# Living in the IT Era

MST 101d Lecture Notes

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Draft version: 13 August 2026

# Preface

I am preparing these lecture notes for *Living in the IT Era*, taught to undergraduate biology students at Bulacan State University's San Rafael Campus. I am not trying to turn you into computer scientists or make you memorise catalogues of devices, inventors, and fashionable technologies. I want these notes to help you understand the digital systems that shape ordinary life, use those systems effectively, evaluate information critically, protect yourself and others, and recognise when specialist technical knowledge is needed.

The material is organised into ten chapters. Each chapter is built around a central question and a practical task. Examples are drawn whenever possible from biology, health, research, and Philippine digital life.

The scope follows the general-education framework for *Living in the IT Era* in CHED Memorandum Order No. 20, series of 2013 [1]. The order places the course within the Mathematics, Science, and Technology elective domain and emphasises the science, culture, and ethics of information technology; its influence on modern life and relationships; and its use for personal, professional, and social advancement.

These notes are a work in progress. Chapters may be incomplete or revised as the course develops. Reports of errors and suggestions are welcome at

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I expect these notes to change as you use them. The first draft inevitably reflects what I know, what I can readily bring to mind, and what I expect a class will need. You may identify a point that needs a better explanation, ask for a practical topic that I had not considered, or show that an apparently minor issue deserves more attention. I welcome those requests and will revise the notes when doing so would make the course more useful.

That flexibility is deliberate. I want the module to respond both to the digital problems you face now and to those you are likely to meet later. I hope you finish the course better prepared to understand new technologies, make sensible decisions about them, and meet the IT challenges ahead.

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# Contents

# Introduction

Most of you already use information technology throughout the day. A phone serves as an alarm, camera, map, notebook, bank, library, entertainment centre, and means of communication. University work may involve search engines, learning platforms, shared documents, spreadsheets, online forms, biological databases, and AI assistants. Familiarity, however, is not the same as understanding. A person can use a system every day without knowing what it does with their information, why it sometimes fails, or what risks accompany its convenience.

I do not expect you to become computer technicians. I want you to know enough to make better decisions: choosing a device or internet service, improving a home network, recognising a scam, protecting an identity, behaving responsibly and civilly online, understanding online tracking, using digital tools in scientific work, and judging claims about AI and other emerging technologies.

The organising idea is information. The usual definition of information technology can sound unnecessarily dry, but the central idea is simple: there is information, and IT is concerned with handling that information electronically. For this course, we shall define information technology as the organised use of computers, networks, and software to create, process, store, communicate, and use electronic data. This working definition is adapted from the University of Cincinnati's overview of the field [2].

I use the term broadly here. IT includes the hardware on which data are handled, the software that gives instructions to that hardware, and the networks that allow devices to exchange data. It also includes data management, cybersecurity, cloud computing, and newer applications such as artificial intelligence and machine learning [2]. These areas overlap. An online laboratory record, for example, may involve a phone or computer, a browser, a wireless network, a remote database, account permissions, and automated analysis.

IT matters because it changes what people can do with information. It can make communication faster, automate repetitive work, organise large collections of records, support decisions, and protect information from unauthorised access. In biology, these functions appear in field observations, laboratory instruments, sequence databases, statistical analysis, medical records, and collaboration between researchers. None of these systems removes the need for human judgement.

A computer can process a large data set quickly without knowing whether the measurements were sound or whether the conclusion is justified.

Data are recorded representations such as numbers, text, images, audio, and measurements. They become informative when they are interpreted in context. For example, 37.8 is only a recorded number until we learn that it is a patient's temperature in degrees Celsius. Context allows the value to answer a question or support a decision.

Most digital activities can be understood through five actions. A system receives **input**, performs some form of **processing**, may retain data in **storage**, produces **output**, and often **communicates** with another device. These actions need not occur in one machine. A student may enter information on a phone while the processing and storage take place in a distant data centre.

## The Course at a Glance

The course follows a route rather than a catalogue. Chapter 1 gives us a working map of devices, connections, and software. Chapter 2 goes beneath the screen to the physical and industrial systems on which that map depends. Chapters 3–4 then show how infrastructure becomes communication and useful digital work. Chapters 5–8 follow information into platforms, human conduct, security threats, and safeguards. The final two chapters use the whole map to examine artificial intelligence and other emerging technologies.

Table 1: The ten-chapter course map.

| Chapter | Question | How the course develops |
|---|---|---|
| 1 | **How IT Works and Why It Matters** What parts make up an IT system, and how should we choose among devices, connections, and software? | Establishes our working map: information flow, computer components, specification sheets, internet services, and the purposes, costs, licences, privacy, and security of software. |
| 2 | **The Physical Foundations of Computing** What material and industrial systems make digital activity possible, and how do chokepoints create power? | Goes beneath the map: electrical states, transistors, chips, infrastructure, energy, workers, and supply chains. It then uses Chinese and US leverage to ask what technological interdependence means for the Philippines. |
| 3 | **The Internet, Web, and Home Networks** How does information travel between devices and services? | Takes up the connection distinctions in Chapter 1 and the physical route introduced in Chapter 2. We distinguish the internet from the Web and examine providers, addressing and routing, Ethernet, Wi-Fi, fibre, mobile and submarine links, cloud services, mesh networks, and VPNs. |

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| Chapter | Question | How the course develops |
|---|---|---|
| 4 | **Software, Cloud Services, and Digital Work**<br>How do software and remote services turn infrastructure into useful work? | Returns to the software choices introduced in Chapter 1, now in the setting of connected systems: operating systems, applications, files, cloud storage, collaboration, reproducibility, copyright, and the control exchanged for convenience. |
| 5 | **Platforms, Algorithms, and the Information Environment**<br>How do platforms decide what reaches us and what they learn about us? | Follows information into cookies, digital footprints, tracking, advertising, search, and recommendation systems. We then examine sources, synthetic media, and AI-generated clutter. |
| 6 | **Social Media, Attention, and Relationships**<br>How do digital platforms shape attention, conduct, and relationships? | Moves from what platforms select to what repeated use can do: persuasive design, notifications, social comparison, disinhibition, harassment, and civility online. |
| 7 | **Cybersecurity, Identity, and Cybercrime**<br>How are connected people and systems deceived, exploited, or attacked? | Draws together the vulnerabilities created across devices, networks, software, and platforms. We examine phishing, malicious links and downloads, scams, malware, identity theft, social engineering, and Philippine cybercrime law. |
| 8 | **Authentication, Biometrics, Privacy, and Regulation**<br>How do we protect identity and data, and what do data collectors owe us? | Answers the threats in Chapter 7 with passwords, multi-factor authentication, one-time passwords, passwordless methods, and biometrics, then turns to privacy, responsible data collection, and the Philippine Data Privacy Act. |
| 9 | **Artificial Intelligence: How It Works and Fails**<br>How do AI systems learn, produce outputs, and go wrong? | Uses the earlier chapters on hardware, data, networks, software, and platforms to explain machine learning and generative AI, including training, prediction, hallucination, cascading errors, bias, uncertainty, and sycophancy. |
| 10 | **Responsible AI and the Future of Computing**<br>How should we use powerful and emerging systems without surrendering human judgement? | Brings the course together through verification, privacy, copyright, academic integrity, human oversight, and applications in biology and medicine. Quantum computing and post-quantum security show how a new technology can alter several earlier layers at once. |

You are not expected to become a specialist in every field listed here. You should learn enough to ask better questions, recognise when a claim requires checking, and know when expert help is needed.

**How Classes Will Work.** I will not simply repeat these notes in class. Read the assigned pages before coming; I will announce them in advance. We shall use a **flipped classroom** approach: you first encounter the material through the assigned reading, and then we use class time for a bird’s-eye view, questions, discussion, examples, and practical applications. The reading is part of the course, not optional preparation for it.

# Chapter 1

# How IT Works and Why It Matters

**Learning Outcomes**

By the end of this chapter, you should be able to:

1. identify the basic components of a computer and explain their roles;
2. interpret selected laptop and mobile-phone specifications without assuming that larger numbers are always better;
3. distinguish common internet connection types and interpret download rate, upload rate, latency, jitter, and packet loss;
4. classify software by purpose, delivery, payment, and licence model; and
5. select hardware, an internet service, or software using criteria suited to the user's needs rather than marketing claims alone.

Do not try to memorise every entry in the tables. I want you to learn how to read them when you actually need to compare a device, connection, or application. We will examine a few examples closely in class; you can apply the same questions to the devices and services you encounter.

## 1.1 A Basic Map of a Computer

A computer is a collection of components with different jobs. We begin with a basic table because you need to recognise each component's role, not memorise model numbers or become a repair technician.

| Component | Main role | Plain-language description |
|---|---|---|
| Keyboard, mouse, camera, and microphone | Input | Allow a user or the environment to supply data to the computer. |
| CPU | General processing | Executes instructions and coordinates much of the computer's work. The CPU is a chip inside the computer, not the entire case. |
| GPU | Highly parallel processing | Produces graphics and performs many similar calculations at once; this is also useful in scientific computing and AI. |
| RAM | Working memory | Holds data and instructions that are being used. Its contents are normally lost when power is removed. |
| SSD (solid-state drive) or hard disk | Long-term storage | Retains the operating system, programs, documents, and other data when the computer is switched off. |
| Monitor and speakers | Output | Present visual or audio results to the user. |
| Ethernet and USB ports | Wired connection | Connect the computer to a network, storage device, peripheral, or other equipment. |
| Wi-Fi and Bluetooth | Wireless connection | Exchange data with networks or nearby devices without a cable. |

The components work together. Pressing a key creates input; software assigns meaning to it; the CPU processes the instruction using data held in RAM; the result may appear on the monitor, be saved to storage, or be transmitted over a network. A more powerful component is useful only when the rest of the system and the intended task can take advantage of it.

