System Software

A-Level Computer Science

Operating systems

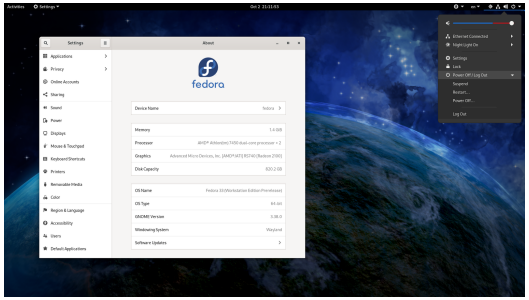
Why a computer needs an OS

Hardware on its own can only fetch and run instructions – it knows nothing about files, programs, networks or users. The **operating system** (OS) is the **software layer** that:

- **manages the hardware** (**processor**, memory, I/O, storage) for the running programs.
- **provides services** (file system, network, user accounts) through a clear interface, so programs need not talk to the hardware directly.
- **provides a user interface** (command line, GUI, touch).
- **lets several programs share the hardware safely** – each gets fair CPU time and is kept out of the others' memory.

Without an OS, every program would need its own drivers, and only one program could safely run at a time.

"Describe the purpose of an OS" – the five-mark list. The OS (1) provides an **interface** between the user and the hardware; (2) **hides the complexity** of the hardware from the user and from application programs; (3) **manages the hardware resources** – processor time, memory, storage and input/output devices – and shares them between programs; (4) loads application software into memory and runs it, giving every program the same platform to run on; (5) lets several programs run at once (**multitasking**) while keeping them, and the users' data, secure. Give five *different* points; "it runs the computer" or "it manages resources" alone earns nothing.



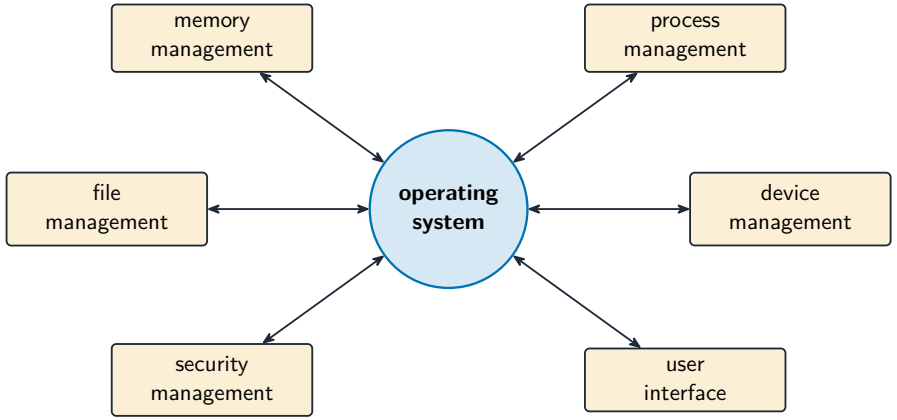
A desktop operating system manages the screen, files and programs for the user

