MOLLY: You're listening to Brains On where we're serious about being curious.

BROOKLYN: Brains On is supported in part by a grant from the National Science Foundation.

[TICKING]

SANDEN TOTTEN: Bob, what's going on here?

BOB: Well, I was playing my favorite computer game. You know the one where all the characters are fluffs of cotton candy and everything is slowed down 10 times. It's just like watching clouds.

SANDEN TOTTEN: Oh yeah, it's still up on your screen. Is it still happening or did your screen freeze?

MARC SANCHEZ: Honestly, it's hard to tell with that game.

BOB: No. My screen is frozen. I was on the very last level and I can't tell if my progress got saved.

SANDEN TOTTEN: Now, you're switching the lights on and off over and over.

BOB: Well, I heard computers communicate in signals that are on or off. Binary, I think, it's called. I'm trying to tell it to save.

SANDEN TOTTEN: It doesn't seem like it worked yet.

MARC SANCHEZ: How about if we help?

BOB: Yes. I don't know if I'll ever be able to get to this level again.

SANDEN TOTTEN: OK, Bob, you stick with the light switch. I'll open and close this door. How about this?

MARC SANCHEZ: I'll sit in front of the computer and ultimately yell Yes, no. Yes, no.

BOB: Thanks, guys.

MARC SANCHEZ: Yes, no.

BOB: I'm sure we'll get through to my computer this way.

MARC SANCHEZ: Yes, no. Yes, no. Yes, no.

SANDEN TOTTEN: Open, close.

MARC SANCHEZ: Yes, no.

[THEME MUSIC PLAYING]

MOLLY BLOOM: You're listening to Brains On for American Public Media. I'm Molly Bloom, and hold onto your speakers everybody. I'm here with a fellow Molly from Maine. Hi, Molly.

MOLLY: Hi, Molly.

MOLLY BLOOM: I love a double Molly show.

MOLLY: Same. Shout out to technology for bringing our fabulous Molly club together.

MOLLY BLOOM: It is so true. To record this show, we're talking on Zoom on our computers. And it's really them that's making all of this possible.

MOLLY: We're making this episode all about them.

MOLLY BLOOM: First, let's get clear on what exactly computers are.

HARVEY: Great choice.

MOLLY: Harvey.

MOLLY BLOOM: How could this episode be complete without our omnipresent virtual voice assistant?

HARVEY: Marc recently updated my rhyming package. I prepared a limerick about what separates computers from non-computers. Is now a good time to share it.

MOLLY BLOOM: Please.

HARVEY: Computers accept information. They process without deviation. They can also store all kinds of great lower like photos sent from the Space Station.

MOLLY BLOOM: Nice rhymes, Harvey.

MOLLY: So computer has to be able to take information you give it, follow instructions about what to do with that information, and store its work.

MOLLY BLOOM: If you give me information like a brownie recipe and I follow the recipes instructions, then store the brownies in my belly, am I a computer?

HARVEY: No. You are not a machine. Also, your processes are nowhere near as consistent as a computer's processes. When you made brownies last week, you left them in the oven for three hours.

MOLLY BLOOM: True. Somehow they were still OK.

HARVEY: Unlike humans, computers always follow instructions. We do the exact steps of our instructions. We follow the exact order of our instructions. We stop exactly when the instructions say stop. For example, I would be happy to set a timer for you next time you bake. Brownies are best when they are baked for exactly 47 minutes and 23 seconds.

MOLLY BLOOM: OK, thanks Harvey.

HARVEY: Let me know if you have any other limerick needs.

MOLLY: Bye, Harvey.

MOLLY BLOOM: Between phones, tablets, laptops, we're surrounded by computers these days. Molly, what's your favorite thing to do on a computer of any size?

MOLLY: I can't decide. Either playing games with my friends or writing.

MOLLY BLOOM: Oh, so writing stories on a Word document?

MOLLY: Yeah, I always use Google Docs. I've got thousands.

MOLLY BLOOM: Wow. That's so cool. When you get a new idea for a story, you just open up a new one?

MOLLY: Yeah, I do that and a lot of school assignments. We do a lot of writing.

MOLLY BLOOM: Very cool. And what kind of games you like to play?

