Computer Science Future

15-110 – Wednesday 05/05

Announcements

- **Check6-2** revision deadline was today

- **Hw6** is due **Friday 05/07 at noon EST**
  - No revision deadline!! Just submit what you've got done at noon.
  - Even if you don't make much progress on Hw6, still submit – you get 40/100 points for working Check6-1 and Check6-2

- Final exam
  - Practice problems will be posted tomorrow

Learning Goals

- Recognize and describe the impact of key future computing ideas, including:
  - **cryptocurrencies**
  - **NFTs**
  - **5G**
  - **deepfakes**
  - **virtual reality**
  - **quantum computing**

Cryptocurrencies

How does money work?

A dollar bill does not have any intrinsic value; it's only worth $1 because we all agree it should be, and we all trust it will continue to hold that value.

This is how all currencies work! Usually we trust currencies because they are backed by a powerful system (a country or government), and we trust that system to not start printing a lot more money.

Cryptocurrencies are just like normal currencies, except that they are **independent** and **decentralized** – they are not backed by a country. So how can we trust in their value?

Collective Accounting

In most cryptocurrencies, the value of the currency is protected by the **collective** that uses the currency. Every person in the collective keeps track of the financial record of the system **independently**.

Whenever someone makes a transaction, they send that information as a message to the rest of the collective. Everyone in the collective can contribute computing power to verify the transaction on their own personal record. This is called **mining**. Occasionally, miners receive a bit of bonus bitcoin for successful verification; this helps incentivize the distributed work.

If a majority of people (weighted by computing power) accept a transaction, it becomes official and is added to the public record.

Everything is public, but you can only spend money from an account if you have that account's **private key** – it uses asymmetric encryption!

Example Transaction

Suppose Soren wants to send Ariana 0.05 bitcoin.

Soren posts a transaction to the collective (using his **private key** to encode) saying he wants to send 0.05 bitcoin to Ariana's account (using her **public key**).

Individuals among the collective use computing power to verify that both account numbers are legitimate and that Soren has enough money to make the transaction.

When 50% of the collective has verified the transaction, it becomes part of the official record.

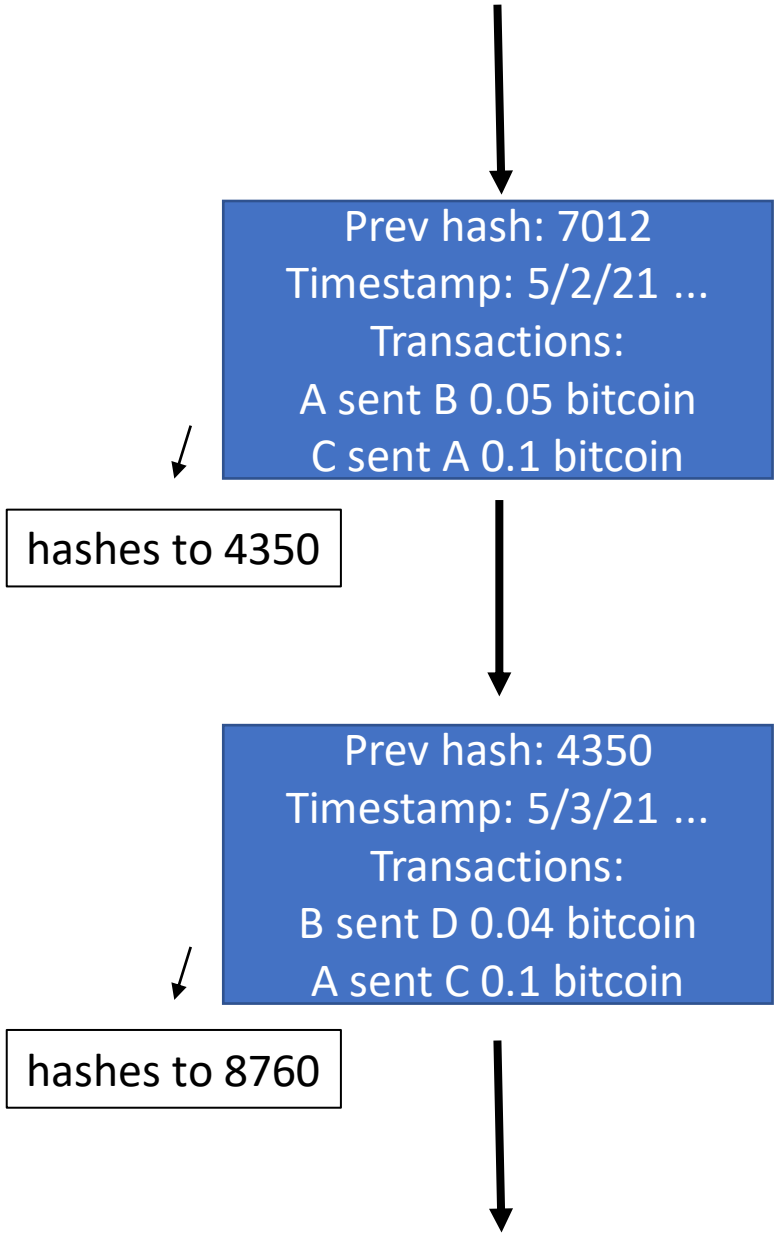
Discuss: What happens if an individual controls more than 50% of mining?

