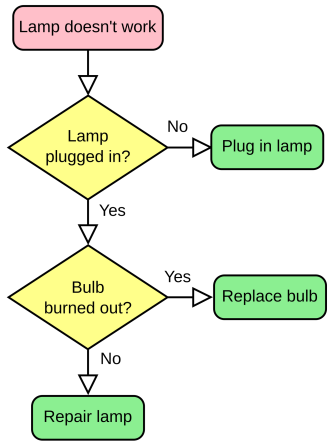
Software Development

A-Level Computer Science

Program development life cycle

A **development life cycle** 开发生命周期 is the set of stages from idea to finished, maintained software. It exists to **plan, manage and control** a project — to build the right product, on time, with good quality.

Software is built by teams who follow a development life cycle to stay coordinated



A flowchart plans a program's logic during the design stage of the cycle

Why a life cycle is needed

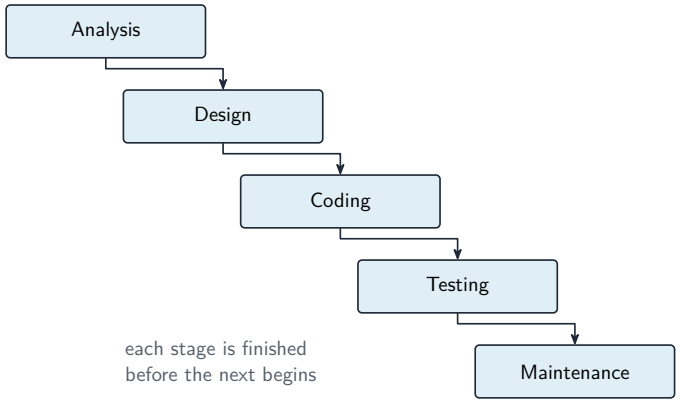
The examiner's list for "the purpose of a development life cycle": it breaks a large project into **stages** that can be planned and managed; it makes sure the **requirements** are found and agreed before design and coding begin; it builds in **testing** and **documentation** rather than leaving them to the end; it lets the team track progress against **milestones** and manage risk; and it gives the customer defined points at which to review the work. Without one, a team codes first and discovers late that it built the wrong thing.

Why there are different ones

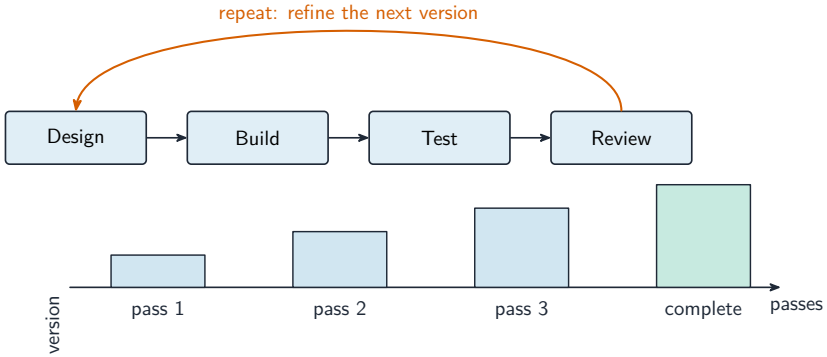
No single life cycle fits every project, so several **development life cycles** exist. The choice depends on the size and complexity, how clear the **requirements** 需求 are at the start, how much change is expected, the risk level, the team, and the deadline.

Common models

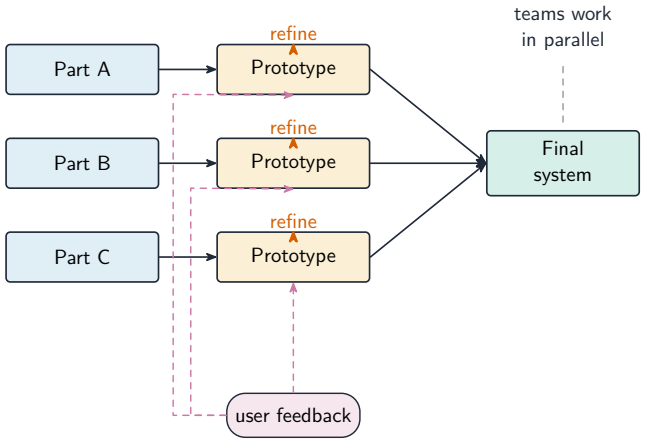
- **Waterfall** 瀑布模型 — a linear sequence (Analysis → Design → Coding → Testing → Maintenance), each stage finished before the next. Clear and well-documented; good for **stable requirements**, but poor at coping with mid-project change, and the customer sees nothing working until the end.
- **Iterative model** 迭代模型 — repeated passes, each producing a partial version that is reviewed and refined. Catches problems earlier; good when requirements are **discovered over time**, but harder to estimate.
- **Rapid Application Development** 快速应用开发 (RAD) — heavy use of a **prototype** 原型 and user feedback. Very fast first delivery; good for **changing requirements**, but depends on user availability and suits smaller systems.
- **Agile** 敏捷 — short iterations ("sprints"), constant collaboration and testing. Flexible and adaptive, but needs a committed customer and a skilled team.



