SYNOPSYS®

to the moon

on sand power

sand

To the Moon on Sand Power

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To the Moon (and back again) on Sand Power

On July 20, 1969, the eyes of the world were focused on the heavens. On that historical day, Neil Armstrong became the first human to set foot on a celestial body other than the Earth. In a giant leap for mankind, Armstrong walked on the moon.

That amazing technical feat was made possible by human ingenuity and the power of thousands of computers that calculated how to launch men to the moon and return them safely to Earth.

The miracle of computer technology is in our homes today. Have you ever wondered what's inside a computer? Or a digital camera? Or any of the electronic products that have become so commonplace to us? The fundamental parts inside are fascinating little devices affectionately known as **chips**. Oddly enough, these chips start out as sand, or **silicon**, one of the most plentiful substances on our planet.

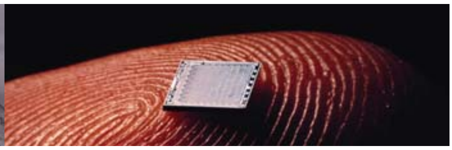
This book will briefly explain for you, in terms that are easy to understand, how chips are designed and manufactured. It will also describe the remarkable technology, called Electronic Design Automation (EDA), that lets today's engineers turn their ideas into a dazzling array of electronic products that touch our lives every day.

electronics


transistor

resistor


capacitor


integrated circuit - chip

The Big Three

Before we look inside a chip, let's start with three primary parts that make up anything electronic. The first part, perhaps the most important, is a **transistor**. Transistors are made of silicon with other exotic chemicals added in. You can think of a transistor as simply a switch, like a light switch. When a light switch is on, electricity goes through and turns on the light. When the switch is off, electricity is blocked and the light is off. Similarly, when a transistor is on, electricity flows through it. When it's off, the flow of electricity is blocked. Electricity, controlled by transistors turning on and off, can be made to do all kinds of things, like take a digital picture or perform a calculation.

The second main part is a **resistor**. These are made from a variety of materials and, as their name implies, they resist electricity. In other words, they slow down the flow of electricity to better control it.

The third part is a **capacitor**. Capacitors are made of all sorts of materials and come in a variety of shapes and sizes. They store up electricity, like an electrical charge, ready to be used whenever it's needed.

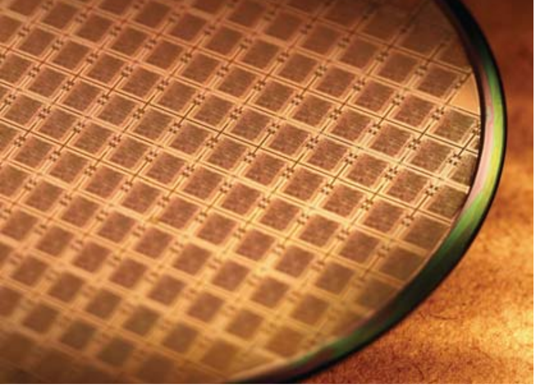
Transistors, resistors and capacitors are connected with wires into an electronic **circuit**. What the circuit does, be it in a camera or computer, depends on how these parts are connected.

Not a Potato Chip

Imagine a million or more transistors, resistors, and capacitors connected with wires into a complex network. Now, imagine them all crammed together so that they fit into a space about the size of your fingernail. Incredible! The combination of all these parts together on a single piece of silicon is known as an **integrated circuit**, or IC for short. Most of us simply call them "chips." As electricity bounces around the chip, going through one switch after another, the chip comes alive, performing the tasks for which it was designed.

The Incredible Shrinking Chip

As you've noticed all around you, computers and other electronic products have shrunk in size over the years. Computers that used to take up entire rooms have become laptop and desktop systems. Calculators, cell phones and stereos are smaller in size and larger in performance. Why? Because of advances in chip manufacturing technology. Transistors, wires, and the other components are now so tiny—



wafer

about one-twelfth the size of a human hair or smaller — that millions of them can fit in a single chip only a quarter of an inch square — and they'll get even smaller in the future!

The number of transistors in a chip has escalated at a dizzying pace since the 1960s. This escalation has become known as **Moore's Law**, a prediction by Intel's co-founder, Gordon Moore. In 1965, Moore predicted that chips would double in complexity every year, pulling potential computing power along with them. Ten years later, Moore revised this rule to every two years. The electronics industry — and not Moore — chose to split the difference to every 18 months, and that is where Moore's Law has remained ever since. You can expect electronic products to double their capabilities and take up half the space almost every other year!