Blockchain

The collective ensures that no one spends more money than they have through a transaction, but how does it ensure that no one modifies the record? They use a **blockchain**.

A blockchain is just a data structure used to store records over time. It is literally a chain (list!) of **blocks**, where each block contains information about the state of the financial system at that point in time (by listing transactions that have been made).

The blockchain is **secure** because every block contains a hash of the block that came before it. This means that no one can go back into the blockchain and edit one of the older records to give themselves money; this would break the hashes on all the subsequent blocks, and people would notice.



Bitcoin

Bitcoin is a specific type of cryptocurrency. It was created by a mysterious individual(s) called Satoshi Nakamoto in 2008. To this day, no one knows who this is...

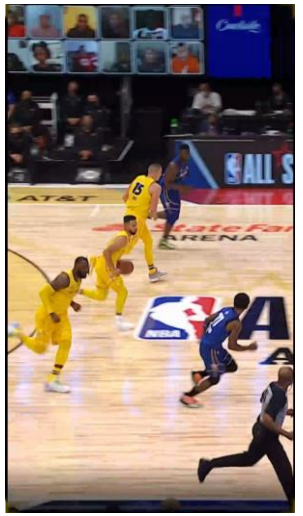
The code was made open-source in 2009. Link here: github.com/bitcoin/bitcoin

Bitcoin started out as worth a few cents per bitcoin. It skyrocketed to $20k per bitcoin in 2017, then dropped in value; over the past year it went up again and is now worth $56k per bitcoin!

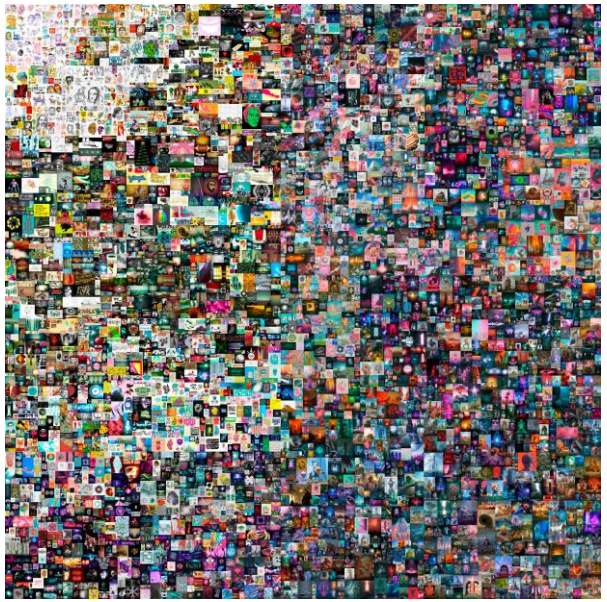
Learn more here [start at 2:41] : www.npr.org/sections/money/2011/07/13/137795648/the-tuesday-podcast-bitcoin

NFTs

NFTs are Ownable Digital Items



An NFT (Non-Fungible Token) is a digital item of some sort that is **owned** by a particular person. NFTs have grown very popular since 2020 and are used to let people purchase digital items like sports gifs or digital art.



The item can still be posted publicly for anyone to see, but there is **digital certificate** that marks the item as officially owned by a particular person. Importantly, the certificate cannot be copied; it is unique to the owner.

How is this possible?

Blockchain Again!

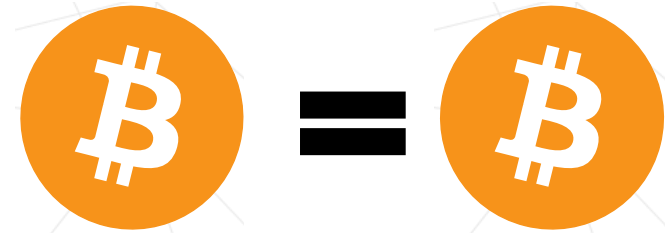
The digital certificate associated with an NFT uses a **blockchain** to track the chain of ownership.

You can often copy the digital item itself, but if you don't have the certificate, you don't actually own it. It's like printing a copy of the Mona Lisa – just because you have a copy of the painting doesn't mean you own the original.

This is similar to how collectible items are verified in real life with a paper certificate.

Difference from Cryptocurrencies

NFTs are different from cryptocurrencies because they are **non-fungible-** one NFT is not equivalent to another. For example, two NFTs of different NBA shots might be worth extremely different amounts of money. This is different from Bitcoin, as one bitcoin is worth exactly as much as another.