A phone needs one just as much: this is a mobile operating system, Android

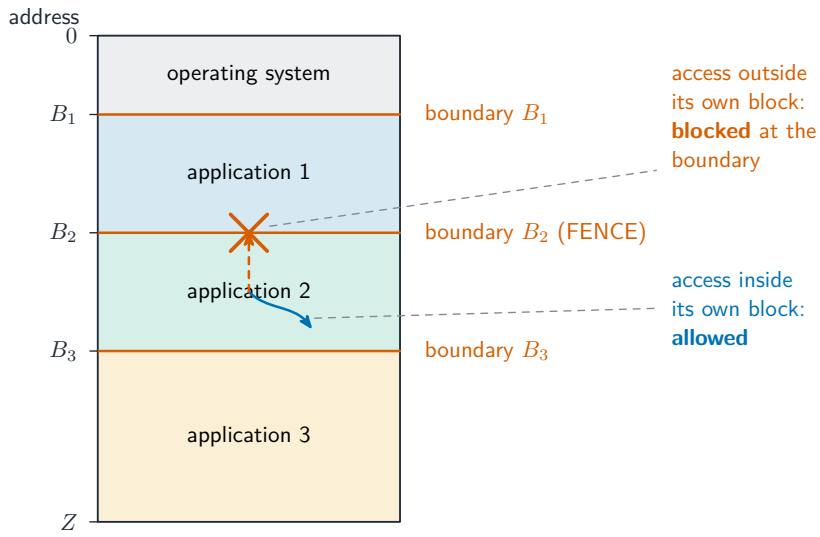
Key management tasks

The syllabus names five. Each point below is one thing the OS actually does, which is what a "describe" question wants.

- **memory management** – allocates memory to each program when it is loaded, keeps every program's memory separate (**memory protection**) so one cannot overwrite another, frees the memory when a program ends, and swaps pages between **RAM** and **secondary storage** (the disk) (**virtual memory** / **paging**) so more programs can be open than physical memory allows.
- **process management** – a running program is a **process**. The OS creates and ends processes, decides which process gets the CPU next (**scheduling**) and for how long (a **time slice**), switches between them, resolves conflicts when two want the same resource, and can kill one that stops responding.
- **hardware management** (input/output and peripherals) – talks to each device through its **device driver**, queues and buffers data going to slow devices such as a printer, responds to **interrupts** from devices, and shares one device between several programs.
- **file management** – creates, names, copies, moves and deletes files and folders, keeps the **directory** structure and a record of where each file is stored on the disk, allocates disk space to files, and enforces **access rights** (read / write / execute) for each user.
- **security management** – user accounts and passwords (**authentication**), access rights, encryption of stored data, a firewall, automatic security updates, and a log of who did what.



The main jobs the operating system manages



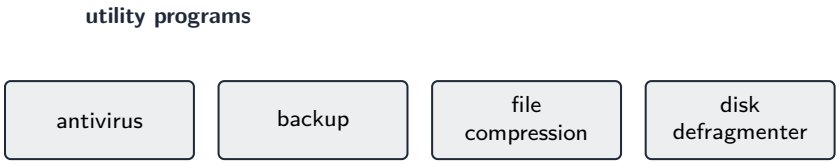
Memory protection keeps each application in its own block of memory

How memory and process management support multitasking (a four-mark favourite). Memory management loads several programs into memory at the same time, each in its own protected area, and keeps track of which addresses belong to which; process management shares the processor between them – each process runs for a time slice, the OS saves its state and switches to the next, and the switching is so fast that all the programs appear to run together. Interrupts let the OS take the processor back from a process whenever a device needs attention.

Interrupts. A **hardware interrupt** comes from a device: a key pressed, a mouse click, a printer out of paper, a disk finishing a transfer, a power failure. A **software interrupt** comes from a program: division by zero, an invalid instruction, an attempt to use memory it does not own, or a request for an OS service. The OS's **interrupt handler** saves the state of the running process, deals with the interrupt, then restores the process (topic 4 covers the fetch–execute detail).

■ Utility software

Utility programs are system software that maintain, repair or optimise the computer rather than doing a user's task; the examiner accepts "performs a specific maintenance task that improves performance or security". Most OSes bundle these:



Utility programs: antivirus, backup, compression and defragmenter

- **disk formatter** – prepares a new disk (or wipes an old one) for use: sets up its **file system** and partitions, deleting any existing data.
- **virus checker** (**antivirus**) – scans files and memory, compares code against a database of known virus **signatures** and watches for suspicious behaviour, then quarantines or deletes what it finds; runs on a schedule and on every download, and needs updating as new viruses appear.
- **defragmentation software** (**disk defragmenter**) – a hard disk stores a file in whatever free blocks it finds, so after many saves and deletes a file is scattered (**fragmented**) across the platter and the read/write head must jump between the pieces. The defragmenter moves the pieces of each file next to each other and gathers the free space into one region, so files load faster and new files are not fragmented. Not needed on an SSD, which has no moving head.
- **disk contents analysis / disk repair software** – shows what is using the disk space (large, duplicate or temporary files) so they can be removed; finds and repairs bad sectors, lost clusters and file-system errors.
- **file compression** (**compression**) – shrinks files so they need less storage and transfer faster; archiving bundles many files into one.
- **back-up software** (**backup**) – copies files to another medium (external disk, network, cloud) on a schedule so data can be restored after loss, corruption or a ransomware attack; a full copy is followed by **incremental backups** of only what changed.
- a **firewall** (filters network traffic by rules) and encryption tools, for security; a **system monitor** and automatic **updates**.