A Chip Is Born

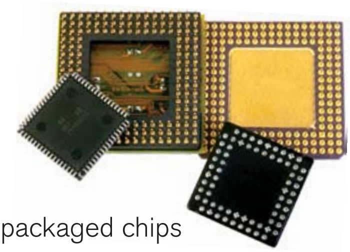
How is a chip, about the size of your fingernail and containing millions of transistors, actually made? The intriguing process of manufacturing a chip starts with a single crystal of pure silicon — so pure that a single drop of dye in five gallons of water would be impure by comparison.

Silicon is melted, purified, and grown into a giant crystal. The crystal is cut into a perfect cylinder about 8 inches in diameter and 3 feet tall. The cylinder is then sliced into thin, circular **wafers** that can hold up to a few hundred copies of a chip. A process called photolithography, literally "printing with light," produces these copies.

First, a special coating — a photographic material — is applied to the wafer. The coating will harden when exposed to light. Next, a stencil is made in the pattern of the transistors and other components that will make up the chip. This stencil is called a **photomask**. The photomask is positioned above the coated wafer and light is shone through it. Below, on the wafer, areas that are exposed to light become hard. Areas in shadow remain soft. Moving the photomask from one side of the wafer to the other in steps, shining light through it at each step, makes multiple copies of the same hardened pattern.

The wafer is then dipped into acid to wash away the soft, unwanted parts of the coating and a raised pattern of the chips remains. The pattern has hills and valleys. Metal and other chemicals are put into the valleys to form transistors, wires, and such.

design


packaged chips

In order to fit more onto the chips, layer after layer is produced this way with different photomasks for each layer—usually 20 or more. Voila! A chip (and hundreds of its identical twins) is born.

Each chip is then cut from the wafer and gets encased in a protective package. The chip has wires attached to it that pass through the package to the outside world so it can be fastened to a circuit board. A circuit board is simply a platform that can hold multiple chips. Look inside any electronic product and you'll see the green circuit boards with the packaged chips attached.

Designing a Chip

While cramming all of this functionality into smaller packages is good news for us as consumers, it takes its toll on the engineers who design these devices. Why? Because trying to design something with millions of switches, wires, and other components is a much too complicated project for the human mind to perform without help. Fortunately, technology exists that gives design engineers that help. It's called Electronic Design Automation, or **EDA**.

When people face a difficult, time-consuming task, they like to use computers to automate it. EDA is automation for the complex job of designing a chip. (There is also automation for chip manufacturing but that's a whole story in itself.) Computers can automate a complex job, but they have to be told what to do. The instructions given to a computer are known as **computer programs** or **software**. In EDA, these computer software programs are referred to as "tools." Electronic engineers use computers that follow the instructions from the EDA tools to get their designs from concept to actual working silicon. The EDA tools help the engineers decide on the architecture of their chip, verify that it will work, and ensure that they get the highest quality product at the end. There are many steps in the process of designing a chip. The main steps in today's process are specification, synthesis, verification, test, and layout.

Getting Started: Specification

The very first thing design engineers do is describe what they want their chip to do. This description is called a **design specification.** It explains whether the chip will add 2 + 2 or whether it will keep track of an astronaut on the way to the moon. Engineers refer to this specification at every step in the design process. This is essential in designing modern chips because separate teams of engineers

automation


simulation with EDA

often design different portions of the chip and the specification is what keeps everyone on track.

Engineers write the specification for a chip in a **computer language** that describes the behavior of each individual part of the chip. Rather than having to think about each transistor and what it does, the design engineer writes a description of a particular behavior, for example, “Open the camera shutter.” EDA tools can understand this language and figure out what to do during each step in the design process. The tools automatically create the design for a chip that will open the shutter of the camera at precisely the right moment, and the engineer doesn’t have to get into the details.

Good Behavior: Simulation

Before starting the actual design process, the engineer makes sure that the design specification is complete and accurate. The specification, or “spec” for short, can be quite elaborate, as you can imagine. An EDA tool is used to perform **simulation** of the design spec. Like an astronaut in a spacecraft simulator preparing for a space ride, the design engineer uses a chip simulator to make sure the chip design will go smoothly.