## 1.2 Reading Hardware Specifications

I chose two expensive flagship devices because their specification sheets contain many of the terms that buyers encounter. I am not suggesting that you buy either of them. The same method applies to a modest laptop or phone: begin with the work it must do, then ask which figures matter for that work and which are mainly selling points.

### 1.2.1 Reading a Laptop Specification Sheet

A laptop specification sheet compresses a great deal of information into a small space. Before interpreting the terms, let us organise one actual example. Table 1.1 summarises specifications reported by EveryMac and Apple for a 2026 16-inch MacBook Pro [3, 4].

Table 1.1: Selected laptop specifications reported by EveryMac and Apple.

| **Specification** | **Reported value** |
|---|---|
| Model and identifiers | Apple MacBook Pro, 16-inch, M5 Max (2026); model number A3429; model identifier Mac17,6 |
| Processor (CPU) | Apple M5 Max with 18 CPU cores; Geekbench 6 scores of 4,307 for single-core and 28,978 for multi-core performance |
| Graphics (GPU) and AI hardware | Integrated 40-core Apple GPU and 16-core Neural Engine |
| Memory (RAM) | 48 GB unified memory as standard; configurable to 64 GB or 128 GB when purchased; soldered and not later upgradeable |
| Storage | 2 TB built-in SSD as standard; 4 TB or 8 TB available when purchased; not later upgradeable |
| Built-in display | 16.2-inch Liquid Retina XDR display; 3456 by 2234 pixels; 254 pixels per inch; adaptive refresh rate up to 120 Hz |
| Camera and audio | 12-megapixel Centre Stage camera with 1080p video and a six-speaker sound system |
| Wireless connections | Wi-Fi 7 and Bluetooth 6 |
| Physical connections | Three Thunderbolt 5 ports using USB-C connectors, HDMI, an SDXC card slot, a 3.5 mm headphone socket, and MagSafe 3 charging; no built-in Ethernet port |
| External displays | Support for as many as four external displays, subject to limits on their resolution and refresh rate |
| Battery and charging | 100 Wh battery; claimed maximum of 16 hours of wireless web use or 22 hours of video streaming; 140 W power adaptor |
| Operating system | macOS 26.3.1 originally installed; EveryMac lists no native Windows support and points instead to virtualisation |
| Dimensions and mass | 0.66 by 14.01 by 9.77 inches; 4.7 lb (2.14 kg) |

The model name tells us which machine is being described, but identifiers such as A3429 and Mac17,6 are often more reliable when checking compatibility, replacement parts, or support. Two laptops sold under similar names may belong to different generations. The date and exact identifier therefore matter.

**Processor, graphics, and memory.** A CPU's core count and clock speed do not by themselves establish that it is faster than another CPU. The processor generation, design, cooling, and task also matter. A **benchmark** is a standardised performance test. Its results can help, but only when the same benchmark and version are used under comparable conditions. A single-core score reflects work that depends mainly on one core; a multi-core score reflects work that can be divided among several cores. GPU core counts are likewise poor for comparisons across different designs or manufacturers. They become meaningful only with suitable tests of the work one actually intends to perform. The Neural Engine is Apple's name for hardware designed to perform certain machine-learning calculations.

RAM is the computer's short-term working space. More RAM allows more programs and larger data sets to remain readily available, but unused capacity does not make every task faster. In this machine the CPU and GPU share unified memory. The important purchasing detail is that the memory is soldered: its capacity must be chosen at purchase because it cannot be expanded later.

**Storage and upgradeability.** The 2 TB figure describes how much the built-in SSD can store, not its speed or the amount of RAM. Photographs, videos, large data sets, and applications consume storage over time. This laptop's internal storage cannot be upgraded after purchase, although external drives and network or cloud storage remain possible. A buyer should distinguish among the standard configuration, an option available when ordering, and a component that can be upgraded later; these are not the same thing.

**Display and connections.** Screen size is measured diagonally. Resolution gives the number of pixels, pixel density describes how closely they are packed, and refresh rate gives the maximum number of times the display can update each second. Higher values can improve particular uses, but they may also increase cost or power consumption. The software being used must be able to benefit from them.

Port descriptions require careful reading. USB-C describes the connector's shape, whereas Thunderbolt 5 describes capabilities such as data transfer, display output, and charging. Devices with the same connector need not support the same functions or speeds. The absence of built-in Ethernet does not prevent a wired network connection, but it requires a compatible adaptor or dock. Likewise, obtaining the benefits of Wi-Fi 7 requires a compatible network, not merely a compatible laptop.

**Battery, portability, and software.** The words "up to" mark a best-case claim measured under stated test conditions. Screen brightness, wireless activity, software, temperature, and workload can make actual battery life shorter. Mass and dimensions matter when a laptop is carried daily, while the operating system matters because required applications and laboratory equipment may support only particular platforms. A powerful computer that cannot run the required software is the wrong computer for the task.

**From specifications to a sensible choice.** Begin with the work the computer must perform, the software and connections it requires, the need for portability, and the available budget. Then compare machines using consistent definitions and suitable tests. Specifications cannot fully describe keyboard comfort, fan noise, repairability, reliability, warranty service, or real-world battery life, so independent reviews and first-hand inspection remain useful. The best choice is not necessarily the machine with the largest numbers; it is the one that meets the user's needs at an acceptable total cost.

The source itself also illustrates why specifications should be checked. It reports two different memory-bandwidth figures, 614 GB/s and 460 GB/s. Apple's specification resolves the discrepancy: the 40-core GPU configuration in this example has 614 GB/s of memory bandwidth, while 460 GB/s belongs to the 32-core GPU configuration [4]. The two figures therefore describe different configurations; only the first applies to the machine in the table. A polished table can organise claims, but it does not make them correct.

### 1.2.2 Reading a Mobile-Phone Specification Sheet

Mobile-phone specification sheets use many of the same terms as laptop sheets, but add cellular networks, SIMs, cameras, positioning, sensors, and resistance to water and dust. Table 1.2 organises selected specifications reported by GSMArena and Apple for the Apple iPhone 17 Pro Max [5, 6].

Table 1.2: Selected mobile-phone specifications reported by GSMArena and Apple.

| **Specification** | **Reported value** |
|---|---|
| Model and release | Apple iPhone 17 Pro Max; announced 9 September 2025 and released 19 September 2025 |
| Regional versions | A3526 (international), A3257 (United States), A3525 (Middle East, Canada, and Mexico), and A3527 (China) |
| Mobile networks | 4G LTE and 5G, with support for older network standards |
| SIM arrangement | Varies by market: combinations include Nano-SIM and eSIM, eSIM only, or two Nano-SIMs |
| Processor and graphics | Apple A19 Pro chipset; six-core CPU and six-core Apple GPU |
| Memory and storage | 12 GB RAM; 256 GB, 512 GB, 1 TB, or 2 TB of built-in storage; no memory-card slot |
| Display | 6.9-inch Super Retina XDR OLED; 1320 by 2868 pixels; about 460 pixels per inch; refresh rate up to 120 Hz; advertised peak brightness of 3,000 nits; GSMArena measured 1,000 nits under its test conditions |
| Rear cameras | Three 48-megapixel cameras: wide, telephoto with four-times optical zoom, and ultrawide; LiDAR depth scanner |
| Front camera | 18-megapixel camera with an additional depth and biometrics sensor |
| Video | Rear-camera recording up to 4K at 120 frames per second, with available rates and formats depending on the selected mode |
| Wireless and positioning | Wi-Fi 7, Bluetooth 6.0, NFC, GPS, and other satellite-positioning systems |
| Physical connection | USB Type-C 3.2 Gen 2 with DisplayPort; no 3.5 mm headphone socket |

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| **Specification** | **Reported value** |
|---|---|
| Sensors and authentication | Face ID, accelerometer, gyroscope, proximity sensor, compass, barometer, and second-generation Ultra Wideband support |
| Battery | 4,823 mAh for the Nano-SIM model or 5,088 mAh for the eSIM-only model; GSMArena active-use test result of 17 hours and 58 minutes |
| Charging | Wired USB Power Delivery; claimed 50 per cent charge in 20 minutes; up to 25 W wireless MagSafe or Qi2 charging; 4.5 W reverse wired charging |
| Construction and resistance | Aluminium unibody; Ceramic Shield glass; IP68 dust and water resistance, with testing to a depth of 6 m for up to 30 minutes |
| Performance tests | AnTuTu scores of 2,600,583 in version 10 and 2,331,417 in version 11; Geekbench 6 score of 10,118; 3DMark Wild Life Extreme score of 6,010 |

**Start with the exact version.** The product name is not enough. The model number identifies the regional version, which can affect the available SIM arrangement, battery capacity, network compatibility, and warranty service. A phone imported from another market may therefore differ from the version sold locally even when both carry the same product name. Before buying, check the exact model against the mobile operator's supported frequency bands and the manufacturer's local support terms. A label such as "5G" does not guarantee 5G service everywhere: the phone, network bands, operator, subscription, and local coverage must all be compatible. A Nano-SIM is a small physical card, whereas an eSIM is a digital SIM profile stored by the phone.

**Processor, RAM, and storage.** As with laptops, CPU and GPU core counts are meaningful only within the context of a particular design. Tests of real applications are more informative than a core count alone. The table also shows why benchmark versions must not be mixed: the same phone receives different AnTuTu scores under versions 10 and 11. This does not mean that its hardware changed between the two tests.