It's like comparing cash to collectible trading cards. You can exchange a $20 bill for another $20 bill, but two collectible trading cards may be worth very different amounts, even though they're printed on the same cardstock.

In fact, collectible trading cards are an excellent analogy for NFTs. They're really just collectible items on the internet.

Ups and Downs of NFTs

There's a lot of debate about whether the recent surge in interest around NFTs is a fad or something that will last.

With both cryptocurrencies and NFTs, there is a major concern around the **carbon footprint** of these digital items. Verifying transactions on a blockchain takes a great deal of computing power, and each time an NFT is sold, it adds another transaction to the blockchain.

On the other hand, NFTs have opened up new possibilities for artists. Some NFT blockchains can be set up so that every time the NFT is sold, a commission is sent back to the original artist. This could move more of the wealth associated with the fine art market back into artists' hands.

Learn more here: https://www.npr.org/2021/03/09/975450173/the-200k-nba-nft

5G

Cellular Networks

Our phones use **cellular networks** to place calls, send messages, and also download data from the internet.

Just like with the internet, these networks have different **protocols** that define how they work. Your phone probably runs on 3G, 4G, or maybe 5G. These are three different generations of wireless protocols.

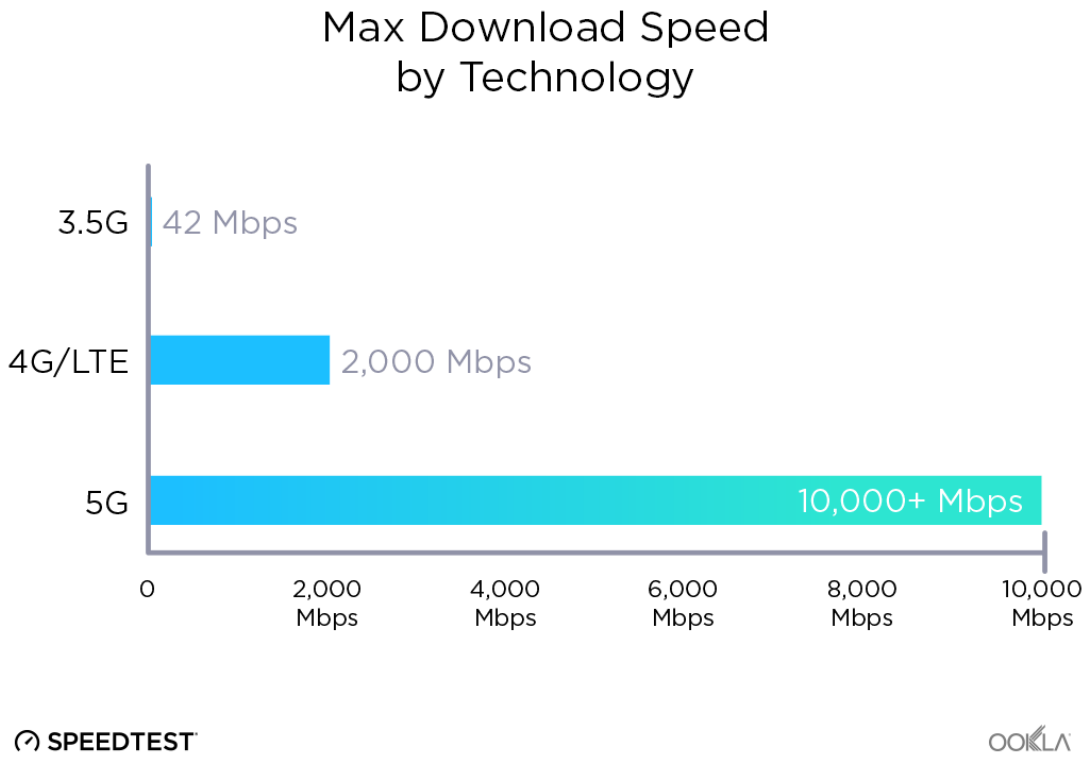
Each new generation broadcasts data at a different **frequency** and can usually transmit data more quickly than the previous generation. We usually get a new generation once every 10 years.

5G vs 4G

Many telecommunications systems started rolling out devices that work on the **5G standard** in 2019. Your phone might be 5G-compatible now!

How is 5G different from 4G? The primary change is that 5G supports **much faster download speeds** than 4G. While 4G can transmit megabytes per second (2^{20} bits), 5G can transmit gigabytes (**2^{30} bits**).

