Chapter 05 Microcomputers

Shambhavi Roy

Clinton Daniel
University of South Florida

Manish Agrawal
University of South Florida

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Roy, Shambhavi; Daniel, Clinton; and Agrawal, Manish, "Chapter 05 Microcomputers" (2023). FUNDAMENTALS OF INFORMATION TECHNOLOGY: Textbook – English. 5. https://digitalcommons.usf.edu/dit_tb_eng/5

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# Chapter 5—Microcomputers

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If you’re not looking toward the future or trying to improve the current technology, you’ll be left behind.

—Gwynne Shotwell, president of SpaceX

Overview

In the previous chapter, we saw how computers are used in organizations. In this chapter, we will introduce the common types of computers and provide an overview of the parts of a typical computer. This will allow you to compare computers with different specifications and make the right choices when selecting a computer for a specific task.

Microcomputers

A microcomputer is a small, standalone computer designed to be used by one person at a time. Almost all computers you have used so far are likely to fall in the category of microcomputers. Microcomputers are less expensive than large corporate computers designed to handle much heavier computational tasks. These corporate computers are also called servers. Microcomputers are also known as Personal Computers (PCs) and are typically used for personal tasks such as writing emails, searching for information on the web, creating documents, making presentations, updating spreadsheets, watching movies, listening to music, and playing computer games.

Microcomputers come in many formats. The most common types are desktop computers, laptops, tablets, mobile phones, and smartwatches on your wrist.

While desktop computers bear no resemblance to smartwatches, both share surprisingly similar architectures. Both have similar hardware components such as memory, storage, input, output, and Central Processing Unit (CPU). Both also have similar software components including an operating system and applications that run on the operating system.

Modern microcomputers can talk to each other and share information. When you snap a photo using your phone, it can become immediately visible on your desktop. Similarly, when you get a phone call or a message on your phone, it can pop up on your desktop, smartwatch, and phone simultaneously. We begin by taking a brief look at each type of microcomputer.

Desktop Computer

A desktop computer is a microcomputer primarily designed to meet the computational needs of a single user at a fixed location. If you have a comfortable desk where you do most of your work and would like a computer to use on the desk without moving it around, a desktop computer may be ideal for you.

While laptops are very popular for their mobility, desktops continue to be very popular for several reasons. Desktop computers generally offer the best value for your money since the components in a desktop do not have to be optimized for size, weight, or power consumption. Also, since desktops don’t have to be light, small, or portable, they can typically use larger power supplies and bigger fans to support
far more powerful processors (CPUs) and video cards. They can be configured with multiple hard disk drives, optical disk drives, and support multiple peripherals like large external monitors, external speakers, microphones, and cameras. Also, since they are designed to be stationary, users can create setups with multiple peripherals and full-size keyboards that do not have to be dismantled each time the device is moved. For their economy as well as setup convenience, desktop computers are very common in organizations, particularly for office staff who do not need portable computers to deliver presentations or take notes in meetings. Desktops are also popular for gaming because they can simultaneously support the most powerful computing units, video cards, and highest resolution monitors without the need to worry about optimizing battery performance.

One additional benefit of owning a desktop computer is the ease of upgrade. Desktops are enclosed in cases that are usually easy to open. Desktops typically offer expansion slots that you can use to add additional memory and Graphic Processing Units (GPUs) over time for a better video gaming experience. Since desktops are larger, they also have several extra ports (USB, USB-C, HDMI, audio, and memory card slots) readily available to add storage and connect peripherals.

As desktops are stationary, they also typically last much longer because they do not encounter shocks from being tossed around. You are also not likely to misplace your desktop at your local coffee shop or drop it from your backpack.

Typically, you’ll choose an operating system between the two dominating the desktop market—Microsoft Windows and Apple Mac OS. Microsoft desktops are generally less expensive and have a significantly larger share of the market compared to Apple Mac OS based desktops.

Linux is also an option for a desktop operating system. Ubuntu is a version of Linux optimized for desktops and laptops. The lack of end user applications such as Office and vendor-specific drivers for peripherals such as printers and cameras limit the usability of Linux desktops for many end users. In recent years, however, as web-based applications such as Office 365 and Google Docs gain popularity for most personal productivity tasks, Linux is becoming an increasingly viable option, particularly for enthusiasts.

**Laptop**

Laptops, small enough to fit in your lap, has a clamshell unit, a screen on the top half and an integrated keyboard and trackpad on the bottom. The great advantage of a laptop is its portability which allows you to work from anywhere—school, home, and coffee shops. In the post-Covid world, with most offices offering hybrid work models, a laptop may be an indispensable possession offering you the ability to work from wherever you want. As laptop prices drop, colleges are increasingly requiring students to own a personal laptop for use in class.

Manufacturers aim to design laptops that are as light as possible and work all day without the need for an external power source. To optimize for portability, the components inside a typical laptop,
including the CPU, Random-Access Memory (RAM), storage, keyboard, monitor, camera, microphone, and speakers focus on power efficiency, and compromise on performance metrics such as speed to keep the unit light. As the CPU is optimized to use less power and minimize heat generation, it may not be as powerful as your desktop CPU. This can be noticeable in demanding tasks such as video conferencing, software development, or when working on large spreadsheets with a lot of formulae.

Powerful chips generate a lot of heat and drain the battery fast, so this design optimization makes sense. Also, laptops typically have expensive Solid State Drive (SSD) storage because SSDs consume little power and are lightweight. Laptop keyboards can also lack features common in full-sized keyboards such as a dedicated numbers keypad.