Bundling these with the OS saves the user installing each one.

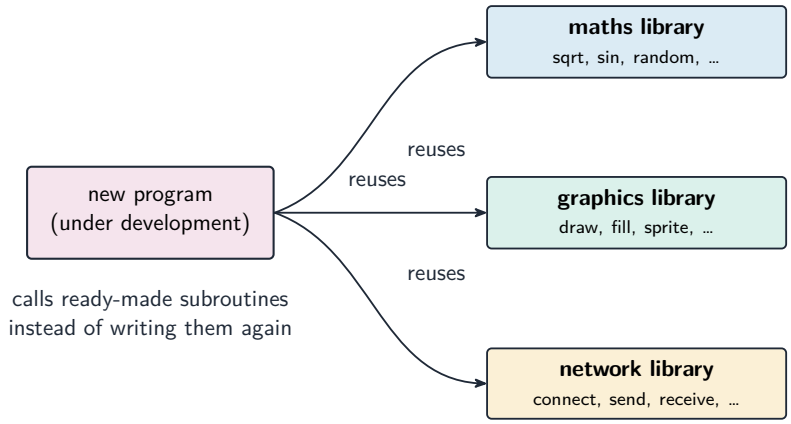
Which utility does what. *Performance:* defragmentation (faster file access), disk repair (a disk with errors is slow or fails), disk contents analysis (free space by deleting junk), compression (more fits on the disk). *Security:* virus checker, firewall, encryption, and backup (the only recovery from ransomware). A "draw one line" question pairs each utility with exactly one purpose – learn the pairs above and use the syllabus names.

> **Worked example.** Explain how defragmentation can improve the performance of a computer (3 marks).

Over time a file is stored in blocks scattered across the hard disk, so reading it needs many movements of the read/write head. The defragmenter rearranges the blocks so each file is stored **contiguously** and the free space is together. Files are then read with fewer head movements, so they load faster, and new files can be written into one continuous space.

Program libraries

A **program library** is pre-written code (**subroutines**, classes, modules) that programs reuse instead of writing it themselves – e.g. a maths library, a network library, a graphics library.

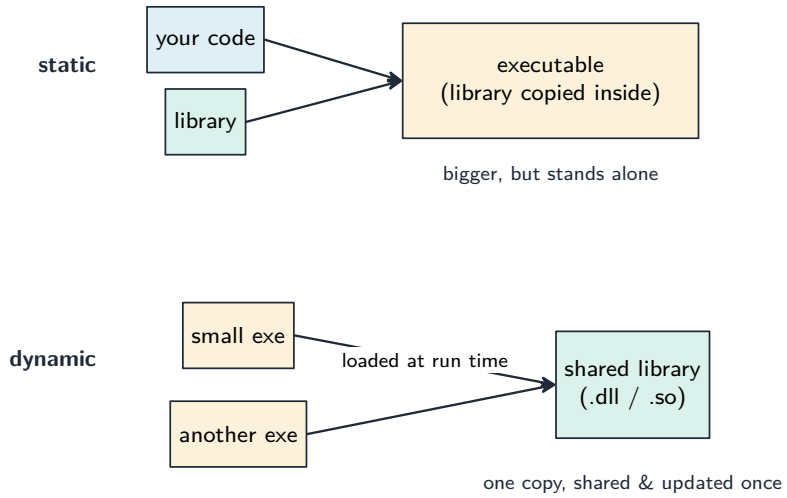


A new program reusing ready-made routines from libraries

Benefits: **saves time** (off-the-shelf code), **reliable** (well-tested, widely used), and **standardised** (consistent behaviour).