Read more: https://www.forbes.com/sites/forbestechcouncil/2019/09/13/what-effect-will-5g-have-on-our-world/?sh=73543da46de9

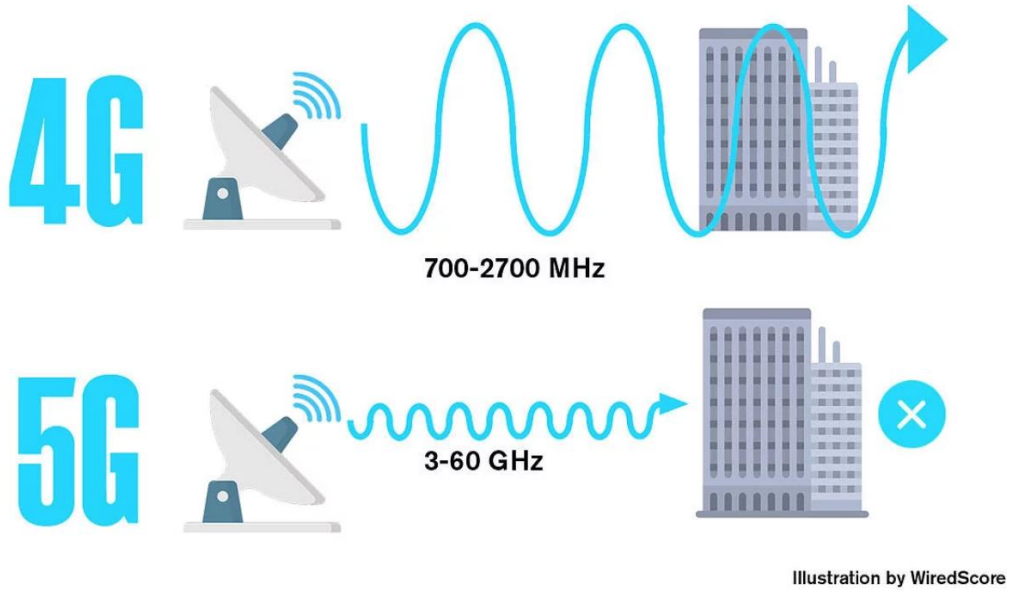


How 5G Works

This speed is possible because the electromagnetic waves 5G uses to transmit data are much shorter than 4G waves; that makes it possible to transmit more data in the same amount of time.

Because these waves are shorter, 5G requires **more access points** than the previous networks; in a crowded area, that could mean one on every city block. This infrastructure change will take a while to implement.

Pittsburgh has already had some new access points installed.



Health concerns?

Some people are concerned that increased use of 5G could lead to health risks, but the science doesn't back this up.

The electromagnetic waves generated by 5G are smaller than previous generations, small enough to the point that they aren't strong enough to break chemical bonds in cells. In fact, the waves can barely get through your skin.

It never hurts to do more research, but the current science does not suggest any serious risks from 5G.

Learn more here: gimletmedia.com/shows/science-vs/j4h39x

Deepfakes

Editing Media

You likely already know about photoshop; it's used widely to edit images, to the point that it's sometimes hard to tell if a photo is original or edited. And we've reached the point where computers can even generate photos of people who don't exist: https://thispersondoesnotexist.com/

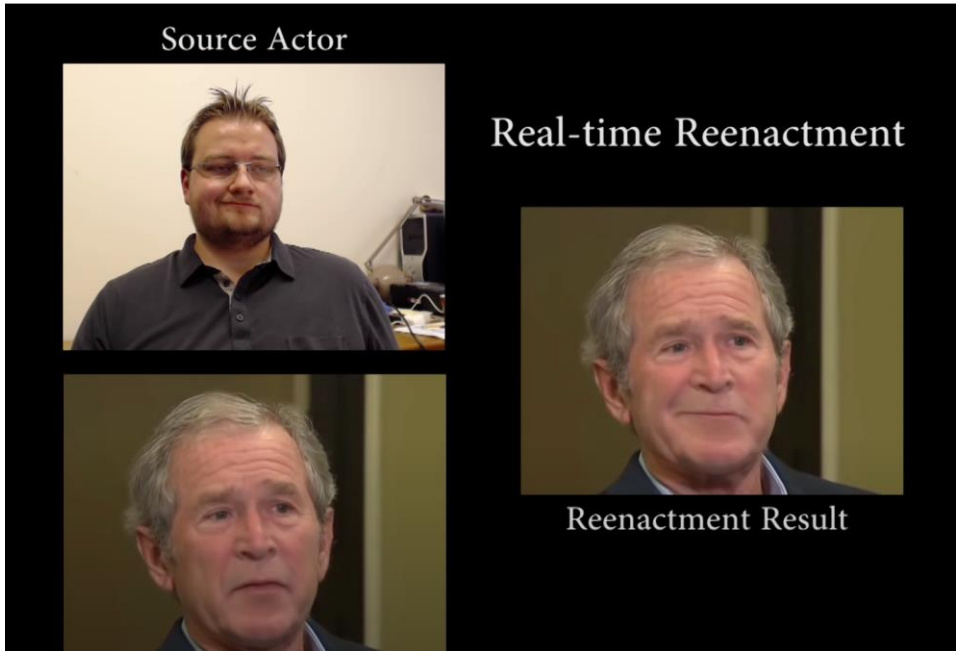
Recent advances in technology are making it possible to edit other types of media as well. For example, consider this 'video' of Mark Zuckerberg, creator of Facebook:

https://www.instagram.com/p/BypkGIvFfGZ/

Video Editing - Deepfakes

Edited videos of this form are called 'deepfakes'. They work by mapping the facial motions of an actor onto the target's face.

