1.4 THE OPERATING SYSTEM ZOO

Operating systems have been around now for over half a century. During this time, quite a variety of them have been developed, not all of them widely known. In this section we will briefly touch upon nine of them. We will come back to some of these different kinds of systems later in the book.

1.4.1 Mainframe Operating Systems

At the high end are the operating systems for mainframes, those room-sized computers still found in major corporate data centers. These computers differ from personal computers in terms of their I/O capacity. A mainframe with 1000 disks and millions of gigabytes of data is not unusual; a personal computer with these specifications would be the envy of its friends. Mainframes are also making something of a comeback as high-end Web servers, servers for large-scale electronic commerce sites, and servers for business-to-business transactions.

The operating systems for mainframes are heavily oriented toward processing many jobs at once, most of which need prodigious amounts of I/O. They typically offer three kinds of services: batch, transaction processing, and timesharing. A batch system is one that processes routine jobs without any interactive user present. Claims processing in an insurance company or sales reporting for a chain of stores is typically done in batch mode. Transaction-processing systems handle large numbers of small requests, for example, check processing at a bank or airline reservations. Each unit of work is small, but the system must handle hundreds or thousands per second. Timesharing systems allow multiple remote users to run jobs on the computer at once, such as querying a big database. These functions are closely related; mainframe operating systems often perform all of them. An example mainframe operating system is OS/390, a descendant of OS/360. However, mainframe operating systems are gradually being replaced by UNIX variants such as Linux.

1.4.2 Server Operating Systems

One level down are the server operating systems. They run on servers, which are either very large personal computers, workstations, or even mainframes. They serve multiple users at once over a network and allow the users to share hardware and software resources. Servers can provide print service, file service, or Web service. Internet providers run many server machines to support their customers and Websites use servers to store the Web pages and handle the incoming requests. Typical server operating systems are Solaris, FreeBSD, Linux and Windows Server 201x.

1.4.3 Multiprocessor Operating Systems

An increasingly common way to get major-league computing power is to connect multiple CPUs into a single system. Depending on precisely how they are connected and what is shared, these systems are called parallel computers, multicomputers, or multiprocessors. They need special operating systems, but often these are variations on the server operating systems, with special features for communication, connectivity, and consistency.

With the recent advent of multicore chips for personal computers, even conventional desktop and notebook operating systems are starting to deal with at least small-scale multiprocessors and the number of cores is likely to grow over time. Luckily, quite a bit is known about multiprocessor operating systems from years of previous research, so using this knowledge in multicore systems should not be hard. The hard part will be having applications make use of all this computing power. Many popular operating systems, including Windows and Linux, run on multiprocessors.

1.4.4 Personal Computer Operating Systems

The next category is the personal computer operating system. Modern ones all support multiprogramming, often with dozens of programs started up at boot time. Their job is to provide good support to a single user. They are widely used for word processing, spreadsheets, games, and Internet access. Common examples are Linux, FreeBSD, Windows 7, Windows 8, and Apple's OS X. Personal computer operating systems are so widely known that probably little introduction is needed. In fact, many people are not even aware that other kinds exist.

1.4.5 Handheld Computer Operating Systems

Continuing on down to smaller and smaller systems, we come to tablets, smartphones and other handheld computers. A handheld computer, originally known as a **PDA** (**Personal Digital Assistant**), is a small computer that can be held in your hand during operation. Smartphones and tablets are the best-known examples. As we have already seen, this market is currently dominated by Google's Android and Apple's iOS, but they have many competitors. Most of these devices boast multicore CPUs, GPS, cameras and other sensors, copious amounts of memory, and sophisticated operating systems. Moreover, all of them have more third-party applications (**"apps"**) than you can shake a (USB) stick at.

1.4.6 Embedded Operating Systems

Embedded systems run on the computers that control devices that are not generally thought of as computers and which do not accept user-installed software. Typical examples are microwave ovens, TV sets, cars, DVD recorders, traditional phones, and MP3 players. The main property which distinguishes embedded systems from handhelds is the certainty that no untrusted software will ever run on it. You cannot download new applications to your microwave oven—all the software is in ROM. This means that there is no need for protection between applications, leading to design simplification. Systems such as Embedded Linux, QNX and VxWorks are popular in this domain.

1.4.7 Sensor-Node Operating Systems

Networks of tiny sensor nodes are being deployed for numerous purposes. These nodes are tiny computers that communicate with each other and with a base station using wireless communication. Sensor networks are used to protect the perimeters of buildings, guard national borders, detect fires in forests, measure temperature and precipitation for weather forecasting, glean information about enemy movements on battlefields, and much more.

The sensors are small battery-powered computers with built-in radios. They have limited power and must work for long periods of time unattended outdoors, frequently in environmentally harsh conditions. The network must be robust enough to tolerate failures of individual nodes, which happen with ever-increasing frequency as the batteries begin to run down.

Each sensor node is a real computer, with a CPU, RAM, ROM, and one or more environmental sensors. It runs a small, but real operating system, usually one that is event driven, responding to external events or making measurements periodically based on an internal clock. The operating system has to be small and simple because the nodes have little RAM and battery lifetime is a major issue. Also, as with embedded systems, all the programs are loaded in advance; users do not suddenly start programs they downloaded from the Internet, which makes the design much simpler. TinyOS is a well-known operating system for a sensor node.

1.4.8 Real-Time Operating Systems

Another type of operating system is the real-time system. These systems are characterized by having time as a key parameter. For example, in industrial process-control systems, real-time computers have to collect data about the production process and use it to control machines in the factory. Often there are hard deadlines that must be met. For example, if a car is moving down an assembly line, certain actions must take place at certain instants of time. If, for example, a welding robot welds too early or too late, the car will be ruined. If the action absolutely *must* occur at a certain moment (or within a certain range), we have a **hard real-time system**. Many of these are found in industrial process control, avionics, military, and similar application areas. These systems must provide absolute guarantees that a certain action will occur by a certain time.

A **soft real-time system**, is one where missing an occasional deadline, while not desirable, is acceptable and does not cause any permanent damage. Digital audio or multimedia systems fall in this category. Smartphones are also soft real-time systems.

Since meeting deadlines is crucial in (hard) real-time systems, sometimes the operating system is simply a library linked in with the application programs, with everything tightly coupled and no protection between parts of the system. An example of this type of real-time system is eCos.

The categories of handhelds, embedded systems, and real-time systems overlap considerably. Nearly all of them have at least some soft real-time aspects. The embedded and real-time systems run only software put in by the system designers; users cannot add their own software, which makes protection easier. The handhelds and embedded systems are intended for consumers, whereas real-time systems are more for industrial usage. Nevertheless, they have a certain amount in common.

1.4.9 Smart Card Operating Systems

The smallest operating systems run on smart cards, which are credit-card-sized devices containing a CPU chip. They have very severe processing power and memory constraints. Some are powered by contacts in the reader into which they are inserted, but contactless smart cards are inductively powered, which greatly limits what they can do. Some of them can handle only a single function, such as electronic payments, but others can handle multiple functions. Often these are proprietary systems.

Some smart cards are Java oriented. This means that the ROM on the smart card holds an interpreter for the Java Virtual Machine (JVM). Java applets (small programs) are downloaded to the card and are interpreted by the JVM interpreter. Some of these cards can handle multiple Java applets at the same time, leading to multiprogramming and the need to schedule them. Resource management and protection also become an issue when two or more applets are present at the same time. These issues must be handled by the (usually extremely primitive) operating system present on the card.