The examiner's benefit list, for the developer. The **library routines** are already written and tested, so development is faster and cheaper; they are reliable and, being used by many programs, largely error-free; the developer needs no expertise in that area (graphics, compression, encryption, path-finding); the program is easier to maintain because common code lives in one place; and a whole team can use the same routines, giving consistent results. **Drawbacks:** a routine may not do exactly what you need and you cannot change it; your program depends on the library being available, correct and secure – a bug or a security hole in the library is a bug in your program; and you must learn how to call it.

- a **static library** is copied into the executable at compile time (stands alone, but larger and needs rebuilding to update).
- a **dynamic library** (DLL, Dynamic Link Library; `.so`) is loaded at run time (smaller executables, shared by many programs, updated once for all).



Static: the library is copied into the executable. Dynamic: a shared library file is loaded at run time

Dynamic Link Library (DLL) files. A DLL is a library that is loaded into memory only when a program calls it, at **run time**, and stays as a separate file rather than being copied into the executable. *Benefits:* the executable is smaller; several running programs share one copy of the DLL in memory; a DLL can be updated (bug fix, new device) without recompiling the programs that use it; and memory is used only while the routine is needed. *Drawbacks:* the program will not run if the DLL is missing, moved or the wrong version; an updated DLL can break a program that relied on the old behaviour; and a fake DLL put in its place runs with the program's rights.

> **Worked example.** A team writing the software for a restaurant robot uses a program library that includes a routine to find the shortest path between tables. Explain two benefits and one drawback to the team.

Benefits: the routine is already written and tested, so the team saves time and can trust the result; the team need not understand path-finding algorithms themselves and

can spend the time on the robot's own features. *Drawback:* the routine may not handle the restaurant's exact needs (moving chairs, one-way aisles) and the team cannot alter it, so they may have to work around its limits.

Language translators

You write source code; the computer runs **machine code** . A **translator** converts between them.

Assembler

An **assembler** translates **assembly language** into machine code: each mnemonic instruction (`LDD`, `ADD`, `JMP`) becomes exactly one machine-code instruction, and symbolic addresses and labels are replaced by real addresses. It is needed because the processor executes only machine code, and assembly is used where the programmer needs direct control of the hardware (embedded systems, device drivers).

Compiler

A **compiler** translates a high-level program into machine code **once, before it runs**.

- it reports **all** errors at compile time; once clean, it produces a stand-alone **executable** that runs **without the compiler installed** and can be run many times.
- generally **faster at run time** (no translation while running), but tied to one CPU/OS – recompile for each platform.

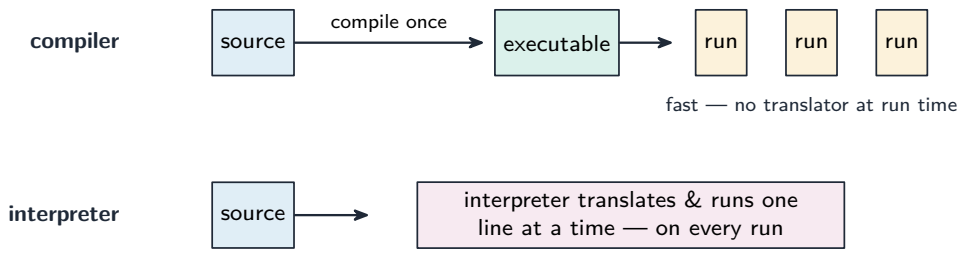
The two-mark description: *a compiler translates the **whole** high-level program into machine code (**object code**) **before** it is run, produces an executable file, and reports **all** the syntax errors together as a list at the end of translation.* It does not run the program.

Interpreter

An **interpreter** translates and runs a high-level program **one line at a time**, producing no executable.

- it reports an error **when it reaches that line**, then stops; you can fix it and continue – good for development.
- the **interpreter must be installed** to run the program; generally **slower** (each run re-translates), but easy to **port** across platforms.