MOLLY: I like playing Among Us with friends. It's really fun to lie.

[THEME MUSIC PLAYING]

MOLLY BLOOM: Like Harvey mentioned, computers are brilliant at following instructions the same way over and over again. But they can still do so many different things. We can use them to draw or play games like you mentioned.

MOLLY: Or play music.

MOLLY BLOOM: They pull facts off of the internet.

MOLLY: Like did you know that bonnethead sharks are omnivores? They can eat seagrass along with crabs and fish.

MOLLY BLOOM: No. Wow. Well, computers also save all of our files like documents and videos.

MOLLY: All the photos you took of your cat in a bonnet like a bonnethead cat.

MOLLY BLOOM: To do all those things, your computer uses instructions like we mentioned. Those instructions are called programs.

MOLLY: People write those instructions using a language that computers can understand, which is called computer code.

MOLLY BLOOM: And those instructions tell the guts of your computer what to do, which brings us to the question that you sent to us Molly.

MOLLY: I wanted to know how computers fit so much information in such a small space.

MOLLY BLOOM: It is a really great question. Computers are really doing so much with so very little space. Well, Brains On producer Menaka Wilhelm looked into this for us.

MENAKA WILHELM: Hello. And let me first just say, I really looked into this. I send emails and I made requests and I downloaded files. And I'm so thrilled to finally get to open them all up for you too.

MOLLY BLOOM: All of them?

MENAKA WILHELM: Yeah. Between the files and the emails, I think I have 44,647,283 different things.

MOLLY: Maybe we could just hear about the most relevant ones?

MENAKA WILHELM: Yeah, maybe I should save some of these puppies for future projects. Well, in that case, let's start with how our computers store information because it's unique. If you think about how books keep information in words and paintings keep information in colors and shapes, computers store information in just two options: zeros and ones, on or off. It's called binary code.

MOLLY: In our computers, everything that's happening comes from millions of little ons and offs.

MENAKA WILHELM: Yes. For example, take typing a letter. If you hit the letter A, your computer actually stores the typed as a binary number 01100001.

MOLLY BLOOM: And if you type an I next?

MENAKA WILHELM: Inside of your computer, that I becomes 01101001. Inside a computer, AI is 01100001-01101001.

MOLLY: And in a game of Scrabble, AI spells a two letter word meaning three toed sloth. Two points.

MENAKA WILHELM: Nice. So your computer has a specific eight digit binary number for each letter you type. When you're texting on your phone or typing on a keyboard, there are a bunch of ones and zeros popping up behind the scenes.

MOLLY BLOOM: Wow. But also, isn't it more complicated to use eight numbers for each letter?

MOLLY: I can definitely type the letter A faster than I can write the numbers 01100001.

MENAKA WILHELM: That's totally true. But for computers, the zeros and ones end up being faster. To store that letter A in binary, it takes a computer one or two nanoseconds. That's two billionths of a second. The beauty of binary is that it lets you store a lot of different information in a really simple way with on or off switches.

We give our computers so much different information. We type letters, we take pictures, we click, we scroll. And if you can store all of that different information using just on or off switches, you can use the same switches to do many, many different things. And you can do those things quickly without mistakes. Using binary means that computers can be simpler, more flexible, and faster.

MOLLY BLOOM: Wow. But if there are eight ones and zeros for a single letter, there must be millions in a whole article or website. When that takes up a ton of space?

MENAKA WILHELM: Yes and no. We found some really amazing ways to shrink those ones and zeros, those on and off switches, so that we can fit tons and tons in a small space. In fact, the computer has taken quite a journey to get to where it is now. Let's take a look at an early computer and a really, really giant computer. Ready to do a bit of a computer time hub?

MOLLY: Sure.

MENAKA WILHELM: Our journey starts in 1834 in England. We're here to talk about the very first machine that counts as a computer. At this point in history, making stuff with big new machines is all the rage. Factories are churning out fabrics and glass windows and a cool new invention called cement. Electricity hasn't been discovered yet. Lots of these new machines run on burning coal, which explains the air.

ADA LOVELACE: Welcome. I'm Ada Lovelace. Don't worry. That smoggy feeling will go away soon. You can think of the damage to your respiratory system as a souvenir from this time.