However, the benefits of being able to sit at a park bench, airport, or meeting room, pull out your laptop and work or be entertained far outweigh the performance compromises of laptops for most users. As laptops come with a built-in rechargeable lithium-ion battery, you won’t need to find a charging source for several hours, even with continuous use. To address some of the limitations of laptops, you can carry a mouse and headphones or wireless earbuds. Some people keep a full-sized monitor, keyboard, and mousepad connected to a docking station at their home or office, so the laptop easily converts into a full-fledged desktop when they work for long hours.

Just like the desktop PC market, even the laptop market is dominated by Microsoft Windows and Apple Mac OS. As Apple manufactures its own hardware, a Mac PC will have Mac OS. However, since Microsoft licenses its operating system to other hardware manufacturers, you are likely to find Microsoft Windows on laptops manufactured by several manufacturers including Samsung, LG, Dell, HP, Acer, and others.

An increasingly popular laptop option, particularly for high school students, is the Chromebook. Chromebooks use an operating system developed by Google, which saves very limited data on the local device, and uses data storage on the cloud instead. This reduces hardware needs on the local device, reducing costs significantly. This approach becomes increasingly effective as more and more applications move to the cloud.

**Tablet**

A tablet computer (known simply as a tablet) is a microcomputer designed for portability and media consumption. They have screen sizes comparable to that of a laptop, but lack the input/output capabilities of a laptop such as keyboards and mice. Instead, they use touchscreens for input and output, much like a smartphone. Tablets have the same components as other microcomputers—RAM, CPU, storage, microphone, camera, and speakers, and they connect to the Internet through Wi-Fi, just like most other portable devices. Some tablet models also support Internet connectivity over a cellular network.

The motivation behind tablets is to have a basic computer that is inexpensive, can be carried easily and be turned on quickly to consume media in a convenient way. If you want to watch cooking shows in your kitchen, read books in subway stations, or attend web conferences from airport lounges, a
tablet may be the optimal device for you. To make them as easy to use as phones, they rely on mobile operating systems like Apple IOS or Google’s Android. Touching and swiping the screen is a fun and engaging experience for most users.

Today, there are about 5 billion mobile devices (smartphones and tablets) in the world. The two primary mobile OS makers (Apple and Google) have app stores where independent software developers offer games and applications. These app stores have unleashed the creative potential of software developers who build applications for tablets and smartphones. As a mobile phone or tablet user, you can access a tremendous array of games and all sorts of applications to enhance productivity, receive therapy, simplify communication, identify trees, improve vocabulary, and learn new languages.

**Smartphone**

Smartphones are portable computers that connect to the Internet using cellular telephone networks. Apple kickstarted the smartphone era by launching the iPhone in 2007. While mobile phones with rudimentary Internet capabilities (e.g., messages and text-based web browsers) existed prior to iPhones, Apple managed to package almost all the capabilities of microcomputers into an easy-to-use device that you could use not only to make calls and send text but also to run most microcomputer applications such as email, word processors, and spreadsheets. The iPhone brought together a purpose-built mobile OS based on UNIX, a touchscreen, and an App store, all into one easy package.

Keep in mind, today’s smartphones are far more powerful than even the Apollo 11 guidance computers, which helped us land on the moon and return safely. At the core, a smartphone is also a microcomputer that has CPU, RAM, storage, display, speakers, and a microphone, with the touchscreen and microphone serving as primary inputs. The app stores (available in Apple’s IOS and Google’s Android) add to the versatility and usefulness of smartphones. Connectivity applications such as Snapchat and Instagram enhance the entertainment value of phones, particularly for younger users; the mobile versions of Zoom, Gmail, and Microsoft’s Office suite turn them into productivity tools; WhatsApp, Slack, and Discord ease casual communication. These applications, created by third-party vendors, greatly enrich the value of smartphones.

Prior to smartphones, we had featurephones that had a non-touch display, press-button based inputs, and a set of built-in features. However, the smartphone is dynamic. You can add new apps, remove old apps, and play a newly released game by buying it on the app store. It is possible to download and use new applications because the Application Programming Interfaces (APIs) of mobile operating systems allow third-party software to integrate tightly with the phone’s software and hardware.

Smartphones have eliminated many electronic utilities. Since smartphones became popular, people have stopped carrying cameras and camcorders and even use their phones as a flashlight at night. Hotels are beginning to eliminate alarm clocks and it is becoming increasingly difficult to find radio-clocks, which were standard fixtures in bedrooms for decades.

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**Smartwatch**

A smartwatch is a microcomputer that you can wear on your wrist. Smartwatches are the newest entrants to the microcomputer line-up. Smartwatches have RAM, internal storage, and a CPU. They either use their own cellular chips or pair with phones to connect to networks. Because of their size limitations, they obviously don’t have a keyboard and mouse. But smartwatches make up for that shortcoming in other ways, primarily by leveraging their seamless connectivity with smartphones. Streaming services make it easy for you to save music on your watch. Because smartwatches use Bluetooth to connect with peripherals, you can put your ear buds on and go for a walk, while listening to your favorite songs streaming out of your watch. You can also make phone calls and send/receive messages while you are exercising and don't have access to your phone.

The main unique selling proposition (USP) of smartwatches is that they help users improve their health. As microcomputers closest to users and wrapped around wrists, smartwatches have the potential to accurately sense many health parameters. Current technologies already allow smartwatches to monitor heart rates, blood oxygen levels, body temperature, step count, and sleep cycles. Some smartwatches can detect a fall and automatically notify nearby emergency services. Other smartwatches can detect irregular heartbeats and remind you to get yourself checked.

The industry is working hard to add additional capabilities, including blood pressure and sugar monitors. If these efforts are successful, smartwatches could help mitigate many common lifestyle health issues like sugar, blood pressure, and fat. In the coming years, smartwatches may be our greatest asset in improving health. Some of you may be the ones to write the software applications that leverage the hardware capabilities of smartwatches to detect and monitor diseases.