The two-mark description: *an interpreter translates **one statement** of the high-level program at a time and **executes** it immediately before moving to the next; no executable file is produced; it stops at the **first** error it meets and reports it.* Both the source code and the interpreter must be present every time the program runs.



A compiler translates once into a standalone program; an interpreter translates line by line, every run

Choosing between them

Use a compiler when:	Use an interpreter when:
run-time speed matters	you want fast edit–run cycles
distributing to users without dev tools	writing cross-platform scripts
the program runs many times	the program is small or run once
	teaching beginners

Benefits and drawbacks, as the mark scheme lists them.

	compiler	interpreter
execution speed	fast – already machine code	slower – translated on every run
what the user needs	only the executable; no translator, and the source code stays private	the source code and the interpreter
finding errors	all errors listed at once, after the whole program is translated	each error reported at the line where it occurs, as you develop
changing the code	recompile the whole program after every change	edit and run again immediately
portability	machine code runs on one platform only; recompile for each	the same source runs wherever an interpreter exists

> **Worked example.** A developer uses an interpreter while writing a program and a compiler when it is finished. Explain how each is used (4 marks).

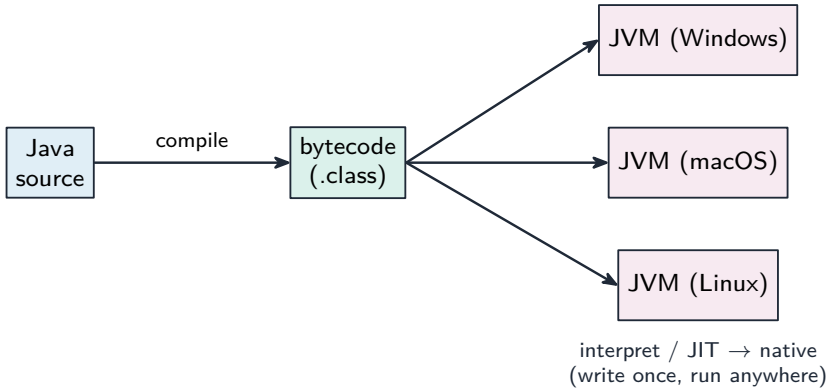
During development the interpreter runs the partly written program at once, without waiting for a complete translation; when it meets an error it reports the line, so the developer fixes it and runs again immediately – a fast edit–run cycle that is easier for

debugging. When the program is finished, the compiler translates the whole program into an executable that runs faster, needs no translator on the user's computer, and does not reveal the source code, so it can be sold to the public.

■ Hybrid: Java

Java is compiled into **bytecode** (a platform-independent intermediate form), which a **virtual machine** (the JVM) then interprets – or uses **just-in-time compilation** to turn hot parts into native code. So errors are caught early, the bytecode runs anywhere with a JVM ("write once, run anywhere"), and long-running programs reach near-native speed. C# and Python use similar designs.

The syllabus phrase is "**partially compiled and partially interpreted**": the compiler stage catches syntax errors and produces compact, **portable** bytecode; the interpreting stage lets that one bytecode file run on any machine that has a virtual machine, at the cost of some speed. Java in **console mode** (a text program run from the command line) is the syllabus's example.

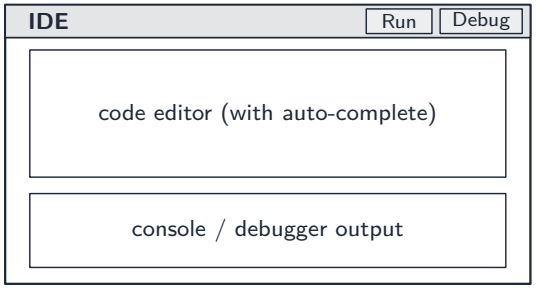


Java compiles to portable bytecode that any JVM runs – write once, run anywhere

> **Worked example.** Java source is compiled to **bytecode**, which a JVM then interprets. Why use both, instead of compiling straight to machine code? A compiler produces machine code for **one** processor and operating system, so a program compiled on one machine will not run on another. Java's compiler instead targets a **virtual** machine, so the bytecode it produces is identical everywhere; each platform then supplies its own **JVM** to interpret that bytecode into its own native instructions. One compiled file therefore runs anywhere a JVM exists - "write once, run anywhere". The price is speed: interpreting bytecode is slower than running native code, which is why a real JVM also uses **JIT** compilation to turn frequently-run bytecode into native code while the program runs. Name **both** sides - the marks are for portability **bought at the cost of speed**.

