



Electronic Computing: Crash Course Computer Science #2

Crash Course: Computer Science

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Carrie Anne: Our last episode brought us to the start of the 20th century, where early, special purpose computing devices, like tabulating machines, were a huge boon to governments and business - aiding, and sometimes replacing, rote manual tasks. But the scale of human systems continued to increase at an unprecedented rate.

The first half of the 20th century saw the world's population almost double. World War 1 mobilized 70 million people, and World War 2 involved more than 100 million. Global trade and transit networks became interconnected like never before, and the sophistication of our engineering and scientific endeavors reached new heights - we even started to seriously consider visiting other planets. And it was this explosion of complexity, bureaucracy, and ultimately data, that drove an increasing need for automation and computation.

Soon those cabinet-sized electro-mechanical computers grew into room-sized behemoths that were expensive to maintain and prone to errors. And it was these machines that would set the stage for future innovation.

[INTRO]

One of the largest electro-mechanical computers built was the Harvard Mark I, completed in 1944 by IBM for the Allies during World War 2. It contained 765,000 components, three million connections, and five hundred miles of wire. To keep its internal mechanics synchronized, it used a 50-foot shaft running right through the machine driven by a five horsepower motor. One of the earliest uses for this technology was running simulations for the Manhattan Project.

The brains of these huge electro-mechanical beasts were relays: electrically-controlled mechanical switches. In a relay, there is a control wire that determines whether a circuit is opened or closed. The control wire connects to a coil of wire inside the relay.

When current flows through the coil, an electromagnetic field is created, which in turn, attracts a metal arm inside the relay, snapping it shut and completing the circuit. You can think of a relay like a water faucet. The control wire is like the faucet handle.

Open the faucet, and water flows through the pipe. Close the faucet, and the flow of water stops. Relays are doing the same thing, just with electrons instead of water. The controlled circuit can then connect to other circuits, or to something like a motor, which might increment a count on a gear, like in Hollerith's tabulating machine we talked about last episode.

Unfortunately, the mechanical arm inside of a relay has mass, and therefore can't move instantly between opened and closed states. A good relay in the 1940's might be able to flick back and forth fifty times in a second. That might seem pretty fast, but it's not fast enough to be useful at solving large, complex problems.

The Harvard Mark I could do 3 additions or subtractions per second; multiplications took 6 seconds, and divisions took 15. And more complex operations, like a trigonometric function, could take over a minute.

In addition to slow switching speed, another limitation was wear and tear. Anything mechanical that moves will wear over time. Some things break entirely, and other things start getting sticky, slow, and just plain unreliable.

And as the number of relays increases, the probability of a failure increases too. The Harvard Mark I had roughly 3500 relays. Even if you assume a relay has an operational life of 10 years, this would mean you'd have to replace, on average, one faulty relay every

day! That's a big problem when you are in the middle of running some important, multi-day calculation.

And that's not all engineers had to contend with. These huge, dark, and warm machines also attracted insects. In September 1947, operators on the Harvard Mark II pulled a dead moth from a malfunctioning relay. Grace Hopper, who we'll talk more about in a later episode noted, "From then on, when anything went wrong with a computer, we said it had bugs in it." And that's where we get the term computer bug.

It was clear that a faster, more reliable alternative to electro-mechanical relays was needed if computing was going to advance further, and fortunately that alternative already existed!

In 1904, English physicist John Ambrose Fleming developed a new electrical component called a thermionic valve, which housed two electrodes inside an airtight glass bulb - this was the first vacuum tube. One of the electrodes could be heated, which would cause it to emit electrons - a process called thermionic emission.

The other electrode could then attract these electrons to create the flow of our electric faucet, but only if it was positively charged - if it had a negative or neutral charge, the electrons would no longer be attracted across the vacuum so no current would flow.

An electronic component that permits the one-way flow of current is called a diode, but what was really needed was a switch to help turn this flow on and off. Luckily, shortly after, in 1906, American inventor Lee de Forest added a third "control" electrode that sits between the two electrodes in Fleming's design. By applying a positive charge to the control electrode, it would permit the flow of electrons as before, but if the control electrode was given a negative charge, it would prevent the flow of electrons.

So by manipulating the control wire, one could open or close the circuit. It's pretty much the same thing as a relay - but importantly, vacuum tubes have no moving parts. This meant there was less wear, and more importantly, they could switch thousands of times per second.