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**Form Factor**

The differences in the types of computers discussed in this section can also be described as differences in their form factors. Form factor is the term used to describe the physical size and shape of a computer device measured by outside dimensions. For many common components, the form factor is also used as an identifier for a class of components. For example, as 3.5” or 5.25” hard drive, or a 1U or 2U server. These specifications define the space needed to fit the components, not the drive's storage capacity or a server’s processing capacity.

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Architecture of a Microcomputer

Microcomputers (or computers for short) take signals from input devices, process these inputs in the CPU using instructions loaded in memory, and send the output to an output device. This general processing sequence is used to understand keyboard strokes. The general architecture of a computer was specified in 1945 in a report produced by the University of Pennsylvania for the US Military. The report is known in the industry as the Von Neumann report. Section 2 of the report is shown in Figure 15. Remarkably, the basic computer architecture and the flow of input and output signals is almost unchanged since the original 1945 report.

FIGURE 15 — Von Neumann architecture of a computer.

We will now look at the computer hardware—the physical parts of a computer you can touch and feel. We will then examine the core parts of computer software—the instructions that tell a computer what to do.

Motherboard

The motherboard is the wiring that connects all the components of a computer. The motherboard of a computer is analogous to the layout of a city or town. The layouts of most towns and cities have well-designed roads connecting homes, schools, parks, libraries, and office complexes. When a city or town is planned, the designers anticipate user needs and come up with an architecture to connect the different parts of the town and facilitate the quick movement of people and goods. They take into consideration the flow of traffic, utilities, and sewage to ensure the city roads do not get choked, and the residents don’t have

to deal with electrical and plumbing disasters every few days. Traffic rules and signs are established for orderly movement. Once the architecture is laid out, and the parts built in accordance with the architecture, the town can continue to function like a well-oiled machine.

The motherboard does for a computer what the layout does for a city. The motherboard is a plan to place various computer parts (CPU, RAM, storage, input and output devices) in the right locations and connect them to each other, so all the parts get the necessary power and are able to communicate with each other at their rated speeds. See Figure 16.

![Figure 16 — A motherboard.](image)

A motherboard not only has designated slots for the core components but it also distributes the right amount of power to each component. To dissipate the heat generated by high performance CPUs, motherboards also have mechanisms to attach heat sinks and fans. The motherboard also has data paths called a bus to move data at high speeds between the components. The motherboard may also have expansion slots for you to add additional RAM (storage) and GPUs (Graphical Processing Units) to allow the computer to scale if needed.

**CPU**

The Central Processing Unit (CPU) is the brain of the computer and performs all the computations necessary to execute the user’s command. Modern CPUs implement the Von Neumann architecture (Figure 15). The core technological marvel that enables CPU capabilities is the transistor. A transistor is an electronic device that amplifies a signal. To create the binary behavior necessary for computer operation, the transistors used in computers are highly sensitive and effectively act as switches. When the input is low, these transistors block the connection (interpreted as 0) and when the input is high,
the transistors enable the connection (interpreted as 1). By rapidly switching between 0 and 1 as directed by the software instructions, transistors help CPUs perform the necessary computations for the user. Modern CPUs have many transistors to do complex data processing. CPUs in popular computers today can have over 100 billion transistors.

Transistors are one of the world’s most sustained innovations. In 1971, Intel’s first CPU, the Intel 4004 had 2,300 transistors and cost $200 for a cost of $0.10/ transistor. The transistors in the Intel 4004 were able to switch between 0 and 1 about 740,000 times per second. Performing each instruction took about 8 switches, and the Intel 4004 was able to complete about 92,000 instructions per second.

In 2022, the AMD Epyc 7773X chip has 26 billion transistors, and sells for ~$9,000, for a cost of $0.0000003 per transistor. While instructions are now considered a simplistic metric, this chip is likely to perform the equivalent of 1.8 trillion instructions per second. So, while the cost per transistor has fallen by a factor of 250,000 between 1971 and 2022, the capabilities have gone up by a factor of almost 20 million. This revolution in costs and capabilities is the key enabler of digitally driven changes in our economy, which make a class like Digital Information Technologies relevant to our society.

CPUs tend to follow Moore’s law, the observation made by Gordon Moore (founder and CEO of Intel) in 1965 that the number of transistors on a microchip doubles approximately every two years. This is seen in the graph below (Figure 17), the growth in the number of transistors on microchips for 50 years since 1970.

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39 There are more detailed explanations online, e.g. “How Transistors Work—The Learning Circuit,” https://www.youtube.com/watch?v=R0Uy4EL4xWs (accessed June 2023).
Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing — such as processing speed or the price of computers.