RAM supports programs while they are running; storage retains applications, photographs, videos, and other files. The storage capacity must be chosen at purchase because this phone has no memory-card slot. Cloud storage can provide additional space and synchronisation, but it may require a subscription and an internet connection and should not be confused with increasing the phone's built-in storage.

**Display and cameras.** Display size is measured diagonally, while resolution, pixel density, refresh rate, brightness, colour reproduction, and power use describe different properties. The sheet lists both advertised brightness levels and a separately measured result. Such figures should be compared only when the testing conditions and definitions match.

A camera's megapixel count describes the number of recorded pixels, not the overall quality of every photograph. Sensor size, lens, aperture, optical image stabilisation, focusing, image processing, lighting, and the photographer all matter. Multiple rear cameras provide different fields of view or optical capabilities; three 48-megapixel cameras should not be read as a single 144-megapixel camera. Optical zoom uses the camera's optics, whereas digital zoom enlarges or crops the recorded image and may lose detail.

**Battery, charging, and durability.** The two battery capacities in the table refer to different regional versions, not contradictory measurements of one battery. Capacity in milliampere-hours is useful, but it cannot by itself predict running time across phones with different displays, processors, software, and network conditions. A controlled active-use test is generally more informative, although no single test can reproduce every person's use. Fast-charging times are also conditional on a suitable charger, cable, temperature, battery state, and charging protocol.

An IP68 rating indicates performance under specified laboratory conditions; it does not mean that the phone is impossible to damage with liquid. Wear, impact, repairs, depth, time, temperature, pressure, and the type of liquid can affect resistance. Durability, repairability, spare-parts availability, and warranty conditions deserve attention alongside processor and camera figures.

**Software, privacy, and cost.** An operating-system version on a specification sheet is a snapshot, not a promise of support for a particular number of years. Check the manufacturer's current update policy and whether essential applications will run on the device. Face ID is convenient, but biometric authentication also raises questions about how biometric data are stored and what fallback method is used; these questions return in our study of privacy and cybersecurity.

Price is unusually unstable: it changes with storage, market, taxes, seller, promotions, and time. A sensible comparison fixes the required storage and features, checks the exact regional model, and considers the total cost of the phone, accessories, repairs, cloud services, and expected period of use. The best phone is the one that meets those requirements reliably, not simply the one with the longest specification sheet.

For your work in biology, a phone may also be a field notebook, camera, location recorder, timer, reference tool, or means of entering observations. Suitability for scientific work depends not only on the hardware but also on measurement accuracy, consistent methods, file formats, data export, privacy, and whether the work can be checked or repeated.

## 1.3 Internet Connection Types

A useful device still needs a suitable connection. The internet reaches homes and other premises through several technologies. The connection type affects the speeds that are possible, the consistency of those speeds, latency, reliability, installation, and cost. It also determines which services can feasibly be offered at a particular address. The table below draws on the overview by David Anders and Sean Jackson but omits its provider-specific and United States market information [7].

| **Connection** | **How data reach the premises** | **Main characteristics** |
|---|---|---|
| Fibre-optic | Pulses of light travel through thin strands of glass or plastic. | Can provide very high and often similar download and upload speeds. Building the required network is costly, so service is not available everywhere. |
| Cable | Electrical signals travel through coaxial cable of the kind also used for cable television. | Can provide high download speeds, but upload speeds are often lower. Capacity may be shared locally, so performance can fall during busy periods. |
| DSL | Electrical signals travel through copper telephone lines. | Makes use of existing telephone infrastructure and, unlike dial-up, allows telephone voice service to be used at the same time. Performance depends strongly on line quality and distance from network equipment and is generally more limited than fibre or cable. |
| Fixed wireless | Radio signals travel between a base station and a receiver at a fixed location. | Can serve places where laying a cable is impractical. Distance, obstructions, alignment, interference, and network demand can affect performance; some systems require a mounted outdoor receiver. |
| Cellular home internet | A router receives a 4G LTE or 5G mobile-network signal and shares the connection with devices in the premises. | Is often quick to install, but performance varies with coverage, indoor signal strength, network load, and the router's position. |
| Satellite | A dish or terminal exchanges radio signals with satellites in orbit. | Can reach remote places without nearby terrestrial cables or towers. It requires a suitable view of the sky and may involve costly equipment, data limits, and greater latency. Low-Earth-orbit systems reduce the signal's travel distance compared with geostationary systems. |

In the broad technical sense, cellular home internet is also a form of fixed wireless access. The table separates it because consumer plans based on mobile 4G or 5G networks are commonly discussed apart from systems using a dedicated fixed receiver.

Use these descriptions to identify broad families, not to predict a particular level of service. Two connections using the same technology may perform differently because of the local infrastructure, distance, equipment, congestion, maintenance, and plan conditions. Parts of a network may also use different media. For example, fibre may carry data across most of a provider's network while another technology completes the final connection to a building. The exact connection installed at the premises matters more than a vague marketing label.

**The internet connection is not the Wi-Fi.** The service provider's connection brings internet access to a modem, optical network terminal, fixed receiver, satellite terminal, or cellular router. An optical network terminal is the box at the end of a fibre connection. Wi-Fi is the short-range wireless network that a router normally uses to share the connection within the premises. A weak Wi-Fi signal in one bedroom does not necessarily mean that the internet service entering the home is slow. Conversely, an excellent Wi-Fi signal cannot make a slow external connection faster. Testing a computer over a wired Ethernet connection, where practicable, helps distinguish an internal Wi-Fi problem from a problem with the internet service itself.

**What the performance figures mean.** Download rate describes how quickly data travel from the internet to the user, as when loading a page or streaming a video. Upload rate describes travel in the other direction, as when sending a file, backing up photographs, joining a video call, or submitting a large data set. A connection is **symmetrical** when its download and upload rates are approximately equal; otherwise it is **asymmetrical**.

Connection rates are normally advertised in megabits per second (Mbps) or gigabits per second (Gbps), while file sizes are commonly stated in megabytes (MB) or gigabytes (GB). Since one byte contains eight bits, a rate of 100 Mbps corresponds to at most

$$\frac{100}{8} = 12.5 \text{ MB/s}$$

before overhead and other real-world limitations are considered. Here, **overhead** means the additional data and work required to manage the transmission itself. Thus, Mbps and MB/s are not interchangeable. The time required to transfer a file can be estimated by dividing its size in bits by the transfer rate in bits per second, provided that the units are first made consistent.

Rate is not the whole story. **Latency** is the time taken for data to travel between points in a network. Speed tests commonly report the round-trip time in milliseconds; a smaller value is generally better for conversation, remote control, and online games. **Jitter** is variation in that delay, while **packet loss** occurs when some transmitted data fail to arrive and may have to be recovered or sent again. A connection with a high advertised rate can still feel poor during a video call if latency, jitter, or packet loss is excessive.

**Choosing a connection and plan.** Begin with what is actually available at the exact address. Consider how many people and devices will use the connection at once, and distinguish download-heavy activities from tasks that need substantial upload capacity or low latency. Read whether an advertised rate is a maximum or an expected range and whether the service has a data allowance, a fair-use policy, or reduced speeds after a threshold. Account for installation charges, required equipment, contract length, post-promotional price, repair response, and the cost of ending the service.

When you compare internet plans, check these six factors. No single factor decides every case: a household that mainly streams recorded video may value different things from one that regularly joins live classes, makes calls, plays online games, or uploads large files.

| Factor | What to compare |
|---|---|
| Total cost and budget | The installation charge, equipment charge, regular price after any promotion, data-related charges, contract terms, and the cost of cancelling must fit the household's realistic budget. |
| Actual needs and shared use | List the activities that matter, the number of simultaneous users and devices, and any need for reliable access at particular times. Do not pay for a headline feature that the household will not use. |
| Transfer capacity (download and upload) | Compare both directions of transfer, not download alone. Upload capacity matters for video calls, cloud backup, submitting work, sharing media, and sending data. |
| Responsiveness (latency) | Lower delay is especially important when people must interact in real time: calls, live classes, remote access, and online games. |
| Consistency (jitter) | Small variation in delay helps live audio and video remain smooth. A connection can have an acceptable average latency but still perform poorly if the delay changes sharply from moment to moment. |
| Delivery reliability (packet loss) | Lost packets can cause interruptions, garbled audio, frozen video, retries, and failed transfers. Ask about outages and test for loss at the times the service will actually be used. |

When comparing plans in the Philippines, give the provider the exact service address and ask which connection will actually be installed. Availability can differ within the same municipality or city, and the advertised plan may not be offered at every address.

Once connected, test at different times and record download rate, upload rate, latency, and whether the test used Ethernet or Wi-Fi. A single result is only a snapshot. Several measurements under stated conditions provide better evidence of the service the household actually receives.

## 1.4 Software Selection

Hardware determines what a device is physically capable of doing, but software turns that capacity towards a particular task. Choosing software therefore begins with the task, not with whichever application happens to be popular. You must also consider compatibility, cost, privacy, security, support, and whether you will still be able to open or export your work later.

### 1.4.1 Types of Software by Use

Software can be grouped according to its principal purpose. These categories are convenient rather than absolute: one application may perform several kinds of work and therefore belong to more than one category.