Integrated Development Environment (IDE)

An **integrated development environment** (IDE) brings the tools to write, test and debug code into one application:

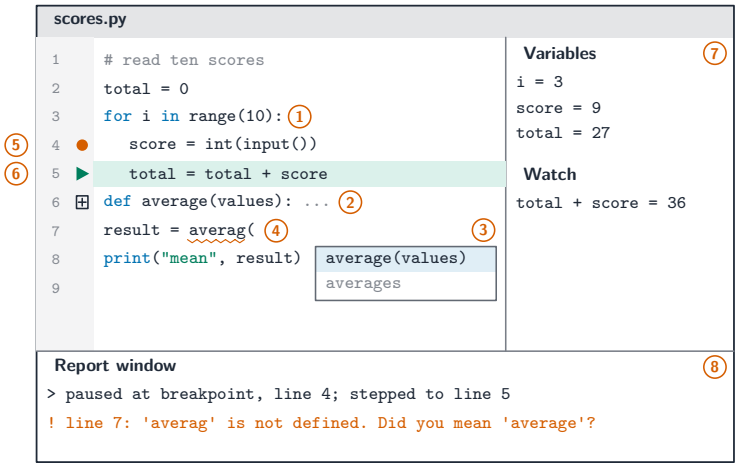


An IDE bundles the editor, a Run button and a debugger

The syllabus groups the features into four kinds. Learn which feature belongs to which, because questions ask you to sort them and to describe one from each group.

- **For coding: context-sensitive prompts** – as you type, the IDE pops up the identifiers, keywords or parameters that fit at that point in the code; **auto-complete** finishes the name for you; automatic indentation and bracket matching keep the layout right as you type.
- **For initial error detection: dynamic syntax checks** – the editor checks the syntax as you type and underlines or highlights a mistake immediately, before the program is translated; after translation, error messages with line numbers.
- **For presentation: prettyprint** – keywords, identifiers, strings and comments shown in different colours or fonts (**syntax highlighting**) with consistent indentation, so the structure is visible at a glance; **expand and collapse code blocks** – hide the body of a loop, an IF or a subroutine so you see the outline.
- **For debugging: breakpoints** – the program pauses when it reaches a marked line; **single stepping** – from the pause, run one line at a time; a window that shows the current values of **variables and expressions** as they change; and a **report window** that lists errors, warnings and output.

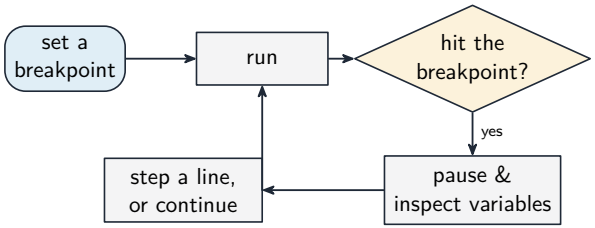
Other features: translator integration (compile or run with one key, errors shown inline), a **debugger** that drives the debugging features above, **version control** integration (git), project management, a help system, **refactoring** tools (safe renaming) and **unit test** integration.



1 prettyprint: coloured keywords/strings/comments
2 expand / collapse a code block
3 context-sensitive prompt
4 dynamic syntax check, flagged as you type
5 breakpoint: the program pauses here
6 single stepping: run one line at a time
7 variables and expressions, watched while paused
8 report window: errors, warnings and output

The IDE features the syllabus names, in the places you would see them on screen

An IDE speeds development by putting writing → running → debugging → fixing behind one interface. Common IDEs: Visual Studio, PyCharm, Eclipse, VS Code.