How it works:
www.youtube.com/watch?v=ohmajJTcpNk



Intention vs. Potential Use

This technology is intended for post-production editing in film. For example, Disney has used deepfakes in several recent Star Wars movies to bring back actors who have aged a great deal or passed away since their original appearance.

Some people also use this technology for fun, turning all movies into Nicholas Cage movies or having Dr. Phil interview Dr. Phil.

There are lots of concerns about the potential repercussions of deepfakes when used for more serious purposes, like spreading fake news. This can be done by editing real footage or creating non-existent people to spread propaganda.

Audio Editing

Adobe (the company that created Photoshop) also showcased research on a system that could edit audio, Project VoCo:

www.youtube.com/watch?v=I3l4XLZ59iw&t=58

Again, this technology is intended for post-production use, but could obviously be put to other purposes as well.

Learn more here:
www.wnycstudios.org/podcasts/radiolab/articles/breaking-news

Virtual Reality

Virtual Reality is Full-Scale Simulation

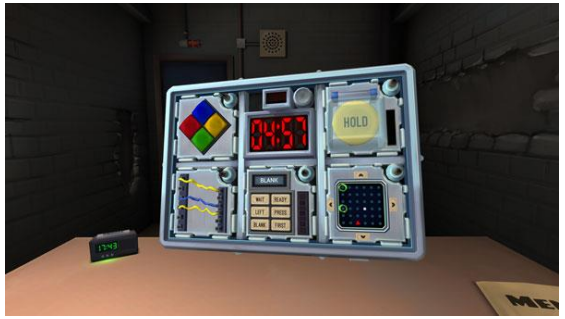
Virtual reality (VR) is a technology that lets you experience a virtual space as if you're actually there. You can see the world, hear your surroundings, and sometimes move around and interact with different parts.

At its most basic, VR uses a headset to change what you see and hear and controllers to let you interact with the world around you. Especially advanced VR may also use trackpads or wearables to allow for more advanced movement and interaction.

VR has been explored widely in pop culture and is available commercially in several game consoles. But what can it actually do?

Virtual Reality Capabilities

Most VR kits available for commercial purposes today focus on the **headset**. That means that common VR applications are mostly focused on the visual and auditory.



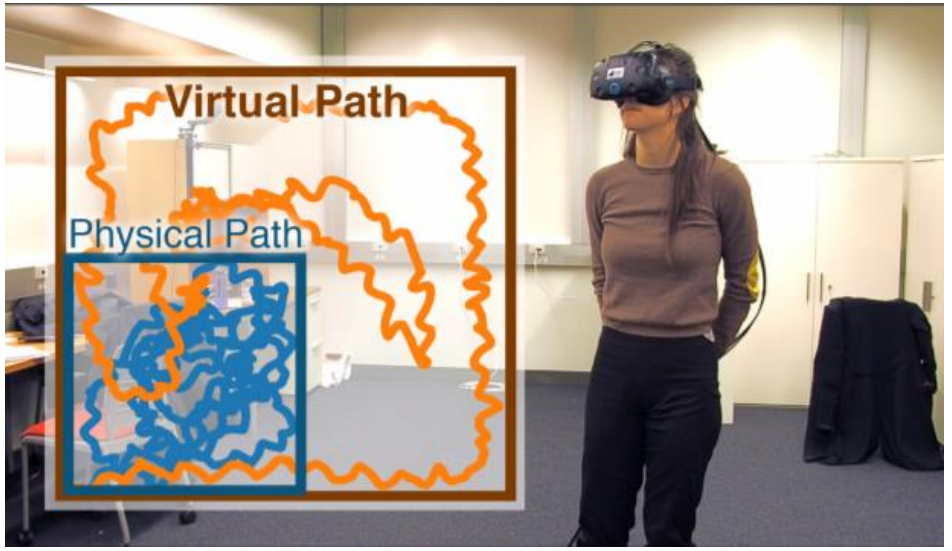
Recent developments have used hand tracking (with controllers) and head tracking to allow basic **interaction** with the VR environment.

Currently you can play games, watch documentaries, and participate in social experiments through VR.

Virtual Reality Limitations

Though you can see, hear, and interact with objects in a virtual reality, other senses – touch, smell, taste – are much more limited. Controllers may be able to vibrate, but they cannot replicate most touch sensations.

Additionally, any simulation that involves moving across space has a simple limitation- the size of the room. Developers can use clever design tricks to make a virtual space seem bigger than the physical equivalent, but design only goes so far.