Table 1.3: Common types of software classified by use.

| **Type** | **Principal use** | **Examples of tasks** |
|---|---|---|
| System software | Operates the device and manages its hardware resources. | Running the operating system, controlling a printer, and managing files and memory. |
| Productivity software | Helps users create, organise, calculate, and present work. | Writing documents, using spreadsheets, preparing presentations, and taking notes. |
| Communication and collaboration software | Allows people to exchange messages or work together. | Email, instant messaging, video meetings, shared calendars, and collaborative editing. |
| Scientific and data software | Collects, manages, analyses, models, or visualises data. | Statistical analysis, database work, programming, bioinformatics, mapping, and laboratory data collection. |
| Creative software | Produces or edits visual, audio, and multimedia material. | Drawing, photography, page layout, animation, audio recording, and video editing. |
| Utility software | Maintains, organises, diagnoses, or extends a computer system. | Backing up data, compressing files, managing storage, and monitoring system performance. |
| Security software | Helps protect devices, accounts, networks, or data. | Malware detection, password management, encryption, firewalls, and secure authentication. |
| Educational software | Supports teaching, learning, practice, or assessment. | Learning platforms, simulations, tutorials, reference tools, and quizzes. |
| Entertainment software | Provides recreation or access to media. | Games, media players, streaming, and digital reading. |

The intended use determines which features deserve attention. A spreadsheet may be entirely adequate for a small table but awkward or unsafe for a large, shared research data set. A sophisticated statistical package may be powerful but unnecessarily difficult for a simple calculation. Software should be proportionate to the task and the consequences of error.

### 1.4.2 How Software Is Supplied and Paid For

The labels used for software do not all describe the same thing. Some describe how software is delivered, some describe how payment works, and others describe what its licence permits. A single product may therefore carry several labels. For example, an online service can be SaaS, subscription-funded, and partly open source at the same time. **Proprietary software** is software whose owner does not normally supply the source code or grant users permission to inspect, modify, and redistribute it.

Table 1.4: Common ways in which software is supplied, licensed, or funded.

| **Model** | **What it means** | **Important qualification** |
|---|---|---|
| Perpetual or one-time-purchase licence | The user pays once for permission to use a particular product or version indefinitely. | The payment may not include future major versions, continuing support, cloud storage, or compatibility with future devices. The user normally buys a licence, not ownership of the code. |
| Subscription licence | Continued use or access requires payment at regular intervals. | Updates and services may be included, but access to the software or some features may end when the subscription ends. |
| Software as a Service (SaaS) | The provider operates the software as an online service, commonly accessed through a browser or application. | SaaS describes delivery, not necessarily price. It may be subscription-funded, free to the user, advertising-funded, or paid for by an institution. Internet access and the provider's continued operation may be essential. |
| Freeware | Proprietary software is supplied without a monetary charge. | A zero price does not normally grant permission to inspect, modify, or redistribute the source code. Other costs may include advertising, data collection, or paid companion services. |
| Free and open-source software (FOSS) | The source code is available under a licence that grants rights to use, inspect, modify, and redistribute it subject to stated conditions. | Open source does not necessarily mean that every service, copy, or form of support is free of charge. Its licence obligations still apply. |
| Freemium | A basic version is free, while additional features, capacity, or convenience require payment. | The free version may impose storage, export, collaboration, usage, or advertising limits. |
| Institutional or educational access | A university, school, or employer pays for or negotiates access on behalf of eligible users. | Access may end when the agreement expires or the user leaves the institution. Personal files should be exported before eligibility ends. |
| Trial or demonstration version | Use is allowed temporarily or with restricted features so that the product can be evaluated. | The software may stop working, limit saving or export, or require payment after the trial. |

Keep two questions separate: how software is paid for and where it runs. Installed software can require a subscription, while a web-based service can be provided without charge. Likewise, "freeware" is not a synonym for "open source": the first concerns price, whereas the second concerns licence permissions.

### 1.4.3 Choosing Software

Begin by stating what the software must accomplish and which file formats, devices, operating systems, and collaborators it must support. Test whether it can import existing work and export data in a form that other applications can read. A convenient tool can become a trap if all of the user's work is held in a proprietary format that cannot be moved elsewhere.

Look beyond the price shown on the first day. Add renewals, storage, additional users, paid extensions, training, accessories, and the cost of moving data to another system. A one-time purchase is not automatically cheaper than a subscription, nor is free software automatically the better choice. The answer depends on the task and the period over which the software will be needed.

Privacy and security matter whenever software handles personal, academic, financial, health, or research data. Before using it, check what data it collects, where those data are stored, who can access them, whether suitable backups and encryption are available, and how the provider responds to security problems. Software should come from a dependable source and receive appropriate updates. Open source permits inspection of the code, but that fact alone does not guarantee that a particular program is secure or well maintained.

Also consider usability, accessibility, documentation, technical support, offline operation, and the ability of collaborators to use the same files. Using an unlicensed copy of commercial software is not a sensible way to save money. An altered installer may contain malicious software, and unauthorised use also breaches the licence. A simpler legal tool that does the required job is usually the better choice.

**Freeware and paid software.** Freeware removes the immediate purchase cost and can make useful tools available to people who could not otherwise afford them. It may also be convenient for a small or occasional task for which buying a large commercial package would be excessive. Many freeware programs come from reputable developers and are maintained responsibly. The absence of a price is not itself a warning that software is malicious.

But do not assume that every free download is safe. A file presented as freeware may have been altered, repackaged, or imitated by someone other than the real developer. Some freeware is supported by advertising, optional bundled programs, extensive data collection, or repeated pressure to buy another product. The program itself may not contain malware, yet an advertisement or false download button may lead the user to an unsafe site. The United States Federal Trade Commission therefore advises users to avoid software-download advertisements and unfamiliar download sites and to obtain software from a source they know and trust [8].

Paid software often has funding for continued development, documentation, technical support, testing, and regular updates. An established developer also has a reputation and customer relationships to protect. These considerations can provide useful evidence of trustworthiness, but payment is not a guarantee of quality, security, or privacy. A paid product can contain a vulnerability, stop receiving updates, impose restrictive licence conditions, collect more data than the task requires, or show advertising. Applications and websites may use identifiers and other information for tracking and personalised advertising regardless of whether the user paid for access [9].

| Software | Possible advantages | Questions to ask |
|---|---|---|
| Freeware | No purchase cost; easy to try; may be sufficient for a small or occasional task. | Is this the developer's official copy? How is development funded? Does it display advertisements, install extras, collect data, receive updates, and provide a way to export files? |
| Paid software | May provide sustained development, documentation, support, updates, and specialised features. | Is the developer dependable? What is the total cost? What happens when payment or support ends? What data are collected, and can work be moved to another product? |

Treat price as one piece of evidence, not as a security test. Before installing any program, confirm the developer and exact website or official store, avoid advertisements masquerading as download buttons, check the requested permissions, and keep both the program and device updated. For important work, also confirm that files can be backed up and exported. These checks apply to free, paid, subscription, and open-source software alike.

**Practical Work**

List the digital systems you have used since waking up. Choose one activity and trace its input, processing, storage, output, and communication. Identify the hardware, software, data, and networks involved. For one piece of software, identify its principal use and how it is supplied or paid for. End by stating one thing about the system that you would like this course to help you understand.

## 1.5 Questions for Discussion and Exercises

We will use some of these questions in class. Use the others to review the chapter and test whether you can apply its ideas.

1. A student enters observations into an online form during a biology laboratory activity. Identify a possible input, processing step, form of storage, output, and act of communication. Name the main hardware and software involved.
2. Explain the difference between RAM and long-term storage. Why would a computer need both?

3. A laptop is advertised as having more CPU and GPU cores than another model. Explain why those figures alone do not prove that it will be faster for a student's work. Identify one non-upgradeable component and explain how the words "up to" should affect the interpretation of its battery claim.
4. Table 1.1 gives two memory-bandwidth figures. Explain how the manufacturer's specification resolves the conflict and what this example teaches about apparently authoritative tables.
5. Why should a buyer check the exact regional model of a phone rather than relying on its product name alone? In your answer, use the SIM or battery differences in Table 1.2, and explain why three 48-megapixel cameras are not one 144-megapixel camera.
6. Explain the difference between the connection that brings internet service into a home and the Wi-Fi network inside it. How could you investigate which one is causing a slow connection?
7. Ignoring overhead, estimate how long a 100 Mbps connection would take to download an 800 MB file. Show the conversion between bytes and bits before calculating the time.
8. A household regularly makes video calls, uploads large files, and has several simultaneous users. Apart from advertised download rate, what features and plan conditions should it examine before subscribing?
9. Explain why SaaS, subscription software, freeware, and open-source software are not four mutually exclusive categories. Then assess the claim that freeware is probably malware whereas paid software is safe.
10. A biology group needs software for recording observations, analysing data, and sharing results. State the questions the group should ask before choosing a product. Include compatibility, cost, privacy, data export, and continued access in your answer.

# Chapter 2

# The Physical Foundations of Computing

**Learning Outcomes**

By the end of this chapter, you should be able to:

1. trace a familiar digital activity through the physical devices, connections, facilities, energy, and workers that make it possible;
2. explain, without unnecessary engineering detail, how electrical states, transistors, circuits, and software belong to different levels of a computing system;
3. describe the main stages through which chips and electronic devices are produced and the physical requirements that keep digital systems operating;
4. explain how concentration, chokepoints, substitution, and interdependence create both technological power and technological vulnerability;
5. distinguish participation in a global value chain from control of that chain; and
6. evaluate a technological policy or partnership according to stated Philippine interests rather than automatic loyalty to a foreign power.

*How do physical and financial chokepoints become political leverage?*

Digital activity can feel weightless. A photograph disappears into "the cloud", a video call joins people in different provinces, and a search result arrives before anyone has time to wonder where it came from. Yet every one of these actions depends on matter moving, storing, or transforming energy. There are chips, batteries, radios, routers, cables, data centres, cooling systems, ports, mines, factories, and people behind the screen.