These triode vacuum tubes would become the basis of radio, long distance telephone, and many other electronic devices for nearly a half century. I should note here that vacuum tubes weren't perfect - they're kind of fragile, and can burn out like light bulbs, they were a big improvement over mechanical relays.

Also, initially vacuum tubes were expensive - a radio set often used just one, but a computer might require hundreds or thousands of electrical switches. But by the 1940s, their cost and reliability had improved to the point where they became feasible for use in computers... at least by people with deep pockets, like governments. This marked the shift from electro-mechanical computing to electronic computing.

Let's go to the Thought Bubble.

The first large-scale use of vacuum tubes for computing was the Colossus Mk 1 designed by engineer Tommy Flowers and completed in December of 1943. The Colossus was installed at Bletchley Park, in the UK, and helped to decrypt Nazi communications.

This may sound familiar because two years prior Alan Turing, often called the father of computer science, had created an electromechanical device, also at Bletchley Park, called the Bombe. It was an electromechanical machine designed to break Nazi Enigma codes, but the Bombe wasn't technically a computer, and we'll get to Alan Turing's contributions later.



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Anyway, the first version of Colossus contained 1,600 vacuum tubes, and in total, ten Colossi were built to help with code-breaking. Colossus is regarded as the first programmable, electronic computer. Programming was done by plugging hundreds of wires into plugboards, sort of like old school telephone switchboards, in order to set up the computer to perform the right operations. So while “programmable,” it still had to be configured to perform a specific computation.

Enter the The Electronic Numerical Integrator and Calculator – or ENIAC – completed a few years later in 1946 at the University of Pennsylvania. Designed by John Mauchly and J. Presper Eckert, this was the world's first truly general purpose, programmable, electronic computer.

ENIAC could perform 5000 ten-digit additions or subtractions per second, many, many times faster than any machine that came before it. It was operational for ten years, and is estimated to have done more arithmetic than the entire human race up to that point. But with that many vacuum tubes, failures were common, and ENIAC was generally only operational for about half a day at a time before breaking down.

Thanks Thought Bubble.

By the 1950's, even vacuum-tube-based computing was reaching its limits. The US Air Force's AN/FSQ-7 computer, which was completed in 1955, was part of the “SAGE” air defense computer system we'll talk more about in a later episode.

To reduce cost and size, as well as improve reliability and speed, a radical new electronic switch would be needed. In 1947, Bell Laboratory scientists John Bardeen, Walter Brattain, and William Shockley invented the transistor, and with it, a whole new era of computing was born!

The physics behind transistors is pretty complex, relying on quantum mechanics, so we're going to stick to the basics. A transistor is just like a relay or vacuum tube - it's a switch that can be opened or closed by applying electrical power via a control wire. Typically, transistors have two electrodes separated by a material that sometimes can conduct electricity, and other times resist it – a semiconductor.

In this case, the control wire attaches to a “gate” electrode. By changing the electrical charge of the gate, the conductivity of the semiconducting material can be manipulated, allowing current to flow or be stopped – like the water faucet analogy we discussed earlier.

Even the very first transistor at Bell Labs showed tremendous promise – it could switch between on and off states 10,000 times per second. Further, unlike vacuum tubes made of glass and with carefully suspended, fragile components, transistors were solid material known as a solid state component.

Almost immediately, transistors could be made smaller than the smallest possible relays or vacuum tubes. This led to dramatically smaller and cheaper computers, like the IBM 608, released in 1957 – the first fully transistor-powered, commercially-available computer. It contained 3,000 transistors and could perform 4,500 additions, or roughly 80 multiplications or divisions, every second. IBM soon transitioned all of its computing products to transistors, bringing transistor-based computers into offices, and eventually, homes.

Today, computers use transistors that are smaller than 50 nanometers in size – for reference, a sheet of paper is roughly 100,000 nanometers thick. And they're not only incredibly small, they're super fast – they can switch states millions of times per

second, and can run for decades.

A lot of this transistor and semiconductor development happened in the Santa Clara Valley, between San Francisco and San Jose, California. Since the most common material used to create semiconductors is silicon, this region soon became known as Silicon Valley. Even William Shockley moved there, founding Shockley Semiconductor, whose employees later founded Fairchild Semiconductors, whose employees later founded Intel - the world's largest computer chip maker today.

Ok, so we've gone from relays to vacuum tubes to transistors. We can turn electricity on and off really, really, really fast. But how do we get from transistors to actually computing something, especially if we don't have motors and gears? That's what we're going to cover over the next few episodes. Thanks for watching. See you next week.

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