**Transistor count**

<table>
<thead>
<tr>
<th>Year in which the microchip was first introduced</th>
<th>Transistor count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>50,000,000,000</td>
</tr>
<tr>
<td>1972</td>
<td>100,000,000,000</td>
</tr>
<tr>
<td>1974</td>
<td>200,000,000,000</td>
</tr>
<tr>
<td>1976</td>
<td>400,000,000,000</td>
</tr>
<tr>
<td>1978</td>
<td>800,000,000,000</td>
</tr>
<tr>
<td>1980</td>
<td>1,600,000,000,000</td>
</tr>
<tr>
<td>1982</td>
<td>3,200,000,000,000</td>
</tr>
<tr>
<td>1984</td>
<td>6,400,000,000,000</td>
</tr>
<tr>
<td>1986</td>
<td>12,800,000,000,000</td>
</tr>
<tr>
<td>1988</td>
<td>25,600,000,000,000</td>
</tr>
<tr>
<td>1990</td>
<td>51,200,000,000,000</td>
</tr>
<tr>
<td>1992</td>
<td>102,400,000,000,000</td>
</tr>
<tr>
<td>1994</td>
<td>204,800,000,000,000</td>
</tr>
<tr>
<td>1996</td>
<td>409,600,000,000,000</td>
</tr>
<tr>
<td>1998</td>
<td>819,200,000,000,000</td>
</tr>
<tr>
<td>2000</td>
<td>1,638,400,000,000,000</td>
</tr>
<tr>
<td>2002</td>
<td>3,276,800,000,000,000</td>
</tr>
<tr>
<td>2004</td>
<td>6,553,600,000,000,000</td>
</tr>
<tr>
<td>2006</td>
<td>13,107,200,000,000,000</td>
</tr>
<tr>
<td>2008</td>
<td>26,214,400,000,000,000</td>
</tr>
<tr>
<td>2010</td>
<td>52,428,800,000,000,000</td>
</tr>
<tr>
<td>2012</td>
<td>104,857,600,000,000,000</td>
</tr>
<tr>
<td>2014</td>
<td>209,715,200,000,000,000</td>
</tr>
<tr>
<td>2016</td>
<td>419,430,400,000,000,000</td>
</tr>
<tr>
<td>2018</td>
<td>838,860,800,000,000,000</td>
</tr>
<tr>
<td>2020</td>
<td>1,677,721,600,000,000,000</td>
</tr>
</tbody>
</table>

Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)

**FIGURE 17** — The exponential increase in transistor counts per microchips doubles every two years.

This exponential growth has not only given us faster computers but has also made them smaller, cheaper, and less power hungry. This has enabled form factors such as smartwatches and enabled even low-income people in developing countries to own computers and smartphones and communicate over the World Wide Web.

**Buying Tip**

Before you decide to buy a computer with the latest, most powerful CPU, you should keep in mind that the CPU is also typically the most expensive part of your computer. You may never utilize the power of the CPU if you plan to use the computer just to create Word documents, PowerPoints, write emails, and browse the web.

**RAM**

Random Access Memory (RAM) is much faster than all other kinds of storage devices like hard disk drives (HDDs), solid-state drives (SSDs), and optical drives.
It is used to temporarily store computer instructions that need to be accessed frequently, along with the data processed by these instructions. For example, when you launch the Chrome browser, the CPU needs a place to temporarily store the Chrome program as well as the webpages you are viewing and track all the changes you are making.

**Memory Types**

Memory comes in many types. In addition to RAM, modern CPUs also have extra-fast memory within the processor chip called the cache.\(^{46}\) The cache is designed for instructions and data to be readily available within the CPU for instant access. In fact, there are multiple levels of cache in modern processors as seen here.

As of 2020, the cache memory within the processor chip is 10–100 times faster than RAM memory.\(^ {47}\) It takes 1–4 nano seconds to retrieve data from the cache, and about 100 nano seconds to retrieve data from RAM.

If you happen to open many tabs on your browser and end up consuming all available RAM, your browser will become slow and might even crash. Computers try to augment RAM by using space on the hard drive as an extension of the computer’s RAM. This additional space is called the page file, or virtual memory.\(^ {48}\) Since the hard drive is usually many times slower than RAM, your computer’s performance could get noticeably slower as the page file use increases. In these cases, it is useful to open the Task Manager to kill some unused programs and free up RAM to regain computer speed.

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Opening the Task Manager

In Windows, right click the start (or Windows) button on your taskbar to access the Task Manager. In the Task Manager, the “Processes” tab will clearly identify the programs that are consuming most memory and CPU. You can also open the Task Manager by using the “Ctrl+Shift+Esc” keyboard shortcut.

In Figure 18, the Snagit app is consuming the most memory.

RAM is typically measured in gigabytes (GBs). A byte is equal to 8 bits. A bit, the unit of computer information, is a binary digit and takes a value of either a 1 or a 0. For example, the state of a light bulb—on or off, can indicate a 1 or 0. All information, whether in text, photo, audio, or video format, is converted into binary format and represented as bytes. Once this translation happens the computer can store it in RAM and process it in the CPU.

RAM is one of the most critical components to speed up a computer. Your RAM requirement is one of the key decisions you’ll need to make before purchasing a computer.
How Much RAM Do You Need?

Here are the RAM recommendations from Crucial, one of the leading manufacturers of RAM. 49 & 50

Generally, we recommend 8GB of RAM for casual computer usage and Internet browsing, 16GB for spreadsheets and other office programs, and at least 32GB for gamers and multimedia creators. How you use your computer influences how much RAM you need, so use this as a guideline.

<table>
<thead>
<tr>
<th>IF THIS IS HOW YOU USE YOUR COMPUTER</th>
<th>HERE’S HOW MUCH MEMORY WE RECOMMEND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Casual User</strong></td>
<td>At least 8GB</td>
</tr>
<tr>
<td>Internet browsing, email, listening</td>
<td></td>
</tr>
<tr>
<td>to music, or watching videos</td>
<td></td>
</tr>
<tr>
<td><strong>Intermediate User</strong></td>
<td>At least 16GB</td>
</tr>
<tr>
<td>Internet browsing, email, Word</td>
<td></td>
</tr>
<tr>
<td>Processing, spreadsheets, running</td>
<td></td>
</tr>
<tr>
<td>simple graphics programs, flash</td>
<td></td>
</tr>
<tr>
<td>games, music, videos or multitasking</td>
<td></td>
</tr>
<tr>
<td>**Professional User/Gamer/Graphic</td>
<td>At least 32GB</td>
</tr>
<tr>
<td>Designer**</td>
<td></td>
</tr>
<tr>
<td>High performance gaming, multimedia</td>
<td></td>
</tr>
<tr>
<td>editing, high-definition video,</td>
<td></td>
</tr>
<tr>
<td>graphic design/3D modelling, intensive multitasking</td>
<td></td>
</tr>
</tbody>
</table>

Unfortunately, RAM is only operational when it is powered. Even a momentary power loss clears up the contents in RAM.