Those physical foundations have political consequences. In November 2025, the *South China Morning Post* examined China's use of controls on rare-earth exports amid a wider dispute over access to advanced chips and chipmaking equipment [10]. A rather small amount of a specialised material can hold up the production of cars, electronics, motors, and other much more expensive goods. The dispute is not simply a contest between a powerful China and a vulnerable United States. China has material and industrial chokepoints; the United States has financial and technological ones. Both still need capabilities supplied by other countries.

So let us begin with the exact link each side can influence. How can it apply pressure? What substitutes are available, and what would using that power cost? We need some technical knowledge to answer these questions, but not a degree in electrical engineering. We need to see the system clearly enough to judge claims about it.

**Before Class**

1. **Read.** *How China's Rare Earth Leverage Works—Limits, Risks and Global Responses*, by Kandy Wong, *South China Morning Post*, 12 November 2025; updated 13 November 2025 [10].

2. **Watch.** *From Sand to Tech: Global journey of the Semiconductor*, CGTN Europe [11].

3. **Map.** On one page, sketch the journey of a phone, laptop, router, or data-centre server from materials to use. Label the stages and places named in the sources, circle one link that appears difficult to replace, and note one simplification that the chapter helps you correct. Bring the sketch to class.

Treat both sources as starting points rather than final authorities.

## 2.1 A Digital Action Has a Physical Route

Suppose a biology student photographs a leaf specimen and uploads the image to a shared folder. The camera sensor responds to light. Electronics convert its output into data. The processor follows software instructions to construct an image, RAM holds material being used, and storage retains the file. The phone's battery supplies energy while its radio sends a signal to a Wi-Fi router or mobile base station.

The photograph then passes through equipment operated by several organisations. It may travel through fibre-optic cables, switching and routing equipment, and possibly submarine links before reaching a provider's data centre. There, servers check the account, storage systems retain the file, and other network equipment makes it available to authorised users. Power equipment keeps the facility running and cooling equipment carries away heat. When a classmate opens the photograph, another physical route delivers a copy to another physical device.

In Chapter 3, we will examine how networks organise and direct data. For now, keep three observations in mind. First, the user's phone is only one part of the system. Second, "wireless" normally describes only part of the journey: a radio link often leads to extensive wired infrastructure. Third, the cloud is not an immaterial place. It is a way of using computers belonging to someone else, in buildings somewhere else.

| Part of the route | What must work | One possible interruption |
|---|---|---|
| Student's device | Sensor or input, processor, memory, storage, software, battery, and network interface | Full storage, a damaged battery, an application error, or a failed radio |
| Local connection | Router or mobile base station, power, and a usable signal | Power failure, poor coverage, interference, or an overloaded network |
| Provider networks | Cables, network equipment, power, maintenance, and links to other networks | A damaged cable, failed equipment, or an upstream outage |
| Remote service | Servers, storage, account systems, cooling, electricity, and staff | A service fault, failed storage, loss of power, or a security incident |
| Other user's device | A working connection, compatible software, display, and permission to access the file | No access permission, an unsupported format, or another local outage |

An online activity can therefore fail even when the student's phone is in perfect condition. It can also continue when one component fails if the system has a second route, backup power, replicated storage, or another form of **redundancy**. Redundancy can look wasteful during ordinary operation, because capacity is kept in reserve. During a failure, it becomes the reason a service survives. This tension between low cost and resilience will reappear in the discussion of supply chains.

### 2.1.1 Keeping the Infrastructure Running

A digital system has two broad kinds of physical requirement. It has an **embodied requirement**: the materials, energy, factories, transport, and labour used to make its equipment. It also has an **operational requirement**: the electricity, cooling, connectivity, maintenance, and replacement parts needed while that equipment is in use.

Data centres make the distinction easy to see. Their servers, storage devices, network equipment, buildings, generators, batteries, and cooling systems must first be manufactured. Once installed, they need reliable electricity and temperature control. Cooling may use air, water, or a combination, depending on the facility and local conditions. Efficiency per task can improve while total demand still grows. The International Energy Agency reports rapid reductions in the energy used for individual AI tasks alongside a 17 per cent increase in global data-centre electricity demand in 2025 [12]. Equipment efficiency does not by itself make total resource use disappear.

Workers are part of this physical system. Engineers design equipment; miners and refinery workers produce materials; factory workers manufacture and test components; seafarers, drivers, and port workers move them; technicians install and repair equipment; and power, telecommunications, and data-centre workers keep services operating. A diagram that contains only boxes and arrows can hide all of them.

## 2.2 From Electrical States to Useful Work

At a basic level, digital electronics distinguishes physical states that can be treated as 0 and 1. The states may be represented by controlled electrical conditions. There are no tiny printed zeroes and ones travelling through a chip. A **bit** is an interpretation of a physical state.

A **transistor** is an electronic device that can control current. The first successful point-contact transistor was demonstrated at Bell Telephone Laboratories in December 1947 by John Bardeen and Walter Brattain [13].


Figure 2.1: A 1997 commemorative replica of the first point-contact transistor, demonstrated at Bell Telephone Laboratories in December 1947. The photograph is a public-domain work of the Executive Office of the President of the United States, obtained through Wikimedia Commons.

Many transistors can be connected into circuits that perform small logical and memory operations. Many such circuits can be organised into a processor that follows instructions, or into memory that holds information for rapid use. Software supplies organised instructions. An application such as a camera or spreadsheet is therefore several levels removed from the electrical conditions inside the machine, but it cannot operate without them.

| Level | Question answered at that level |
|---|---|
| Electrical state | Which controlled physical condition is present? |
| Transistor and circuit | What small operation can be performed or remembered? |
| Processor and memory | Which instructions and data are being handled? |
| Operating system | How are the device's resources made available and managed? |
| Application | What recognisable task is being performed for the user? |
| Human and institution | Who chose the task, rules, data, and purpose? |

These descriptions are not competing explanations. Saying that a student submitted an assignment, that an application transmitted a file, and that transistors changed electrical states can all describe the same event at different levels. Confusion results when a claim appropriate to one level is silently transferred to another. A computer can compare encoded values, for example, without understanding why a teacher imposed a deadline.

Modern chips integrate enormous numbers of transistors. Miniaturisation allows much work to be performed in a small space, but switching and moving information require energy, and some energy becomes heat. Designers must balance speed, power use, battery life, cost, and cooling. A phone becoming warm during a demanding task is therefore not mysterious. Unusual heat, swelling, a burning smell, a damaged cable, or repeated shutdowns, however, should not be ignored.

The main material in most modern chips is a **semiconductor**, whose electrical behaviour can be carefully controlled. Silicon is widely used, but a chip is not merely a polished piece of silicon. It is a manufactured arrangement of extremely small structures, layers, and connections. That observation takes us from how a chip works to the more politically important question of how a chip comes to exist.

## 2.3 No Country Makes a Phone by Itself

A product may carry the words "Made in" followed by one country. That label does not normally tell the full history of its materials, design, machinery, components, software, assembly, or transport. A phone is better understood as the temporary meeting point of several value chains.

### 2.3.1 From Design to Chip

Chip production can be understood without memorising every chemical or machine:

1. A chip is **designed**. Engineers decide what it should do and create the detailed description needed to manufacture it.
2. Semiconductor material is purified and formed into thin **wafers**.

3. A fabrication plant repeatedly forms and connects microscopic structures on those wafers. This requires specialised equipment, chemicals, gases, exceptionally clean conditions, water, electricity, and skilled work.

4. The wafer is divided into individual pieces called **dies**. The dies are tested; not every die necessarily works as intended.

5. Working dies are **packaged** so that they can be protected, supplied with power, cooled, and connected to other components. They are tested again before being incorporated into a larger product.

The United States Department of Commerce describes design, fabrication, assembly, testing and packaging, materials, and manufacturing equipment as distinct but connected parts of the semiconductor supply chain [14]. A firm may design chips without owning a fabrication plant. A fabrication firm may manufacture designs created elsewhere. Other firms may specialise in equipment, materials, packaging, or testing. This specialisation can improve efficiency and make extraordinary technical capability possible. It also creates dependencies.

Figure 2.2 provides a useful bird's-eye view. Read it from top to bottom: the geographical distribution changes as the chain moves from design and design tools to equipment, materials, fabrication, and the final assembly, testing, and packaging stage. No column dominates every row. The graphic is a snapshot rather than a timeless league table. Its regional categories simplify multinational firms and cross-border production, and percentages from different sources should be compared only when their dates, products, and measures are consistent.

Silicon is abundant in the Earth's crust, but an ordinary pile of sand is not a tray of computer processors waiting to happen. The difficult parts include purification, precise design, specialised equipment, repeated processing, quality control, packaging, knowledge, and the coordination of suppliers. A country can possess a raw material without possessing all the capabilities needed to turn it into a competitive chip.

### 2.3.2 Beyond the Chip

Even the most advanced processor is not a phone. A complete device also needs working memory and storage, circuit boards and connections, a display, cameras, radios, speakers, microphones, sensors, a battery, charging electronics, a case, connectors, and software. These require different materials and manufacturing processes.