A debugger: set a breakpoint, run, then pause to inspect variables and step through the code

> **Worked example.** A function `Calculate()` returns an unexpected value when the program runs. Describe how the debugging features of a typical IDE help find the cause (4 marks).

Set a **breakpoint** on the first line of `Calculate()`, so the program pauses there instead of running through. Then **single-step** through the function one line at a time. After each step read the values of the variables and of any expression you have asked the IDE to **watch**, and compare them with the values you expected; the first line after which a value is wrong is where the logic error is. The **report window** shows any run-time error message and the output produced so far.

> **Worked example.** Put each feature in its syllabus group: prettyprint, context-sensitive prompt, dynamic syntax check, breakpoint, expand/collapse code blocks, report window.

Coding: context-sensitive prompt. Initial error detection: dynamic syntax check. Presentation: prettyprint, expand/collapse code blocks. Debugging: breakpoint, report window.

■ Software licences used when translating or distributing code

A software licence specifies the permitted use, copying, modification and redistribution of a copyright work. **Free Software** concerns the freedoms to run, study, change and share software; it can be sold. **Open-source** licences permit access to source and licensed modification/redistribution. Freeware can cost nothing while withholding source and modification rights. For a redistribution question, identify the actual licence's conditions; see topic 7 for comparisons and justified choices.

Definitions the examiner accepts

A definition question is marked against fixed wording. Learn these exactly, and give one answer only.

Term	Definition
operating system	software that manages the computer's hardware and resources and provides an interface between the user, the application programs and the hardware
utility software	system software that performs a specific task to maintain, optimise or protect the computer, such as a virus checker or a defragmenter
program library	a collection of pre-written, tested routines (subroutines, classes, modules) that a program can use instead of writing its own
Dynamic Link Library (DLL)	a program library whose routines are loaded into memory only when the program calls them, at run time, and are shared between programs
assembler	a translator that converts an assembly language program into machine code, one instruction for each instruction
compiler	a translator that converts the whole of a high-level language program into machine code before it is run, producing an executable file
interpreter	a translator that translates and executes a high-level language program one statement at a time

Term	Definition
integrated development environment	a single application that provides the tools for writing, translating, running and debugging a program
context-sensitive prompt	a pop-up that suggests identifiers, keywords or parameters that fit at the current point in the code
dynamic syntax check	checking the syntax of the code as it is typed and flagging an error before the program is translated
prettyprint	displaying code with keywords, identifiers and comments in different colours or fonts and with consistent indentation
breakpoint	a marked line at which the running program pauses so that variables can be inspected
single stepping	running a paused program one statement at a time under the programmer's control

Exam tips

- List the OS's jobs by their syllabus names (memory, process, hardware, file and security management) and say what each *does* – "manages resources" alone is too vague.
- Compare **compiler vs interpreter vs assembler**: what each translates, when it translates it, and how errors are reported.
- Explain what an **IDE** provides using the syllabus groups: coding, initial error detection, presentation, debugging.
- A "benefit to the developer" answer names the developer's saving: time, cost, expertise, reliability or maintenance. A "drawback" names a dependence: availability, version, fit, security.
- For "describe the operation of" a translator, give three things: what is translated (whole program or one statement), when (before running or while running), and how errors are reported (all at once or at the first error).

■ Common mistakes

- Writing "the OS controls the computer" or "manages resources" with no example task. Each mark is one named task with what it does.
- Saying an interpreter "compiles line by line". An interpreter translates **and executes** each statement; it never produces an executable.
- Saying a compiler runs the program. It only translates; the executable runs later, without the compiler.
- Putting a DLL "inside" the executable. That is a static library; a DLL stays a separate file loaded at run time.
- Saying defragmentation "deletes" or "compresses" files, or is needed on an SSD. It only moves blocks so each file is stored contiguously.
- Filing prettyprint or collapsing blocks under "debugging". They are presentation features; debugging is breakpoints, single stepping, watching variables and the report window.