The waterfall model: each stage is finished before the next begins



The iterative model: repeated passes refine the program



Rapid application development: teams work on parts in parallel

Principles, benefits and drawbacks — as the mark scheme lists them.

Model	Principle	Benefits	Drawbacks
waterfall	the stages run in a fixed order, each completed and signed off before the next starts; going back means restarting the sequence	simple to manage; every stage is fully documented; requirements are fixed early, so costs and dates can be estimated	inflexible once a stage is finished; no working software until late; a mistake in analysis is expensive to fix later; the customer cannot see progress
iterative	a small working version is built first, then repeatedly improved through further versions until complete	working software early and often; problems found in early versions; the customer's feedback shapes each version; requirements can change	hard to estimate the total time and cost; repeated testing costs effort; needs the customer to be available; can drift if versions are not planned
RAD	prototypes of parts of the system are built quickly and refined with the user until accepted, often in parallel by several teams	very fast delivery of a first version; the user is involved throughout, so the product fits their needs; changes are easy to absorb	needs skilled developers and committed users; documentation is weak; less suited to large or safety-critical systems

Worked example. A company must be the first to launch a website for a new games console, and the design will change as the console's features are announced. Name the most suitable life cycle and justify it.

RAD. A prototype of the site can be built and shown to the users within days, and refined as the requirements change; the site is small enough for a prototype-driven approach, and speed of delivery is the main requirement. Waterfall would fix the requirements before any page was built and deliver nothing until the end.

The standard stages

Each stage has a purpose, an output and typical activities — a "describe the … stage" question wants two or three of these.

- **analysis** — find out **what** the program must do. Activities: interviews, questionnaires and observation of the current system; a feasibility study; agreeing the **requirements** specification, which every later stage is checked against.
- **design** — decide **how** it will do it. Outputs: the **structure chart** (modules and parameters), **flowcharts** or **pseudocode** for each module, **identifier tables** and data structures, screen and file layouts, and the **test plan** written *now*, from the specification, before any code exists.
- **coding** (**implementation** 实现) — write the program in a high-level language, module by module, following the design; each module is tested as it is written.
- **testing** — run the program against the test plan (normal, abnormal, extreme and boundary data) and correct the errors found; integration, alpha, beta and acceptance testing follow.
- **maintenance** 维护 — after release, correct faults, adapt the program to new hardware, software or law, and improve it (see below).

Worked example. Complete the waterfall diagram *Analysis* → *?* → *?* → *?* → *Maintenance* and describe what happens at the design stage.

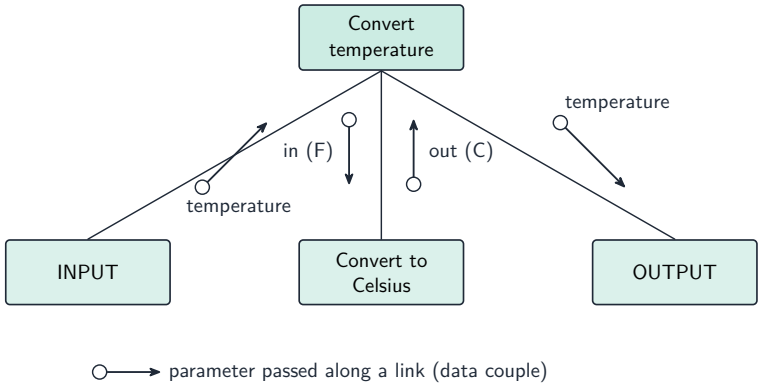
The missing stages are **Design, Coding, Testing**. At the design stage the requirements are turned into a plan for the program: the problem is decomposed into modules (a structure chart), the algorithm for each module is written as pseudocode or a flowchart, the data structures and identifiers are chosen, the screens and files are laid out, and the test plan is written from the specification.