Sidebar: Augmented Reality

You may also have heard of **augmented reality (AR)**. This is like virtual reality, except that the virtual components are **overlaid** on the real world instead of taking the real world's place.

AR is also used in widely, in games and applications.

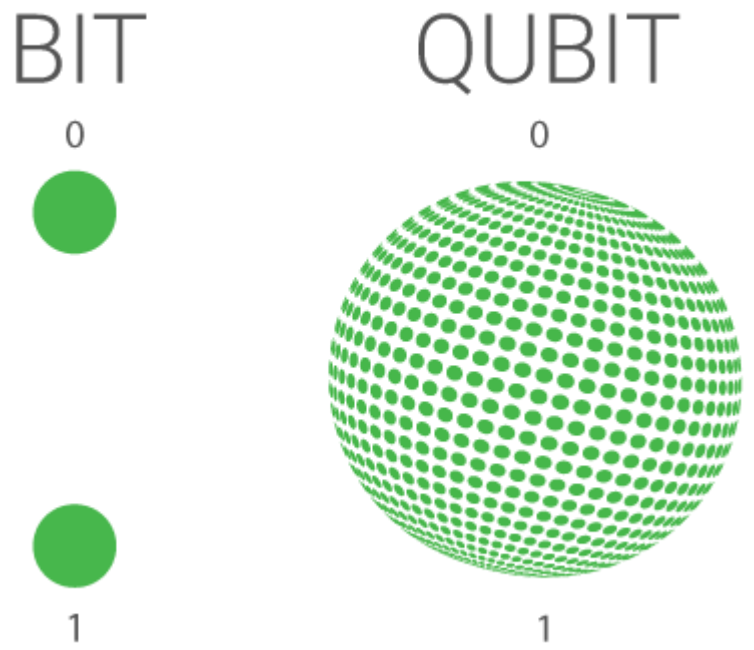
Quantum Computing

Quantum Physics vs Quantum Computing

Quantum physics states that particles are not limited to being in only one state at a time. A particle can also be in a **superposition** of states.

For example, a particle that could be in the "spin up" or "spin down" states could also have those two states superimposed; then it would be in some mixture of both states at the same time.

This same idea is used in **quantum computing**. A classical bit can be in one of two states (0 or 1); a quantum bit, or a **qubit**, can be 0, 1, or a mixture of 0 and 1. The mixture percentage is a real number, not a binary value.



Entanglement

When qubits are represented by physical phenomena such as particle spin, it's possible to connect the states of several qubits together. This is called **entanglement**.

If a system of N qubits is fully entangled, we can represent $\mathbf{2^N}$ possible data values **simultaneously** instead of just representing one value. For example, two entangled qubits can have a state that is a mixture of 00, 01, 10, and 11.

This is what makes quantum computers so powerful – they rapidly speed up **efficiency** by playing by non-classical rules.

Quantum Algorithms

When we represent data using qubits, we can process that data using **quantum algorithms** that operate on all the possible states of the data at the same time.

This produces a quantum result, which we then need to translate back into a classical (non-quantum) answer. This is done probabilistically, but certain translation algorithms (like Grover's Algorithm) have a high likelihood of success.

If this translation can be done quickly, it can lead to **huge efficiency gains**. For example, Grover's algorithm can take a O(N) algorithm and solve it in $O(\sqrt{N})$ time.

Quantum Implications

Quantum computing may seem very theoretical, but it can have real impacts on the computing we do today.

For example, consider **integer factorization**. This is an intractable problem for classical machines, but Shor's Algorithm can solve it in $O((\log N)^2)$ time, if N is the size of the integer. This has been successfully implemented only for tiny integers so far - up to the number 21.

Why does this matter? RSA – the algorithm that provides encryption on the internet – depends on integer factorization being hard to do!

Quantum Breakthroughs

In October 2019, Google announced that it had created a quantum processor, called Sycamore, that could represent 53 qubits.

This processor could solve a task that would take a classical computer thousands of years in only 200 seconds. IBM later claimed that it would only take a classical computer a few days, but this is still a huge improvement.

Paper here: www.nature.com/articles/s41586-019-1666-5

Learn more here: www.youtube.com/watch?v=lypnkNm0B4A

Learning Goals

- Recognize and describe the impact of key future computing ideas, including:
  - **cryptocurrencies**
  - **NFTs**
  - **5G**
  - **deepfakes**
  - **virtual reality**
  - **quantum computing**