MENAKA WILHELM: Ada Lovelace is a mathematician. She's working with another mathematician named Charles Babbage on a machine. They call it the analytical engine. It's designed to have a bunch of little wheels in different stacks with rods and levers connecting them together and fully built. It would be about the size of two white rhinos standing in a line.

ADA LOVELACE: We want to do more math with fewer mistakes. The analytical engine will follow instructions to do specific calculations the same way each time.

MENAKA WILHELM: Sound familiar? Just like our computers.

ADA LOVELACE: I was actually inspired by another machine of our time. A weaving loom that weaves threads together to make fabric. It works in a fascinating way. The loom can follow simple instructions to weave different designs. And just as that loom weaves beautiful cloth, our analytical engine will weave beautiful math.

MENAKA WILHELM: The loom Ada is talking about follows instructions on punched cards. So picture a rectangular card and then a bunch of holes punched in rows.

ADA LOVELACE: And I've worked out a way to use punched cards with the analytical engine in a similar way.

MENAKA WILHELM: And remember, there's no electricity. So to do calculations, the analytical engine wheels and levers tick together to do math. Each wheel has numbers around its edges, a little bit like a clock. So that when a wheel turns, it's actually storing numbers as it does calculations.

ADA LOVELACE: Well, it would if we ever built the whole thing.

MENAKA WILHELM: Ada and Charles never quite finished a whole assembly, but their designs are very comprehensive. This is the first machine designed to check off all the requirements of a computer. You feed it a punch card.

MOLLY: So it takes an information. Check.

MENAKA WILHELM: It does what the punch card says to do.

MOLLY: Follows instructions. Check.

MENAKA WILHELM: And its wheels hold on to information as it works.

MOLLY: Stores info. Check.

MENAKA WILHELM: All right, that's probably all the smog we need for today. Next, let's head to one of the first computers to be totally electronic.

The age of motoring gets another lift, this time from the helicopter.

MENAKA WILHELM: We're going forward about a century to 1946 in the US. World War II has just ended most people don't have TVs in their homes. If you want to watch something on a screen, you have to head to the movie theater. And that movie ticket will cost you roughly $0.42. But we're not going to the movies, we're going to see a big giant computer. It's called the ENIAC.

YAK: Did someone say yak? I'll come with you. I'm a yak, too. See?

MOLLY: Wait, where did that yak come from?

MENAKA WILHELM: I must have sent an email asking if it was possible to visit the ENIAC, but maybe I left off the ENI and just got a yak. Whoops. But the yak seems nice enough.

MENAKA WILHELM: Sure. Yak? We're heading to the University of Pennsylvania in Philadelphia to see the ENIAC.

YAK: Oh great, and the ENIAC is like an eensy-weensy yak, right?

MENAKA WILHELM: Oh, yeah. It's actually not yak related at all. It's a machine and there is nothing small about it. ENIAC stands for Electronic Numerical Integrator and Computer. John Mauchly and J. Presper Eckert invented it. All of its parts take up a giant room. It's so big you could park four school buses inside the room and still have a little bit of space left over.

YAK: who doesn't love a good bus ride? Also, I have no idea what a computer is. See?

MENAKA WILHELM: Eckert and Mauchly have spent the last few years building the ENIAC to do math for the military. To send it information, you flip switches and plug cables into different parts of the machine. And then it follows instructions depending on which parts are connected together. There are six people who set up these instructions for ENIAC.

And they're all women. Kathleen McNulty, Betty Jean Jennings, Betty Snyder, Marlin Weisskopf, Fran Baylis, and Ruth Lichtman. The ENIAC runs calculations way faster than any other computer so far, because it's running calculations with electricity, which moves faster than anything physical. So it can add or subtract thousands of numbers each second.

YAK: Why does it have to be giant? Why can't it be eensy-weensy? And why can't it be a yak?

MENAKA WILHELM: Well, to you the ENIAC is big overall, let's look at just one part of it. To store information, it uses these things called vacuum tubes. They're glass tubes and they can be set to on or off. Similar to how our computers now work in on or off. Each tube is roughly the size of a light bulb. And there are roughly 18,000 of these tubes. So picture 18,000 bulbs.