**RAM and a Worker’s Pocket of Tools**

You can think of RAM as being analogous to a worker’s pockets. The data and instructions in RAM are analogous to the tools a plumber or an electrician carries with them when they perform tasks inside homes. The worker has the entire set of tools and supplies in their parked truck, but it would take forever to complete any job if they had to go back to the truck every time they needed a screwdriver or tape. Instead, having these tools ready at hand speeds up their work. Similarly, having data and instructions at hand in RAM and cache helps the CPU speed up execution.

**Storage**

Computer storage is the technology that stores the software (e.g., operating system and applications) and data on the computer. Storage is also popularly known as hard drives. A critical feature of storage technology that differentiates it from RAM is that applications and data are retained in storage even after the power is turned off. This ability to retain data for long periods without power or external connectivity allows you to store software and relevant data (e.g., documents, games, songs, and movies) in your computer throughout your school years and beyond. When the computer is powered on, the computer loads the operating system from storage into memory. As RAM cannot store data unless the computer is on, every computer comes with in-built secondary storage to keep your content safe when it is powered off.

Modern storage devices have reasonably large capacities and can store all the data and applications most users need. If your storage needs exceed the capacity of the built-in storage device, you have a few options. Most users connect external storage devices to augment the storage capacity of their computers. External storage is typically connected to your computer using a USB cable.

Cloud storage services such as DropBox, Box, OneDrive, iCloud, and Google Drive are also options to store personal data for a fee. Cloud services eliminate the risk of data loss. Cloud services like Backblaze offer even more comprehensive backup capabilities, saving

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all the files on a computer. Both external drives and cloud services can also be used to back up your data and move it between computers.

Your storage needs depend upon the kind of information you work with. If you work mostly with text, your typical Word document will be a few kilobytes (1 kilobyte = 1000 bytes) in size. Photos are usually larger, about 4–5 megabytes (1 megabyte = 1000 kilobytes or 1 million bytes) in size. Higher resolution photos can be even larger. Audio files are comparable in size to photos, with each song typically taking up about 5MB (in compressed formats like MP3) and about 50MB in CD quality uncompressed formats. 4k videos in current smartphones take up about 1 gigabyte (1 gigabyte = 1,000 MB or 1,000,000 bytes) per minute. The table below shows the common prefixes for file sizes.

<table>
<thead>
<tr>
<th>Memory unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilo Byte</td>
<td>1 KB = 1024 Bytes</td>
</tr>
<tr>
<td>Mega Byte</td>
<td>1 MB = 1024 KB</td>
</tr>
<tr>
<td>Giga Byte</td>
<td>1 GB = 1024 MB</td>
</tr>
<tr>
<td>Tera Byte</td>
<td>1 TB = 1024 GB</td>
</tr>
<tr>
<td>Peta Byte</td>
<td>1 PB = 1024 TB</td>
</tr>
<tr>
<td>Hexa Byte</td>
<td>1 EB = 1024 PB</td>
</tr>
<tr>
<td>Zetta Byte</td>
<td>1 ZB = 1024 EB</td>
</tr>
<tr>
<td>Yotta Byte</td>
<td>1 YB = 1024 ZB</td>
</tr>
<tr>
<td>Bronto Byte</td>
<td>1 Bronto Byte = 1024 YB</td>
</tr>
<tr>
<td>Geop Byte</td>
<td>1 Geo Byte = 1024 Bronto Bytes</td>
</tr>
</tbody>
</table>

**HDD vs SSD vs Portable Flash Drives**

There are two popular storage technologies currently in use—magnetic disks and solid-state disks. Magnetic disks store data as changes in magnetization on tracks on a disk. Solid state disks (SSD) store data as the charge state of a transistor. Let’s take a quick look at each type of storage.

Magnetic disks, also called hard disk drives (HDDs), are a legacy technology that store digital data on glass platters coated with magnetic material. Data is stored as the direction of magnetism of the material. HDDs have a reader head that can magnetize portions of the disk during the writing process and read the direction of magnetization during the read process. The disks in an HDD spin as fast as possible, while the head writes or reads data on the disk. The weight of the rotating platter makes hard disks heavy, slow, noisy, and hungry for power. However, at the current time, HDDs are cheaper than SSDs and can store significantly more data that SSDs. So, if you plan to store a lot of media files (songs, movies, and games), hard disk drives may be a good secondary storage option for you.
Solid-state drives (SSDs) are a newer type of storage devices that use transistors to store data. The transistors used in SSDs can save a charge even when not connected to power, enabling them to save data over long periods. SSDs do not have any moving parts, unlike HDDs. Not having any moving mechanical parts allows SSDs to be faster, longer lasting, and power efficient. Most newer computers come installed with SSDs as the primary internal storage.

As of 2020, it takes 16,000 nano seconds (16 microseconds) to read data from an SSD and 2,000,000 nano seconds (2 milli seconds) to read data from a hard disk drive.\(^53\) Thus, L1 cache is the fastest, L2 cache is 4 times slower than L1 cache, RAM is 25 times slower than L2 cache, SSD is 160 times slower than RAM and magnetic disks are 125 times slower than solid state disks.