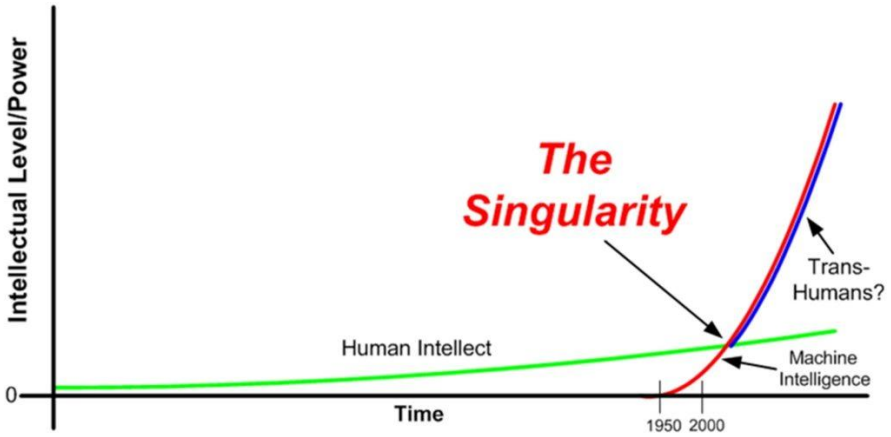
The Singularity

Bonus slides – material will not be tested on the final exam

Unstoppable AI Intelligence

The idea of 'The Singularity' is often used in science fiction to describe the point at which AI intelligence grows so spectacularly fast that it outpaces human growth. What that leads to – the end of humanity, or a new age of prosperity? – is speculation, as we can't guess what would happen next.

Many popular figures in science have expressed concerns about the growth in artificial intelligence, warning that intelligent AIs could endanger humanity. Other figures have claimed that it will take a long time to develop the field to this point, if it ever gets there at all. There's no real consensus at this time.



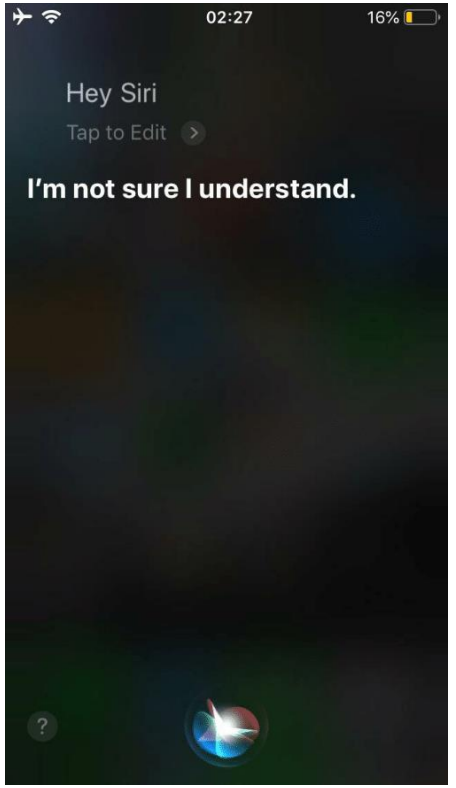
General Intelligence in AIs

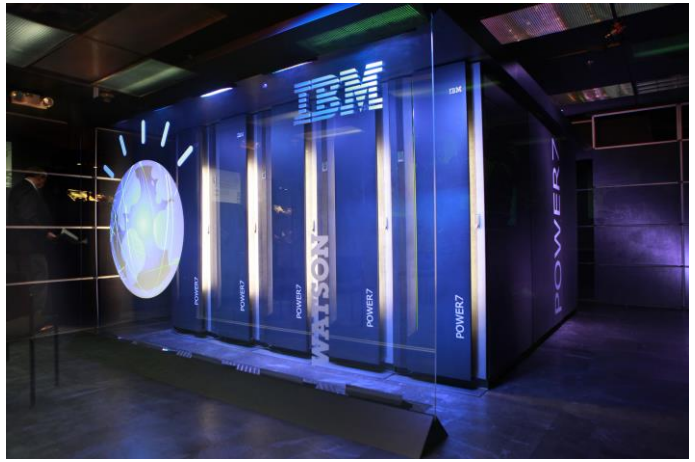
Before artificial intelligence can outpace human intelligence, we need to develop algorithms that demonstrate **artificial general intelligence**.

A general AI agent should be able to learn anything that a human can learn. In other words, it should be hard to distinguish from a human being.

Even AI agents that can do a large range of things- like Siri, or Watson- are not *generally* intelligent; you can't teach them an entirely new field.

How can we tell if an AI *is* generally intelligent?