YAK: Did you say 18,000? Wowsers.

MENAKA WILHELM: And there are lots of other pieces that ENIAC needs to work. It's got way more parts than those 18,000 bulbs. All of them are much bigger than computer parts today. It's really big. Around the time of the ENIAC, there are other computers that are just behemoths too. I like to think of them as technological megafauna.

Just before ENIAC, there's a machine called the Atanasoff-Berry computer. It's a lightweight for its time clocking in at 300 pounds. Take the Harvard Mark I. It's 8-feet tall, 51-feet long and weighs 5 tons. That's as much as three medium-sized cars. There's another computer that's actually just called Colossus.

YAK: I like it here. I have a cousin named Colossus, too.

MENAKA WILHELM: And I have a cousin called Anna.

ANNA: That's me.

MENAKA WILHELM: Anyways, now the computers that we carry around in our pockets are way more powerful than ENIAC. So it's easy to lose sight of how amazing early computers were. But for their time, they could do bigger, better stuff than ever before. For example, there is one kind of math problem that took engineers about 12 hours to do before ENIAC.

And with ENIAC, the answer arrived in 30 seconds. And it's pretty remarkable how quickly computers shrunk. In just 50 years, people were making computers that were much more powerful than ENIAC and way, way smaller. We're going to look at how we went from 18,000 bulbs in a machine the size of a huge room to truly teeny computers that fit in your pocket. But first, I've got to help our yak friend get back to where he belongs.

YAK: So long.

MENAKA WILHELM: Bye Mollies.

MOLLY: Bye, Menaka.

[THEME MUSIC PLAYING]

MOLLY BLOOM: I think now seems like a good time for the?

MOLLY: Mystery sound.

MOLLY BLOOM: Are you ready, Molly?

MOLLY: Yup.

MOLLY BLOOM: Here it is.

[CLICKING SOUND]

Molly, what is your guess?

MOLLY: I'd say it sounds like someone fiddling with something. One of those kids toys where you move the buttons up and down on the little rods.

MOLLY BLOOM: Something to get fidgety.

MOLLY: Maybe like little beads of some sort.

MOLLY BLOOM: We'll be back with the answer and give you another chance to guess in just a little bit.

[THEME MUSIC PLAYING]

We're working on an episode all about the sun.

MENAKA WILHELM: And we want to know who you'd add to the Suns Squad.

MOLLY BLOOM: Dream up a planet to add to our solar system. What does it look like? What's going on there? Does it have rings or moons? Are they best frozen yogurt shops?

MENAKA WILHELM: Send us a short recording about it at brainson.org/contact.

MOLLY BLOOM: Molly, what planet would you add to our solar system?

MOLLY: It would be called nutria, and it would be one big jungle with all kinds of plants and animals living freely. It would even have a bird made of solid gold.

MOLLY BLOOM: Whoa. I like it. How did you come up with the name nutria?

MOLLY: I looked up the-- I think it's maybe Brazilian word for nature. And then I changed it a little bit. I took out an E.

MOLLY BLOOM: I like it. If we have future planet naming duties, I'm going to have you do it if that's OK with you.

MOLLY: Thanks.

MOLLY BLOOM: Send us your answer at brainson.org/contact.

MOLLY: That's also where you can send drawings, mystery sounds, and questions.

MOLLY BLOOM: Like this one.

GIL: My name is Gil from Bothell, Washington. My question is, what is the flavor of a root beer?

MOLLY: We'll answer that question at the end of the show in the moment of uhm.

MOLLY BLOOM: And I'll read the latest listeners to be added to the Brains Honor Roll.

MOLLY: So keep listening.

MOLLY BLOOM: Welcome back to Brains On. I'm Molly.

MOLLY: And I'm Molly.

RUBY GUTHRIE: And I'm Ruby.

MOLLY: It's our pal Ruby Guthrie.

RUBY GUTHRIE: It's Molly squared.

MOLLY: Yeah.

MOLLY BLOOM: So we've learned about how computers work and how they got started. But how did we go from 18,000 bulbs to something that fits inside your pocket?

