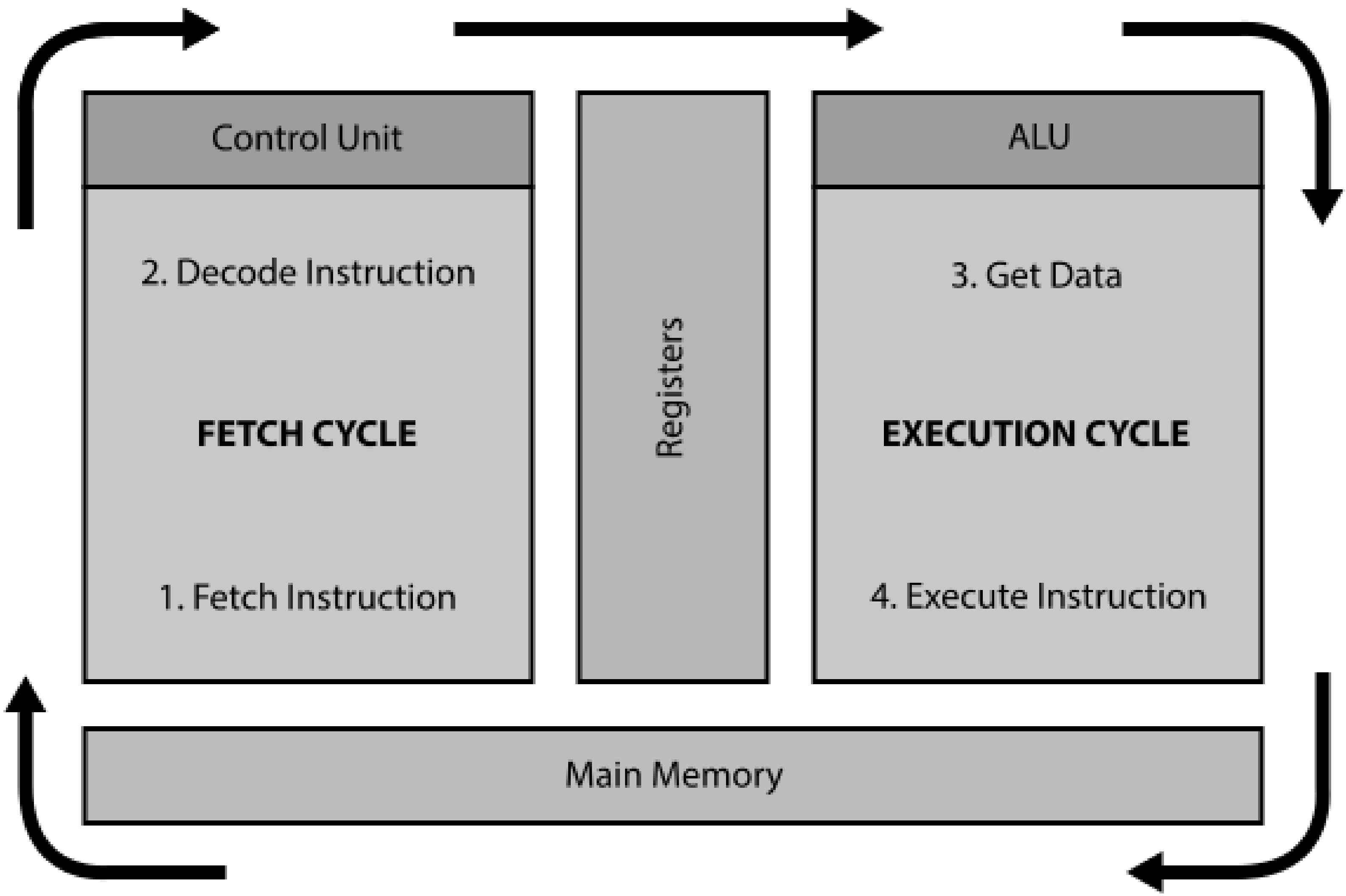




The Fetch-Decode-Execute Cycle

- 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**

The Fetch-Decode-Execute Cycle



What About the Software?

- Software consists of instructions for the CPU to execute
- The problem is that CPUs “understand” something called **machine language**, which consists of zeroes and ones
- A single instruction for a modern computer might consist of some combination of 32 or 64 zeroes and ones!
- Most programming now is done using **high-level programming languages**, which consist of English and English-like words with some mathematical notation thrown in
- This semester you’ll be learning the basics of Python, which is a popular and easy-to-learn, high-level programming language

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 modern computer science has existed as a field for about 80 years, its roots in mathematics and computation go back thousands of years!
- CS is a very peculiar field in that it relies partly on old mathematical ideas, yet it advances in development 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