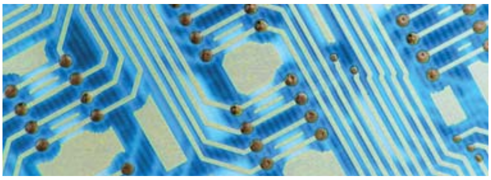
Spec to Specks: Synthesis

Once the design specification is deemed correct, it’s time to let a computer translate it into the millions of little components that will make the chip perform according to the specification. Using EDA tools to perform this task is called **logic synthesis**. What used to take three years by hand can now be completed in three weeks!

Trust but Verify: Verification

In a perfect world, we would assume that all the components resulting from the engineer’s description would add up to a chip that performs flawlessly. Then there’s the real world, where mistakes happen. The earlier an error is detected and corrected, the less impact it has on the cost to design the chip and the shorter the design cycle becomes. EDA tools again come to the rescue to verify the design at each step. To ensure that the chip is functioning properly, that the transistors are turning on and off to control the electricity flow correctly, the engineer uses more tools for **simulation**. To ensure that all this happens at the proper time, the engineer uses tools for **timing analysis**. The real world gets closer to perfection.

techno



layout

Check Every Switch: Test

The chip is now synthesized — the components have been determined — and verified — it will function correctly, at the right time. When the chip will eventually be manufactured, the manufacturer will need a way to test the actual silicon parts. The design engineer is the only one who knows what the chip is supposed to do, so the engineer is responsible for creating a **test program**. The test program describes, in great detail, how to turn every transistor on and off at the proper times in order to exercise the chip completely. You can imagine the huge number of combinations of “turn this one on and that one off” that must be tested. Again, EDA tools known as **test synthesis** and **automatic test pattern generation** are employed.

Connect the Pieces: Layout

Next it’s time to decide where all the transistors and wires will be located on the actual silicon chip. This information will be used to create the photomask for manufacturing. Transistors that routinely interact with each other must be placed close to each other so that space on the chip will be utilized efficiently and the timing of the electricity moving around will happen correctly. Clusters are placed together in a floorplan much like a floorplan for a house. Within the clusters, each individual transistor is given an assigned position. Locations are then found for the miles of wires that will connect everything. This step in the design process, finding locations for transistors, wires, and other components is called **layout** or **place and route**. It would be an impossible task to lay out a million components by hand! Figuring out how to position all those miniscule parts and how to wire them together in an extremely small space couldn’t happen without EDA tools to determine the placement and routing.

Double-Check: Verification After Layout

At this point, we want to be absolutely sure that the chip’s design is still functional and that its timing is accurate. Long wires could cause delays in getting the electricity through the chip. Connections might be incorrect. Because the transistors and the wires that connect them are so small and close together, they could disturb electricity as it moves around, sort of like static on a car radio when you drive under high-tension wires. The engineer uses EDA verification tools again to double-check the final design. If any problems are found at this stage, they are isolated, analyzed and fixed. If not, the chip is ready to manufacture.

logy

inside a computer

Turn Sand into Chips

When everyone is satisfied that the design works, it's sent to a fabrication facility or **fab**. Enormous amounts of data are provided to the fab so the design can be turned into the actual working chips through photolithography on silicon wafers, as previously described. Once the chips are manufactured and packaged, they are placed on a tester, a large and very expensive piece of equipment. The tester uses the test program that was previously created during the design process to send electricity throughout the chip. This makes sure that all of the tiny components are there, functioning and hooked up correctly. Chips that fail the test are thrown away — a rather severe penalty for failure!

Connect the Chips

The finished, tested chips are connected to each other on a circuit board to be put into the final product (computer, digital camera, etc.) The mystery of what's inside a computer is now solved: circuit boards that have chips on them — chips full of transistors that are made of sand. The power of sand inside a computer is able to help take you to the moon!

Find Out More

So there you have it, the story of Electronic Design Automation and how sand becomes chips that send people to outer space. The most amazing part is how, in less than 50 years, computers have shrunk from massive room-consuming behemoths to powerful little devices that perform miracle upon miracle and can fit right in the palm of your hand. In short, the EDA industry, leveraging the power of technology, has enabled these amazing electronic developments that enhance so many aspects of our lives.

For a more detailed, yet easily understood and entertaining, explanation of the topics briefly described here, read *EDA, Where Electronics Begins* by Clive "Max" Maxfield and Kuhoo Goyal Edson, published by KuhooZ, Inc., September 2001 and available at www.edac.org and www.techbites.com.

silicon

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