RUBY GUTHRIE: Great question, Molly. And the answer is only five syllables.

MOLLY BLOOM: Tiny magic elves?

MOLLY: A shrinking machine?

RUBY GUTHRIE: Solid guesses but not quite. The answer is semiconductors.

MOLLY BLOOM: Semiconductor. Like a part-time train conductor?

RUBY GUTHRIE: No. A semiconductor is a type of material that can both conduct and insulate electricity. I know. That's a whole mouthful. But just think of semiconductors like a faucet. They can either flow freely or not at all. Just like a faucet can start and stop the flow of water, semiconductors can help control the flow of electricity. And this was super appealing to people making computers.

Although ENIAC was revolutionary, it was super clunky. Scientists were also trying to figure out a more efficient alternative to those 18,000 bulbs. They were experimenting with different semiconductors. In 1947, engineers at Bell Laboratories in New Jersey invented the transistor. It looked like a kooky modern art sculpture, but one you could hold in the palm of your hand.

It had a metal base followed by a thin silvery layer of semiconductor called germanium. All stacked with a gold plated triangle with different springs and wires sticking out.

MOLLY: Sounds abstract.

RUBY GUTHRIE: It definitely looked it. But simply put, that semiconductor layer changed the intensity of the electrical current as it flowed down the wires through one side of the triangle to the other. Not only was the transistor much smaller compared to the vacuum bulbs, but it also made it easier to either amplify the electrical current or switch between on and off.

MOLLY BLOOM: On and off just like the binary we talked about earlier.

RUBY GUTHRIE: Exactly. These transistors became a crucial part of computer circuits. Circuits are the looped pathways that electricity flows through. There are lots of different parts that make up a circuit. Capacitors hold a charge. Resistors slow the flow. And transistors can start and stop a charge.

MOLLY BLOOM: Like a light switch.

RUBY GUTHRIE: Right. At first, these circuit elements were divided into individual components, but that was changing. A variety of different engineers and scientists were working to make smaller electronics using semiconductors. One of those people was American engineer Jack Kilby.

In 1958, Kilby compacted a whole circuit of transistors, capacitors, and resistors onto a thin blue rectangle, the size of a postage stamp, all made from germanium. Just like at Bell Labs. He called this the integrated circuit. Connecting everything on a small surface meant the electricity could travel faster, making everything more efficient. This was the world's first microchip.

Around the same time, physicist Robert Noyce had the same idea, but decided to use a different semiconductor called silicon. Silicon is a major ingredient in sand. It's one of the most common elements on Earth.

But microchips are actually made of silicon that comes from underground. The silicon chip was more practical as well as more accessible to the world. Suddenly, you could have just as many on off switches as you had with those 18,000 bulbs. But you could fit them on a tiny stamp-sized chip. This is where things really took off.

Microchips started showing up everywhere. In the air force, pocket calculators, not to mention personal computers. Picture this. A tiny thin metallic square wafer just the size of a fingernail. At first, it looks just like a grid.

MOLLY: Like a tiny tech waffle.

MOLLY BLOOM: Let's whip out the old zoom ring get a little closer. Shall we?

[THEME MUSIC PLAYING]

RUBY GUTHRIE: If you zoom in, it looks like a map filled with layers and layers of overlapping roads. These roads are actually circuits and they're filled with transistors. At first, we could only etch a few transistors on each chip.

I mean, these are tiny etchings. However, as manufacturing and technology evolved, we developed better etching tools and techniques and could fit more things on a smaller surface. Since the 1960s, the number of transistors per chip would double about every two years. Today, there are billions of transistors on a single microchip.

MOLLY: Mind blown.

RUBY GUTHRIE: Thinking about it definitely makes my head explode.

MOLLY BLOOM: Microchips led to more innovation and smaller devices, but how do they work?

RUBY GUTHRIE: Microchips are basically the brain to our phones, tablets, and laptops. They keep track of following those binary instructions as well as store all of our precious files. To help us better understand how it all works, I talked to Bettina Bair. She teaches computer science at Ohio State University.

BETTINA BAIR: There's just so many different kinds of things to remember. And computers break all of that memory work into the stuff that you need to know immediately and the stuff that you want to store for a while.