A popular small version of an SSD is called a portable flash drive (also known as a USB stick). These devices are designed to be compact and often given out as company swag for marketing purposes. If you plug the flash drive or USB stick into your computer, the operating system will automatically detect the USB key as a storage device and the contents of the key become available in your File Explorer. You can treat the USB key like a storage device into which you can add or remove files. USB sticks are useful when you want to move content from one computer to another.

File Safety With Portable Drives

Before you remove the USB stick or other external storage device from the USB port of your computer, you should remember to “Eject” to avoid corrupting the data on the device. To “Eject,” right click on the USB drive in your File Explorer and select “Eject.” You’ll get a message stating it is now safe to disconnect the device. Properly removing the external device ensures that the operating system has cleaned up and closed files to avoid damaging the contents of the external storage device.

Bus

The bus in a computer is a communication system that transfers data between a set of components. As we have seen, the components on a computer operate at vastly different speeds. Buses allow the CPU to operate at the highest speeds possible, without getting slowed down by the slowest components. The buses in the earliest computers were simply a set of wires connecting components. Developments in bus technologies have enabled CPUs to become significantly faster even as peripherals like printers and keyboards (and human users) have not evolved at a comparable pace. Modern micro-computers have several buses, each operating at its own speeds.

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Buses in General

The term “bus” is a general term for a shared connection that maintains uniform properties across its span to which several consumers are connected in parallel. Thus, the power distribution lines delivering power at a fixed voltage to electrical substations can be considered a distribution bus, and the power lines supplying power to homes in a neighborhood at the constant 120 volts and 60 Hertz can be considered load buses. Similarly in a computer, each bus operates at the same clock speed and has the same data across its span at any given time.

GPU

A graphics processing unit (GPU) is a computing technology designed to run several small programs simultaneously. While modern CPUs have multiple cores and threads and can run tens of multiple programs in parallel, GPUs can run thousands of programs in parallel. The overall size of the processor chip is about the same in both CPUs and GPUs. While CPUs are organized as a small number of highly capable processors, GPUs are organized as many relatively simple processors with relatively limited capabilities. For most tasks, the complexity of CPUs is sufficient. However, for a small subset of tasks, mostly in image processing and machine learning (ML), there is a need to perform many simple operations in parallel. As image processing becomes popular for gaming and machine learning becomes popular for artificial intelligence, GPUs have become increasingly popular. This is also reflected in the market caps of the principal CPU manufacturer, Intel ($120bn) and the principal GPU manufacturer, Nvidia ($400bn).

A lot of young people use personal computers primarily to play video games. Over time, the games have become hyper-realistic and take place in a fantasy world where artificially created characters interact with each other. Complex lighting and shadow patterns on high resolution monitors with fast refresh rates can make these games very realistic. For a while, CPUs were stretched thin dealing with complex gaming algorithms and high-resolution images designed to simulate a true-to-life experience.

The computing industry addressed the problem by introducing chips dedicated to processing graphics and rendering video content on the screen. These chips, known as GPUs work in tandem with the CPU of the computer. The CPU handles the user input and does all the computations (e.g., Did two objects collide? What is the location of objects on the screen). So, the CPU is still the overall boss, but it can send video gaming/image processing workloads to the GPU, which does the computations needed to render each pixel (e.g., color, shading, brightness) in the frame. Modern high resolution gaming monitors can have over 8 million pixels (3,840 x 2,160) and with frames refreshed 60 times a second (refresh rates), about 500 million computations are needed each second to just display the images.

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54 Peter Ashman, “Why do CPUs have so few cores compared to GPUs?” https://qr.ae/pr8Rkp (accessed June 2023).

While this is a lot of computations, all the computations are similar and simple. These are a perfect fit for GPUs, and therefore CPUs delegate these computations to GPUs for optimal performance.

GPUs themselves come in two formats: Integrated GPU (Figure 19) and Discrete GPU (Figure 20). Integrated GPUs look like just another chip on the motherboard and cannot be upgraded by the end user. On the other hand, Discrete GPUs can be purchased, replaced, and upgraded by the end user. It connects to the motherboard through an expansion slot on the PCIe bus and comes with its own cooling fans. Typically, Discrete GPUs are far more powerful than Integrated GPUs.

**GPUs for Video Content Creation**

Because GPUs were originally designed to handle fast/high resolution video rendering, they have become the go-to choice for video content creators, too. If you like to capture videos, edit them, splice them with additional audio/video content, then a powerful GPU on your PC will make your video editing program much faster. Whether you are an anime creator, an Adobe Photoshop user, or a producer of content for educational purposes, you may consider buying a computer with a powerful GPU or adding one to your current system.

**GPUs for ML and Crypto Mining**

Even though GPUs were designed primarily for graphics and video rendering, data scientists working on machine learning (ML) models also found GPUs useful. The job of going through all photos uploaded by users to Facebook and removing objectionable content is a difficult and expensive task for humans. Facebook users upload more than 350 million photos per day. To manually view each one and determine if it is suitable for consumption can be daunting. Machine learning algorithms are an effective and cheap way to do the job. As most machine learning algorithms involve a lot of identical operations (addition and multiplication), GPUs are great ML use cases.

During 2015–2022, crypto mining became very popular. In crypto mining, computers search for solutions to cryptographic problems for the right to add a block to a chain and get the reward associated with adding the block to the chain. GPUs can search far more options than CPUs in a given time. Therefore, during the recent crypto boom, it became difficult for regular users to purchase GPUs as they were in high demand by crypto miners, who were willing to pay premium prices for these GPUs.