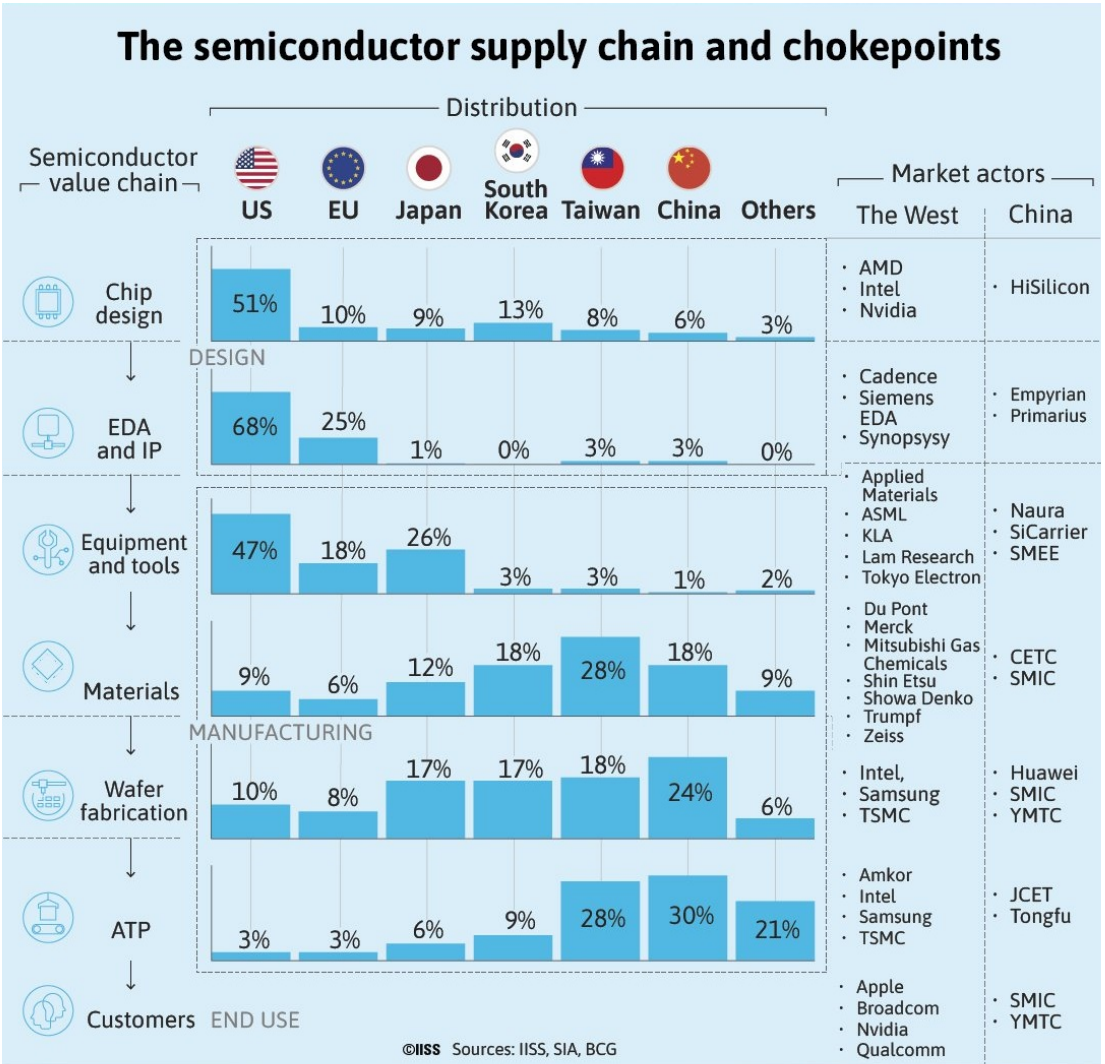


Figure 2.2: The semiconductor value chain and selected geographical chokepoints, as presented by the International Institute for Strategic Studies at the 2025 Global Security and Innovation Summit [15]. **EDA** means *electronic design automation*: specialised software used to design, simulate, verify, and lay out electronic circuits. **ATP** means *assembly, test, and packaging*: the back-end stage in which fabricated dies are made into usable components, checked, and packaged for incorporation into products. In “EDA and IP”, **IP** means *intellectual property*, such as reusable chip designs, not Internet Protocol. Graphic © IISS; the graphic cites IISS, SIA, and BCG as its sources and is excluded from the MIT licence for these notes.

| Part | What it contributes | Earlier links that may be required |
|---|---|---|
| Chips | Processing, memory, storage, sensing, communication, and power control | Design, specialist materials and equipment, fabrication, packaging, and testing |
| Circuit board and connectors | Physical and electrical connections among parts | Metals, glass fibre or other substrate materials, chemicals, and precision manufacturing |
| Display and cameras | Visual output and image capture | Glass, electronic materials, sensors, lenses, coatings, and assembly |
| Battery | Portable energy | Mineral extraction, chemical refining, cell manufacture, control electronics, and safe transport |
| Speakers, motors, and sensors | Sound, movement, vibration, and measurement | Magnets, coils, metals, ceramics, and specialised components |
| Case and protective parts | Structure, durability, and heat management | Metals, glass, plastics, forming, machining, and coatings |

Rare-earth elements enter this story through particular materials and components, including some high-performance permanent magnets and specialised electronic, optical, and industrial applications. They are not the principal ingredient of every chip, and the seventeen elements grouped under the term "rare earths" are not interchangeable. The relevant question is always which element, in which form, at which stage, for which use.

### 2.3.3 Chain, Network, and Life Cycle

The word **supply chain** is useful because it emphasises connection: if an indispensable link fails, the final product may not appear. The real arrangement is more like a network. One component has several suppliers; one refinery serves several industries; a factory depends on electricity, water, finance, transport, software, standards, and workers; used products may supply recycled material.

The broader **value chain** asks where useful capabilities and economic value are added. Its stages can be summarised as follows:

| **Stage** | **Examples** | **Question to ask** |
|---|---|---|
| Extraction | Mining and recovery of raw materials | Who has usable deposits, and what are the environmental and community costs? |
| Processing | Separation, refining, and production of usable materials | Where does the knowledge and industrial capacity exist? |
| Components | Chips, batteries, displays, circuit boards, magnets, and sensors | Which parts are difficult to substitute or expand quickly? |
| Assembly and testing | Combining parts, checking quality, and preparing products for sale | How much capability and value are retained locally? |
| Distribution | Ports, shipping, warehouses, retailers, and service providers | Which routes and markets are necessary? |
| Operation and support | Electricity, networks, data centres, maintenance, updates, and repair | What keeps the product useful and secure? |
| End of life | Reuse, parts recovery, recycling, and safe disposal | Can value be recovered and harm reduced? |

Participation at one stage matters, but it is not control of the whole. A country may assemble many devices while importing important components. Another may mine a mineral but send it elsewhere for refining. Another may design advanced chips while relying on foreign fabrication, packaging, customers, and materials. “We are part of the chain” and “we can command the chain” are very different claims.

Nor does price reveal strategic importance. A component costing only a few pesos can halt the sale of a product worth thousands if the component is indispensable and no qualified replacement is available. Conversely, an expensive component may provide little leverage when buyers can obtain an equivalent product from several suppliers. Power arises from the structure of dependence, not from national pride or the size of an object.

## 2.4 When One Link Becomes Leverage

Four concepts help explain why one participant can exert pressure on others:

1. **Concentration.** A large share of a required material, component, or capability is supplied from a small number of places.
2. **Chokepoint.** A link is sufficiently important and difficult to bypass that its interruption constrains the wider system.
3. **Substitution.** Another material, supplier, design, or process can perform the required role. Substitution may nevertheless require redesign, testing, approval, new equipment, and time.
4. **Interdependence.** A powerful supplier still depends on other participants for some combination of inputs, equipment, knowledge, finance, transport, security, and customers.

Concentration alone does not prove that an interruption will be effective. A buyer may have inventories. Other producers may possess unused capacity. The controlled input may be important in one product but irrelevant to another. Smuggling or indirect trade may weaken a restriction. A substitute may be inferior but adequate. To assess leverage, we must ask how much is controlled, at which stage, for how long, with what alternatives, and at what cost to both sides.

### 2.4.1 China's Rare-Earth Leverage

**The advantage is not simply geological.** China's position is not explained merely by the location of mines. For the magnet rare earths it examines, the International Energy Agency reports that in 2024 China accounted for 60 per cent of mined production, 91 per cent of refined output, and 94 per cent of permanent-magnet production [16]. Processing and manufacturing capability are therefore at least as important to the case as possession of deposits.

**The process is difficult.** Other countries can perform these activities. The difficulty is reproducing the whole system quickly, at competitive cost, and at the required quality. Rare-earth elements are reasonably plentiful in the Earth's crust, but economically useful concentrations are less common. They normally occur mixed with one another, and their similar chemical properties make them difficult to separate. Mining therefore produces an intermediate material, not a finished magnet. The useful minerals must first be concentrated from the ore, a process called **beneficiation**. Chemical treatment and separation then produce individual oxides, which must be converted into metals and alloys before a magnet can be made [16].

**An industrial base.** China's advantage comes from capacity across these connected stages, not just from opening mines. Its large magnet industry provides steady demand for processors farther up the chain. Scale, skilled workers, established suppliers, shared infrastructure, access to energy and other inputs, and links among refining, metal and alloy production, and magnet manufacture reinforce one another. A new project outside China often starts at smaller scale with higher capital and operating costs. It must secure permits, manage chemical and sometimes radioactive waste, obtain specialised equipment, find buyers for the valuable elements and for other elements separated at the same time, and raise money before customers have accepted its output [16].