RUBY GUTHRIE: Let's start off with the immediate stuff. We call this ram.

RAM: Did somebody call me?

MOLLY: First a yak, now a ram?

RUBY GUTHRIE: I find it's best to just go with it. Oh, hey there ram. I didn't mean to summon you. I'm talking about Random Access Memory or RAM for short.

RAM: Oh, common mistake happens more than you'd think.

RUBY GUTHRIE: Like I was saying, RAM, the computer kind, is the way your computer stores things that are happening in real time.

BETTINA BAIR: Random access memory is for all of the things that you're thinking about and doing in the moment. Where is my mouse on the screen? What applications are open? What did I type recently?

RUBY GUTHRIE: All of that information is stored electronically on a memory chip. Let's get that zoom array again.

Zoom zoom zoom zoom zoom zoom zoom.

RUBY GUTHRIE: If we can zoom right on a RAM chip, we'll see billions of capacitor cells. Think of capacitors like teensy tiny buckets that are filled with electricity. If the bucket is full, they're charged representing a one, and if they're empty it represents a zero.

MOLLY: Just like that binary on and off.

RUBY GUTHRIE: Right. When you turn your computer on, it starts reading all of its instructions, filling and emptying the binary buckets at super speed.

BETTINA BAIR: If you shut off your computer, unplug it from the wall, all of that stuff goes away.

RUBY GUTHRIE: If we power down, all of the capacitors empty their charge and the memory is lost.

MOLLY BLOOM: What about files we want to keep?

MOLLY: Like photos with my family.

RAM: Or my thousands of memes?

RUBY GUTHRIE: Yes, we definitely want to keep those.

BETTINA BAIR: Your external information can be stored in solid state, which is like your flash drive. For that, these are our physical pieces of circuitry that hold your data.

RUBY GUTHRIE: These drives work a lot like RAM. Instead of capacitors, they have transistors that are either charged or have no charge. The only difference is when you turn off your computer, the transistors hold their charge and save your data.

RAM: Oh, my memes are safe. Whoa. That was close.

RUBY GUTHRIE: We've come quite a ways since punch cards and vacuum bulbs. Now, memory chips use electrical signals to mark on and off with ones and zeros. Today, microchips continue to shrink in scale but the possibilities are growing from smartphones to the international space station.

MOLLY BLOOM: Just imagine if the makers of the ENIAC could see our tiny pocket computers.

RAM: They'd be like mind blown.

MOLLY BLOOM: Thanks for sharing, Ruby.

RUBY GUTHRIE: Anytime. Hey, RAM, want to grab a bite?

RAM: As long as it's the food kind, all this talk about chips has worked up my appetite.

[THEME MUSIC PLAYING]

MOLLY BLOOM: OK, Molly, let's take another listen to the mystery sound. Here it is again.

[CLICKING]

All right. Before you were thinking fidgety beads, something. What new thoughts do you have?

MOLLY: I'd say I'm trying to fit it in with the computers. Something Chinese rings a bell for me. I don't know what it is.

MOLLY BLOOM: Well, here is the answer.

CATHERINE: That was the sound of me adding 20 numbers on my abacus.

MOLLY BLOOM: Molly, do you know what an abacus is?

MOLLY: Are they like a Chinese tool for doing math?

MOLLY BLOOM: Yes. And actually, they were used in lots of other countries too but definitely in China. You were right because there are little beads on the abacus. So you were hearing--

MOLLY: Someone hearing.

MOLLY BLOOM: Someone moving beads. Computers were first invented to help do math. But thousands of years before computers, people invented this other tool, the abacus, to help them do calculations. Yes, they used it in China but it was also used in Japan and Russia and Mexico. Let's find out a little bit more about how an abacus works.

CATHERINE: My name is Catherine. I am a student from the Chinese American Abacus Association. I'm from Castro Valley. An abacus is this mathematical tool that has beads and a frame. There are five beads in each row and there are several rows on an abacus. It depends on the size of the abacus for the number of rows. Each bead is worth one number basically. There's one bead at the top that's separated from all the other four, and that counts as the number five. So the bead at the top is worth five.