GPUs—The Florida Connection

One of the world’s leaders in GPU development is Nvidia. One of the three co-founders of Nvidia is Chris Malachowsky, an alum of the University of Florida. He received a BS in EE from UF in 1986, and co-founded Nvidia with Curtis Priem and Jen-Hsun Huang in 1993. In 2020, he gifted $25 million to the University of Florida to build HiperGator AI, one of the world’s fastest AI supercomputers, and made it available to students, researchers, and businesses across Florida.57

Input Devices

As computers are designed to interact with humans, they need a mechanism to take our commands and return responses. An input device is a medium through which we can provide actionable tasks for computers. Let’s look at some common input devices to understand them better.

Keyboard

A keyboard is the primary input mechanism of a computer. Keyboard commands get translated into emails, chat messages, clicks on a browser screen, video game movements, or others depending on the program receiving the input. As the standard English keyboard has the letters Q, W, E, R, T, and Y on the top row, it is known as QWERTY. See Figure 21. This arrangement, designed for typewriters, was intended to avoid jamming typebars striking on paper and is, unfortunately, not the most efficient layout for modern computers.

![Figure 21 — A standard English keyboard, also known as QWERTY.](image)

For touch typists (those who type without looking at keys), the letters F and J have a small, raised dot. The dots are meant to help you place your forefingers on the keyboard before you begin typing.

QWERTY vs Dvorak and the Path Dependence of History

The QWERTY layout was designed to slow typists down to prevent key jamming in mechanical typewriters. This was done by placing the most popular keys, e.g., e, t, a in relatively awkward positions, as opposed to convenient locations in the center of the keyboard. Also, the QWERTY layout makes disproportionate use of the left hand, which is not the dominant hand for most people. However, the layout, created in 1873, became popular with typewriters.

August Dvorak created an alternate keyboard layout in 1936 to reduce finger movement for common words by placing common keys closer to the center of the keyboard, thereby increasing typing speed, reducing errors, and increasing comfort. However, the Dvorak keyboard never gained popularity despite the potential advantages. Another persistent historical artifact is the staggered arrangement of keys on different rows, which was done to accommodate the key levers from different rows. This staggering is not needed in electronic keyboards, but the design persists. Many modern designs can be traced to historical constraints that no longer apply. Identifying these opportunities to relax constraints is a potential avenue for innovation.

If you don't want to adjust to the standard keyboard size, you may want to consider ergonomic keyboards designed to fit your fingers (see Figure 22). You can connect any new keyboard to your desktop or laptop through USB or Bluetooth.

Mouse and Trackpad

If you look closely at your computer screen, you will see a small arrow like the one in Figure 23.

This arrow tells the computer where to focus. You can use your mouse/trackpad to shift the point of focus any time. Your mouse/trackpad typically has two buttons, left and right. We use the left button to click and select objects, and the right button is used to open contextual menus that change based on your location. The mouse also has a wheel to scroll through multiple pages easily. If you have a wireless mouse, you can connect it to your device via Bluetooth software.

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59 However, also see Yasuoka, Koichi; Yasuoka, Motoko, “On the Prehistory of QWERTY,” https://repository.kulib.kyoto-u.ac.jp/dspace/bitstream/2433/139379/1/42_161.pdf (accessed June 2023).
The mouse is popular with desktop computers and office areas with sufficient desktop space to move the mouse. Since laptops are often used in tight spaces (e.g., airport seats) with no room to place a mouse, most modern laptops come with touchpads to replace the mouse as a tactile input device. Touchpads or trackpads use a specialized surface to translate the position of a user’s fingers on the device to a location on the screen. The screens of modern smartphones also serve as touchpads.

**Camera and Microphone**

With the popularity of remote work in the post-Covid world, most employees use Zoom, Webex, GoTo, Teams, or Google Hangouts daily to join meetings and conferences. Often, you’ll be required to keep your video and audio on to participate and have the feeling of being in a room with other participants. All these programs depend on the camera and microphone on your computer to share your video and audio with other meeting participants. As online meetings become increasingly important for school and work, the quality of the camera and microphone are becoming increasingly important differentiators of laptops. If these devices are not satisfactory, you can buy and connect an external high-resolution camera and a high-fidelity microphone to your computer to improve your remote-working experience.

**Output Devices**

After a computer accomplishes your tasks, the output devices will communicate the outcome of the actions. A monitor is the primary output medium that you will interact with all the time, whether you watch a movie on Netflix, type an email to a friend, or work on a spreadsheet.

Since you will spend most of your time on the computer looking at the monitor, the monitor has a significant impact on your end-user experience. Fortunately, most modern monitors provide excellent performance at an affordable price. Some extra monitor features may come at a price. For example, touch screens are interesting, but they also consume more power and add weight to the laptop cover. Similarly, large screens are useful during work, but reduce portability. It is therefore useful to carefully assess your needs before you select a monitor.60

To improve your productivity, you can attach more than one display screen to your computer (see Figure 24). You can use the HDMI or USB-C ports on your computer to connect multiple displays.

**FIGURE 24** — The use of two screens can improve productivity.

**Speakers**

Most Laptops and PCs come with built-in speakers to play audio. Most laptops today have very good sound output, including some models which use four speakers to produce rich, realistic sound. It is also becoming increasingly common for users to use earbuds or headphones to minimize disturbance to nearby users. Further, to improve the quality of sound, particularly if you watch videos on YouTube or listen to music on Spotify, you may attach your own high-fidelity speaker through the USB ports or use Bluetooth to connect to wireless earbuds.

**Conclusion**

Have you ever opened the outside case of a desktop to peek at the inside parts? The inside looks like a tightly placed collection of parts, which may be confusing at first glance (see Figure 25). But now that you know the key parts of a computer, you should be able to recognize most parts. If your computer is too outdated or slow, you may even explore opening it up and adding memory to make it faster and last longer. 99
To make these hardware parts work in a coordinated manner, computers have software which tell these hardware components what to do. While the operating system (Microsoft Windows, Apple Mac OS or Linux) is the main software acting as the brain of the computer, you'll generally need to install many other end-user applications (e.g., Chrome, Snapchat, Instagram, DropBox, Google Maps, Spotify, Paint, Snagit, and others) to turn the computer into a versatile assistant.