Nor is announcing a mine the same as creating a mine-to-magnet chain. The IEA identifies refining and magnet manufacture as the slower parts of diversification. Some specialised equipment has few suppliers outside China and may take years to obtain, while industrial knowledge is partly practical knowledge developed through repeated production. A magnet for a motor or data-centre component must also meet the buyer's technical specifications and reliability requirements. Another country can build these capabilities, but money, equipment, workers, customers, environmental safeguards, and time must arrive together [16].

**Controls are specific.** In April 2025, China introduced controls covering seven heavy rare-earth elements and related products. Further controls announced in October were suspended for a year in November [16]. This timeline matters. "China banned rare earths" would be a misleading summary: particular controls, products, destinations, licensing arrangements, and dates must be identified.

This industrial depth is what turns concentration into leverage. A manufacturer that cannot obtain a qualified magnet cannot replace it with a bag of unprocessed ore or an announced mining project. Even a licensing delay can therefore cause uncertainty, higher prices, or interrupted production.

**Leverage has limits.** The leverage is not unlimited. Controls may reduce income for Chinese suppliers and impose costs on firms in China that need foreign markets or components. Customers may build inventories, support competing producers, redesign products, use substitutes, recover material through recycling, or accept higher costs in exchange for more secure supply. Aggressive use of a chokepoint can motivate other participants to weaken it. Leverage is therefore real, but conditional and capable of changing.

### 2.4.2 US Financial and Technological Leverage

**Finance.** The US dollar is widely used as a reserve asset, a currency for trade and payments, and a unit for international banking. Federal Reserve researchers report that it accounted for 58 per cent of disclosed official foreign-exchange reserves in 2024 and about half of international payments sent through SWIFT, a widely used financial-messaging network. Dollar use in trade and international banking was also much larger than the US share of world output or trade [17]. This position makes access to US banks, markets, and dollar settlement valuable even to firms and governments outside the United States.

US financial sanctions draw power from this position and from American legal authority over institutions and transactions connected to its financial system. Exclusion can make payments, borrowing, investment, and trade more difficult. The dollar is not, however, a switch that Washington can turn off for the entire world. The effect of a measure depends on its legal scope, enforcement, cooperation from other governments and financial institutions, and the target's alternatives. The US Treasury warns that alternative payment systems, digital assets, and reduced exposure to the dollar could erode the long-term effectiveness of sanctions; it also stresses clear objectives, multilateral coordination, and attention to unintended harm [18].

**Technology.** As Figure 2.2 illustrates, American firms occupy strong positions in chip design and electronic design automation and intellectual property. US export rules also cover selected advanced computing chips, high-bandwidth memory, semiconductor-manufacturing equipment, software, and technology. Under specified foreign direct product rules, certain items made outside the United States can fall within US export jurisdiction when they are produced using covered American technology or equipment [19].

An early Nvidia case makes this leverage more concrete. In August 2022, the company disclosed that the US government had imposed an immediate licensing requirement on future exports to China, including Hong Kong, of its A100 and forthcoming H100 advanced-computing chips and systems containing them. Nvidia said it would offer Chinese customers alternative products where possible and seek licences when alternatives were insufficient [20, 21]. This was not a ban on every Nvidia chip, and a licensing requirement does not mean that every application will be refused. It nevertheless showed how a government could use jurisdiction over a narrow but important class of technology to affect a foreign country's access and the commercial decisions of its own firms. The example is dated deliberately: the detailed rules and covered products have changed since 2022.

This is substantial leverage, but it is not ownership of "technology" in general. Advanced semiconductor production also relies on equipment and materials from Europe and Japan, fabrication in Taiwan and South Korea, and assembly, testing, packaging, manufacturing, and markets across Asia. China has developed major capabilities of its own and continues to invest in alternatives. The comparison here concerns particular chokepoints, not a ranking of the total scientific or technological ability of two countries.

## 2.5 Two Powers, Different Chokepoints

China and the United States can therefore place pressure on different parts of the same international system. We can compare these forms of leverage without pretending that the two countries' capabilities, policies, or conduct are identical.

| Dimension | China | United States |
|---|---|---|
| Concentrated positions | Rare-earth separation, refining, and permanent-magnet production for important industrial uses | Dollar-centred finance; advanced chip design; EDA and IP; selected advanced chips, equipment, software, and technology |
| Means of pressure | Export licensing, delays, restrictions, and the possibility of withholding difficult-to-replace materials or components | Financial sanctions, restrictions on access to the US financial system, and export controls on specified technologies and products |
| Continuing dependencies | Foreign semiconductor capabilities, equipment, customers, finance, transport, and other internationally supplied inputs | Foreign fabrication, specialist equipment and materials, assembly and testing, manufacturing capacity, allied cooperation, and overseas markets |
| Ways leverage may weaken | New suppliers, stockpiles, recycling, substitution, redesign, and reduced reliance on Chinese processing | Alternative payment channels, reduced dollar exposure, new suppliers, technological substitution, domestic development, and weaker cooperation by other countries |

China's advantage in rare-earth processing does not give it command of every electronic product. American strength in finance and semiconductor technology does not allow the United States to manufacture the whole chain alone. In both cases leverage is strongest when the controlled link is indispensable, substitutes are costly or slow, and other participants cooperate with or comply with the restriction. Using a chokepoint can also encourage customers to escape it.

When a headline says that a country "controls technology", rewrite it more precisely. Identify the stage, product, share, period, legal measure, affected users, and available alternatives. The same standard applies whether the pressure comes from Beijing, Washington, or another government.

## 2.6 What Does "Pro-Philippines" Require?

Public argument often treats international affairs like a basketball match: choose a team, defend every decision it makes, and jeer at the other bench. That habit is especially unhelpful for technology. The physical system just examined does not divide neatly into two self-contained camps. Materials, equipment, designs, factories, workers, shipping routes, investors, markets, and standards cross political boundaries.

Being described as "pro-US" or "pro-China" can also conceal several different decisions. A government can trade with a country, accept a particular investment, cooperate on security, use a technical standard, criticise a policy, or reject a contract. Agreement in one area does not require agreement in all the others.

The supply chains in this chapter point to a prior Philippine interest: global political stability. Philippine households and firms cannot enjoy reliable access to technology if major economies repeatedly interrupt trade, finance, shipping, or production. A conflict among them would travel through the same networks on which the Philippines depends. Interdependence gives countries practical reasons to preserve peace and predictable exchange, but it does not make peace automatic. A chokepoint can be used precisely because others depend on it. Stability therefore still requires diplomacy, predictable rules, peaceful settlement of disputes, functioning trade routes, and enough resilience that no participant can easily hold the rest hostage.

That wider stability is the condition within which the Philippines can try to tilt particular bargains in its favour. The sensible objective is neither automatic alignment nor a refusal to choose. The United States and China do not have identical institutions, capabilities, conduct, or relationships with the Philippines, and particular actions need not deserve identical judgements. The relevant test is what a proposal does to Philippine welfare, capability, security, and freedom of action. Cooperation with the United States in one area and China in another is not necessarily inconsistent. Dependence so deep that the Philippines cannot refuse either partner is the more serious problem.

"Pro-Philippines" sounds reassuring, which is precisely why it must not be allowed to do the work of an argument. Filipinos can disagree honestly about what a policy should prioritise. Consumers may want lower prices, workers may want secure employment, firms may want reliable inputs, communities may oppose pollution, and government agencies may worry about security or excessive dependence. A serious national-interest argument identifies these interests and explains its trade-offs.

The Philippines is not merely a spectator in electronics. According to the Philippine Statistics Authority, electronic products accounted for 54.3 per cent of the country's merchandise export earnings in 2025 [22]. The Board of Investments describes Philippine strengths in semiconductor assembly, testing, and packaging and in electronics manufacturing services, alongside efforts to develop design and higher-value capabilities [23]. These activities provide jobs, exports, experience, and infrastructure. They do not mean that the Philippines controls chip design, fabrication equipment, raw materials, transport, or overseas demand. Participation matters, but it does not amount to complete control.

When you consider a technological investment, restriction, contract, or partnership, give "pro-Philippines" some content by asking these questions.

Table 2.1: Questions for evaluating a technological proposal from a Philippine perspective.

| Concern | Questions to investigate |
|---|---|
| Access and cost | Will useful technology, components, or services remain available at a price Philippine households, schools, firms, and government can afford? Who receives a subsidy, guarantee, or exclusive advantage? |
| Employment and income | How many jobs are likely to be created, what kinds of jobs are they, how secure are they, and who captures the resulting income? |
| Capability | Will Filipino workers, researchers, and firms acquire knowledge, design ability, equipment, intellectual property, or decision-making power? Or will the activity remain easy to move elsewhere? |
| Resilience | Does the proposal reduce dependence on one supplier or merely replace one dependency with another? Are alternative suppliers, routes, parts, and emergency arrangements available? |
| Security and control | Who owns and operates critical equipment? Who can access important data? Can Philippine institutions inspect, regulate, repair, or replace the system? |
| Law and public institutions | Is the arrangement consistent with Philippine law, rights, procurement rules, transparency, and accountable decision-making? What disputes or failures would be difficult to remedy? |
| Environment and communities | Who uses the land, water, and electricity? Who is exposed to pollution, waste, unsafe work, displacement, or other costs? What obligations remain after a facility closes? |
| Future choice | Does the proposal leave the Philippines with more skills, partners, and bargaining power, or make withdrawal prohibitively costly? What happens when the contract, political relationship, or technology changes? |
| Distribution | Which Filipinos gain, which Filipinos pay, and are the promised national benefits actually shared? |

No partner will score perfectly on every question. A proposal may create jobs but consume scarce electricity; reduce immediate prices but deepen dependence; improve security but restrict access; or transfer some knowledge while leaving the most valuable decisions elsewhere. Compare the benefits, costs, alternatives, safeguards, and time horizons openly.