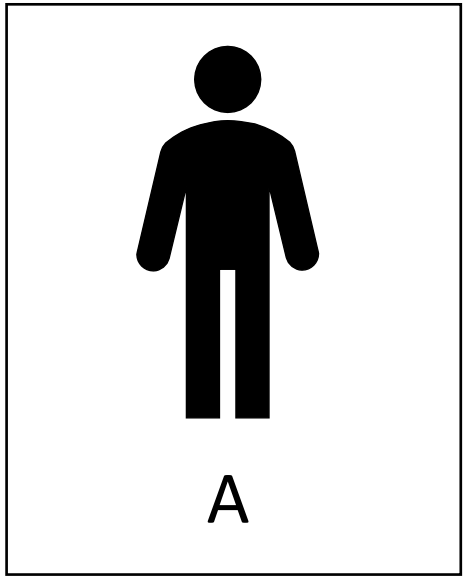


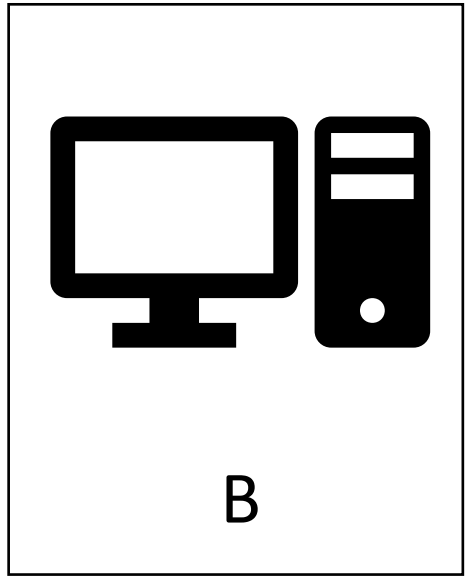


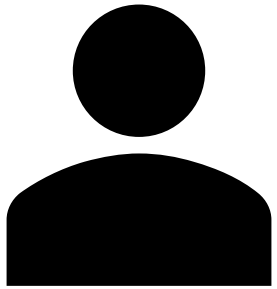
What is Intelligence? – Turing Test

In 1950, Alan Turing introduced the idea of an 'imitation game', now called a Turing Test. In this game, a human volunteer is asked to hold conversations with two different entities, A and B. One is a human; the other is a computer. The volunteer is supposed to guess which entity is the human.

If the volunteer cannot consistently tell the difference between the human and the computer, we say that the computer passes the Turing Test.







Turing Test is Hard to Pass

Turing thought that by 2000, machines would be able to fool 30% of human judges after a five-minute conversation. We use 30% as a benchmark to see whether an agent passes the Turing Test.

Some algorithms have managed to 'pass' the Turing Test, but they've all done so by employing conversational tricks:

- The program ELIZA in 1966 simulated a therapist by looking for keywords in the typed input and sending them back to the judge as a question
- The chatbot Cleverbot in 2011 was rated as more human-like than not in a competition by recycling messages inputted into it by humans in previous conversations
- The chatbot Eugene Goostman in 2014 fooled 33% of judges in a Turing Test competition by pretending to be a 13-year-old boy from Ukraine

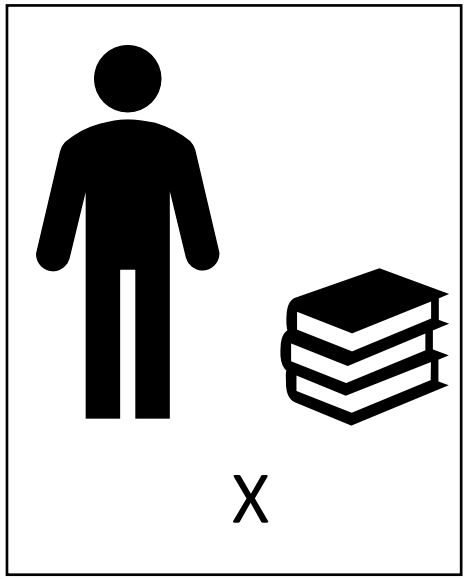
No algorithm has been built that passes the Turing Test authentically, by conversing like a human would.

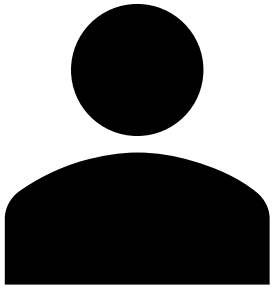
Counter-Example – Chinese Room

Even if an algorithm authentically passes the Turing Test, we still might not call it generally intelligent. Consider the thought experiment called the Chinese Room, which was introduced by John Searle in 1980.

A person (X) is in a sealed room with a large book of Chinese text that maps questions to answers. X cannot read this text. If someone slips a piece of paper under the door with Chinese text on it, they can look for a matching set of text in the book, write down the corresponding answer text, and send the response out.

Imagine that you are outside of the room. You send in questions and the room sends back responses, forming a conversation. You might reasonably assume that a person who understands what they're writing is communicating with you. But X doesn't understand the text they're writing; they're just following a pre-determined set of rules. Who are you really conversing with?





Long Way to Go

Many researchers say we'll be able to build an AI agent that passes the Turing Test within our lifetimes.

Building a generally intelligent AI is harder. Most recent estimates from top AI researchers average around 80 years from now, in 2100!

We've got a long way to go before we'll need to be concerned about consequences from the Singularity.

Learn more here:
www.theverge.com/2018/11/27/18114362/ai-artificial-general-intelligence-when-achieved-martin-ford-book