As seen in Figure 26, end users interact with applications, which request the operating system to have the hardware to perform the needed tasks to meet user needs.

Any software program is a collection of instructions to the CPU to perform a task. These instructions are expressed in binary code for the CPU to perform the required operations. Afterwards, the output is conveyed to us through the correct output device, which translates the 1s and 0s to images, sound, and text.
Chapter Terms and Definitions

**Bit**: A binary digit and a unit of computer information; a bit takes a value of either a 1 or a 0

**Bluetooh**: A technology designed for exchanging data wirelessly between electronic devices over short distances

**Bus**: In a computer a bus is a communication system that transfers data between a set of components

**Byte**: A byte consists of eight binary digits and is commonly used to store various types of data, such as text, images, audio files, and program code

**Central Processing Unit (CPU)**: An electronic circuitry component of a personal computer that is designed to interpret, process, and execute instructions from hardware or software programs

**Computer Architecture**: The way a computer is designed, including its various hardware components and how they work together to perform tasks; it determines the overall functionality and performance of the computer system

**Crypto Mining**: Using computational power of a computer to solve complex problems that produces money in the form cryptocurrency such as bitcoin

**Gigabyte**: A unit of digital information that represents one billion bytes; it is commonly used to measure the storage capacity of computer memory and storage devices, such as hard disk drives, solid-state drives, and memory cards

**Graphical Processing Unit (GPU)**: Electronic circuit technology designed to speed up the creation of images displayed on a device such as computer monitor

**Hard Disk Drive (HDD)**: A type of computer storage device that uses rotating disks coated with magnetic material to store data permanently

**High Definition Multimedia Interface (HDMI)**: A hardware connection technology designed to transmit digital audio and video signals through a cable between HDMI compatible devices

**Input Device**: A device such as a computer mouse or keyboard that delivers data and is able to manipulate components of the computer

**Keyboard**: In relation to computer peripherals, a physical or digital device capable of communicating with a connected computer system through assigned key inputs

**Machine Learning (ML)**: Programmed parameters where data is passed through statistical models in which the model increases accuracy with more data; this presents itself in the form of intelligence that is artificial

**Moore’s Law**: A “law” proposed by Gordon Moore, Intel co-founder, stating that the number of transistors in microchips would double every two years due to advancing computing performance

**Motherboard**: Computer component that acts as a dock, is responsible for controlling core computer processor, and connecting various other pieces of computer hardware
**Mouse:** In relation to computer peripherals, a hand-held input device capable of detecting user manipulation through motion to facilitate interactions with computer systems

**Optical Drive:** A type of computer hardware that uses lasers to read data from or write data to optical discs, such as CDs, DVDs, and Blu-ray discs

**Output Device:** Computer hardware such as a computer monitor or mobile device screen that is designed to convert information into a visual display easily understood by humans

**Personal Computer (PC):** Also referred to as a microcomputer; a device that processes computing functions that serve one or multiple personal or business purposes

**Portable Flash Drives:** Small, portable devices, easily connected to a computer via USB ports, that store digital data using flash memory

**Random-Access Memory (RAM):** Sometimes called the memory of a computing device such as a smart phone or PC; a component within a computing device capable of temporarily storing data that can be accessed by the CPU whenever processing is required

**Smartphone:** A portable computer that can connect to the Internet through cellular networks and offers a range of features such as web browsing, email access, social media apps, multimedia playback, and various downloadable applications

**Smartwatch:** A microcomputer that you can wear on your wrist

**Solid-State Drive (SSD):** A type of computer storage device that has no moving parts and uses flash memory to store data permanently

**Transistor:** A basic electronic component used in computer architecture to amplify and switch electronic signals; it acts as a tiny switch that controls the flow of electrical current by using a small voltage input to control a larger current output

**Universal Serial Bus (USB):** A standard used by the computing industry to specify how hardware in devices can connect, communicate, and supply power across personal computers

**Wi-Fi:** Wi-Fi is a wireless networking technology that enables electronic devices, such as computers, smartphones, and tablets, to connect and communicate with each other via a wireless medium
Gaming Consoles Yesterday, Today, and Tomorrow

Atari is a company founded in 1972 that developed an iconic gaming console which enabled millions of users to play games such as “Pong,” “Asteroids,” “Centipede,” and “Missile Command.” According to atari.com, “Atari played an integral role in the development of the arcade game, game console, and personal computer industries.” In 1977 Atari released the Atari 2600 gaming console (also called the Atari Video Computer System) which featured microprocessor-based hardware that included swappable gaming cartridges capable of storing Kilobytes (KB) of gaming information. Additionally, the gaming console included a motherboard which could control hardware components such as a CPU, RAM, input devices (joy sticks), and output devices.

More than 50 years has passed since Atari was founded and gaming consoles today have been innovated far beyond the computing capabilities of the 1977 Atari 2600. Use the Internet to research any gaming console system (ex. Microsoft Xbox, Sony PlayStation, etc.) of your choice. Answer the following questions based on the results of your online research:

Question 1: List the hardware specifications for the gaming console of your choice. Be sure to list as many hardware components as you can (ex. CPU, memory, input devices, output devices, etc.). After listing each hardware component, briefly describe what the component is used for. Finally, provide a weblink to document where you retrieved the information.

Question 2: Write a short paragraph describing what you imagine gaming consoles will be capable of doing 50 years in the future.