Diversification is often part of the answer, but it is not magic. Maintaining several suppliers can cost more. Stockpiles can become obsolete or prove too small. Domestic production may require subsidies and still depend on imported equipment. Recycling cannot immediately meet all demand. Substitution may reduce performance. Resilience is not the absence of trade; it is the ability to continue, adapt, and choose when one relationship or link is disrupted.

## 2.7 The Point of the Chain

The physical foundations of computing lead to a political lesson, but not to a party line. A phone works only because many layers of technology and many parts of the world meet inside it. A country that controls an indispensable link can gain leverage, yet it normally continues to depend on other links. Attempts to use that leverage can succeed, impose costs on the user, and provoke efforts to escape it—all at the same time.

Strategic independence cannot mean manufacturing every mineral, chip, cable, application, and server within Philippine borders. That is neither a realistic description of modern technology nor an intelligent use of limited resources. It means knowing where the Philippines is vulnerable, developing capabilities that improve its position, maintaining alternatives where the consequences of failure are serious, and negotiating with enough knowledge to say both yes and no.

Being pro-Philippines therefore does not require hostility to the United States, China, or anyone else. It requires refusing to outsource judgement to them.

## 2.8 Questions for Discussion and Exercises

We will work through selected exercises in class. Use the remaining questions to check your understanding of the chapter.

1. Trace what happens physically when a student uploads a laboratory photograph and a classmate opens it. Include the two devices, local connections, provider networks, remote service, electricity, and cooling. Identify two points at which the activity could fail even if both phones work.

2. Explain how the statements “the student submitted an assignment”, “an application transmitted a file”, and “transistors changed electrical states” can all describe the same event. Why would it be a mistake to say that the transistors understood the deadline?

3. A phone is labelled “Made in Country A”. Construct a plausible value chain involving at least four countries or regions. What can the label establish, and what can it not establish? Use concentration, substitution, and interdependence to explain how one inexpensive link could nevertheless become a chokepoint.

4. Compare China’s leverage in rare-earth processing and magnet production with US leverage in finance and advanced semiconductor technology. Identify the mechanism, dependencies, and limits on each side, and explain why the comparison does not establish that either country controls technology as a whole.

5. A foreign company proposes to build a large data centre in the Philippines. Use at least six concerns in Table 2.1 to recommend acceptance, rejection, or renegotiation. State what evidence is missing and which safeguards you would seek.

# Remaining Chapters Under Construction

This edition contains the Introduction and Chapters 1–2. Further chapters are being prepared and will be added as the course progresses. Their contents may also change in response to students' questions, suggestions, and practical needs.

# Appendix A

# Sample Answers to Exercises

Your answer need not match mine word for word. Several questions allow more than one answer because circumstances, priorities, and equipment differ. What matters is that your answer is accurate, relevant to the question, and clearly justified.

## A.1 Chapter 1: How IT Works and Why It Matters

1. The observations entered by the student are the input. The online form may check whether required fields have been completed or convert an entered date into a standard format; this is processing. The responses may be stored in a remote database or spreadsheet. A confirmation message or summary table is an output. Sending the responses from the device to the remote system is an act of communication. The hardware may include a phone or laptop, router, network equipment, and server. The software may include the operating system, browser, online form, and database.
2. RAM holds data and instructions that programs are using at the moment. It is fast working space, and its contents are normally lost when the device is switched off. Long-term storage, such as an SSD, retains applications and files when power is removed. A computer needs RAM for active work and storage for keeping work between sessions.
3. Core counts cannot be compared in isolation because processor design, generation, cooling, software, and the kind of work all affect performance. Suitable benchmarks or tests of the student's actual applications would provide better evidence. In the example laptop, the RAM and internal SSD cannot be upgraded after purchase. The words *up to* indicate a best-case battery result under stated test conditions, not the running time that every user will obtain.
4. Apple's specification assigns 614 GB/s to the M5 Max configuration with a 40-core GPU and 460 GB/s to the configuration with a 32-core GPU. The apparent conflict arose because the source table presented figures for different configurations. The example shows that a detailed

table can still be ambiguous or wrong. Important specifications should be checked against a primary source and the exact model being considered.

5. Regional models may differ in SIM arrangement, battery capacity, supported network bands, and warranty coverage. In the table, some versions accept a physical Nano-SIM while another is eSIM-only, and the listed battery capacities also differ. The exact model therefore matters even when the product name is unchanged. The three rear cameras perform different optical roles. Their 48-megapixel figures cannot be added together as though they formed one 144-megapixel camera.

6. The provider's connection carries data between the home and the wider internet. Wi-Fi distributes that connection wirelessly within the home. To investigate a slow connection, test a computer through Ethernet and compare the result with Wi-Fi tests made near and far from the router. A good Ethernet result but poor distant Wi-Fi result suggests an internal wireless problem. Poor results on both may point to the service, modem or router, congestion, or another shared-network problem.

7. First convert the file size from megabytes to megabits:

   $$800\ \text{MB} \times 8 = 6{,}400\ \text{Mb}.$$

   The estimated download time is therefore

   $$\frac{6{,}400\ \text{Mb}}{100\ \text{Mb/s}} = 64\ \text{s}.$$

   The actual transfer would usually take longer because of overhead, congestion, Wi-Fi conditions, and other limitations.

8. The household should examine upload rate, latency, jitter, packet loss, and performance during busy periods. It should also check whether the advertised rate is a maximum or expected range, whether capacity is shared, and whether the plan has a data allowance or fair-use threshold. Other relevant matters include availability at the exact address, installation and equipment charges, contract length, later price increases, reliability, and repair response. The importance assigned to each factor may vary among households.

9. SaaS describes how software is delivered; subscription describes how access is paid for; freeware describes a zero purchase price; and open source describes licence permissions. One product can fit several of these descriptions at once. The claim that freeware is probably malware while paid software is safe is too broad. Either can be secure or unsafe. Better evidence includes the identity and reputation of the developer, the official download source, permissions, update history, privacy practices, independent reviews, and the ability to export files.

10. The group should begin by defining what must be recorded, which analyses are required, and how results will be shared. It should check compatibility with members' devices and required file formats; the full cost over the project; ease of use, documentation, and support; offline access; backup and recovery; and whether data can be exported in a usable form. Because biological work may involve personal, health, location, or unpublished research data, the group should also examine permissions, storage location, access controls, encryption, privacy terms, and what happens to the files when payment or institutional access ends.

## A.2 Chapter 2: The Physical Foundations of Computing

1. The first phone's camera sensor records the specimen. Its processor and software construct an image, RAM holds current work, storage retains the file, and the battery powers these operations. The phone's radio sends the file through Wi-Fi or a mobile connection. Provider equipment and physical links carry it to a data centre, where account systems authorise the upload and servers and storage systems retain the file. Electricity and cooling keep that equipment operating. When the classmate opens the file, a corresponding route delivers it to the second phone. The activity could fail because the provider's cable is damaged, the remote service is unavailable, the data centre loses power, or access permission is incorrectly set, even if both phones work.
2. The three statements describe different levels of the same event. At the human and institutional level, the action fulfils an academic requirement. At the application level, software prepares and transmits a file. At the circuit level, organised changes in physical states implement the instructions. The transistors have no representation of the course rules or the social meaning of a deadline; saying they understood it would incorrectly transfer a human description to the physical level.
3. One plausible chain has minerals extracted in Countries B and C, materials refined in Country D, chips designed in Country E and fabricated in Country F, displays and batteries made elsewhere, final assembly in Country A, and sales and network services in the Philippines. Depending on the applicable labelling rule, "Made in Country A" may establish where final manufacture or a substantial transformation occurred. It does not by itself establish the origin of every material, component, design, machine, item of software, or source of economic value. Concentration occurs when one of these stages has few suppliers. It becomes a chokepoint when interruption would constrain the whole chain and substitution is slow or costly. The suppliers themselves remain interdependent because they need inputs, transport, customers, and other stages. An inexpensive qualified connector could therefore matter more strategically than an expensive display if the connector has one supplier while several interchangeable displays are available.

4. China's leverage in this case comes from concentrated rare-earth separation, refining, and permanent-magnet production. Export licensing or restrictions can delay inputs for industries that cannot qualify another supplier quickly. China nevertheless depends on foreign semiconductor capabilities, equipment, customers, finance, and other inputs. Its leverage can weaken through new suppliers, inventories, recycling, redesign, and substitution.

   US financial leverage comes from the international use of the dollar and access to American banks and markets. Its semiconductor leverage comes from strong positions in areas such as advanced chip design, EDA and IP, together with export jurisdiction over specified chips, equipment, software, and technology. The United States still depends on foreign fabrication, specialist equipment and materials, assembly and testing, manufacturing, markets, and cooperation from other governments. Alternative payments, reduced dollar exposure, new technologies, and weaker cooperation can reduce its leverage. These are comparisons of particular links, not proof that one country controls finance, materials, or technology in every form.

5. Answers will depend on the proposed facility. A recommendation to renegotiate might require evidence about expected electricity and water demand, the source of power, jobs and training, tax concessions, ownership, data access, network resilience, environmental effects, community consultation, security review, and obligations when the facility closes. Possible safeguards include clear service and environmental standards, independent audits, Philippine legal jurisdiction, emergency and exit arrangements, worker training, transparent incentives, limits on exclusive dealing, and plans for equipment and waste. An answer recommending acceptance or rejection can also be sound if it states the evidence, alternatives, affected groups, and trade-offs rather than relying on the investor's nationality.

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