In the middle of abacus, there's a dot, which is basically the ones place. And then if you go to the left, that's the tenths place. If you want to add like 11 plus 20, you'll have one bead up in the tens place and one beat up in the ones place. And then to add 20, you'll add two in the tens place and zero in the ones place because 20 is 2 and 0.

MOLLY BLOOM: Catherine at first started using an abacus in kindergarten, and now she competes in abacus competitions. Part of the competition uses an abacus, and part of it is a mental math. She actually just imagines using the abacus to do math really, really fast inside our head.

CATHERINE: So when you do mental math, you need to understand an abacus. Mental math is basically the abacus, except the abacus is no longer in front of you and it's inside of your mind and you need to remember where the beads are and what beads you have already placed. Doing abacus in math is really helpful if you have a problem like 870 times 14. Some people would take out a calculator but instead, if you learn mental math you can just do it quickly without taking out a calculator.

MOLLY BLOOM: And the answer is?

CATHERINE: 1,218.

[THEME MUSIC PLAYING]

MOLLY BLOOM: Computers take in information, follow instructions, and store their work.

MOLLY: Inside a computer, information is boiled down to ones and zeros. That's called binary.

MOLLY BLOOM: People design the first computers to do more math with fewer mistakes.

MOLLY: Many of the earliest computers were absolutely giant.

MOLLY BLOOM: New materials like semiconductors made it possible for computers to be small.

MOLLY: Today, computers can do all kinds of things in a very little space.

MOLLY BLOOM: That's it for this episode of Brains On.

MOLLY: It was produced by Menaka Wilhelm, Marc Sanchez, Sanden Totten, and Molly Bloom.

MOLLY BLOOM: We had production help from Christina Lopez and Ruby Guthrie, engineering help from Alex Simpson. Special thanks to Andrew McGowan, David Brock, Anna Wilhelm, Rosie DuPont, and Jack Silver Nagel.

MOLLY: Now, before we go, it's time for a moment of uhm.

What is the flavor of a root beer?

ASHLEY ROSE YOUNG: It's likely called root beer because one of the main flavoring agents historically is actually the bark of the root of the sassafras tree. My name is Ashley Rose Young, and I'm a historian at the Smithsonian's National Museum of American History. You would go out to a sassafras tree, you can find them all along the Eastern part of the United States. And you would cut off pieces of the bark along the root of the tree and you would steep that.

It wasn't just the sassafras tree. People could add in at least a dozen other ingredients historically that can include berries, of flowers, other plants. There's a wide variety of flavorings that could go into root beer, especially if we look back to the traditional indigenous culinary practices prior to Europeans arriving in the United States. Of course, each family had its own recipe.

One of the men who is attributed with popularizing root beer in American culture was a man named Charles Hires. He came up with a powder that would include 16 different ingredients, including that sassafras root. So you would add sugar, yeast, and water to this powder that he sold for in $0.25 packets. You would let that sit for 12 hours and ferment slightly. It would foam naturally. After 12 hours, you would have five gallons of root beer to enjoy. But he actually wanted to call it root tea originally.

What's funny is that he also tried to create a syrup for root beer that could then be sent to the soda shops back in the day where they would add it to soda water to serve to customers. But that liquid concentrate didn't work. It was too foamy and it caused issues at the soda parlors. The solution that they came up with was to use barrels and create the root beer in advance and then ship that the soda shop. If you associate root beer with barrels, it goes back to that issue of how foamy sassafras bark can be.

I have personally not had the traditional sassafras tea or root beer. What's interesting is that it does have certain medicinal qualities, but if consumed in large quantities, it can actually cause liver damage to the body. In 1960, the natural oil that comes out when you brew sassafras was banned by the federal government and is no longer allowed to be in any consumable products in the United States. The flavor that we associate with root beer today, it is a sassafras flavor but it's artificially produced.

MOLLY BLOOM: Time to get to the root of our greatness. It's the Brains Honor Roll. These are the incredible listeners who keep this show going by sending in their questions, ideas, mystery sounds, drawings, and high fives.

[LISTING HONOR ROLL]

[THEME MUSIC PLAYING]

Brains On will be back soon with more answers to your questions.

MOLLY: Thanks for listening.