Program design tools

Structure chart

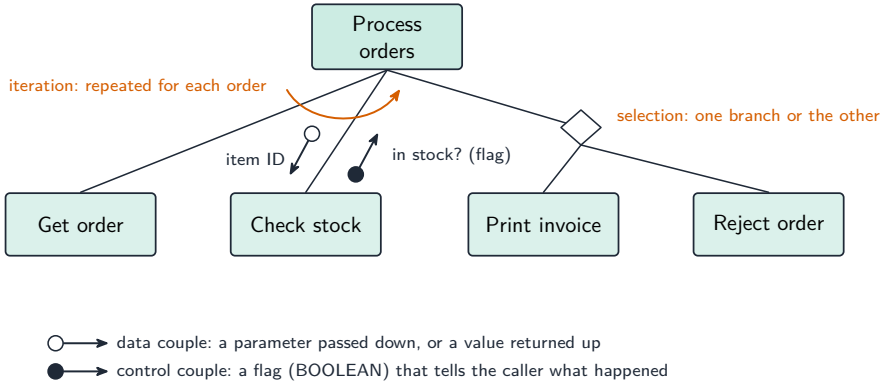
A **structure chart** 结构图 shows the **hierarchical decomposition** 分解 of a program into modules (**subroutines** 子程序) and the **parameters** 参数 passed between them. Each module is a rectangle; lines link caller (above) to callee (below); small arrows show data going down and results coming back up. The design can then be turned into equivalent **pseudocode** 伪代码.

It is a design-stage tool, and you can read the procedure signatures off it.



A structure chart: modules with the parameters passed between them

The symbols the examiner asks about. A box is a module; a line links a caller (above) to the modules it calls (below), read left to right in the order they are called. A small arrow with an **open circle** at its tail is a **data couple** — a parameter passed *down* into a module or a value returned *up*; an arrow with a **filled circle** is a **control couple**, a flag (usually BOOLEAN) that tells the caller what happened. A **diamond** at a branch means **selection**: only one of the modules below it is called, depending on a condition. A **curved arrow** sweeping across the links means **iteration**: the modules under it are called repeatedly in a loop.



The structure-chart symbols: data and control couples, a selection diamond and an iteration arrow

Worked example. Four modules are defined as `PROCEDURE Main()`, `PROCEDURE ReadData(BYREF Count : INTEGER)`, `FUNCTION IsValid(Value : INTEGER) RETURNS BOOLEAN` and `PROCEDURE Report(Total : INTEGER, Count : INTEGER)`. Main calls ReadData, then calls IsValid once for each value read, then calls Report. Describe the structure chart.

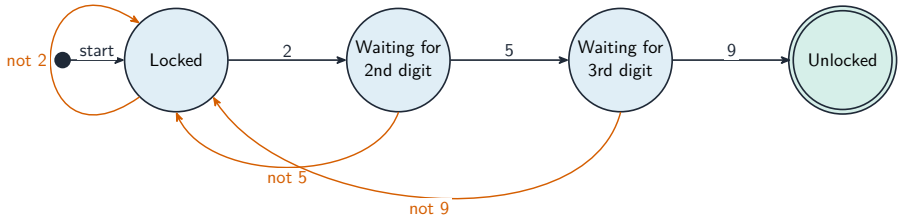
Main at the top; ReadData, IsValid and Report in a row beneath it, left to right in calling order. On the ReadData link an upward data couple `Count` (a BYREF parameter comes back). On the IsValid link a downward data couple `Value` and an upward control couple (the BOOLEAN result), with a curved iteration arrow across that link because it is called for each value. On the Report link two downward data couples, `Total` and `Count`. Reading the other way, a function is any module that returns a value — its header needs `RETURNS` and the returned type.

State-transition diagram

A **state-transition diagram** 状态转换图 shows the **states** 状态 a system can be in and the **events** that move it between them — good for vending machines, traffic lights, user interfaces. **State-transition diagrams** are used to document the behaviour of an algorithm or system. Each state is a circle; each transition is an arrow labelled with the event.

```
   coin inserted                item selected
[Idle] ---------------→ [Awaiting selection] -----------→ [Dispensing]
```

It makes missing transitions easy to spot ("what if a second coin is inserted while awaiting selection?").



A state-transition diagram for a door lock with code 259

Reading and drawing one. Each transition is labelled *input / output* (or *condition / action*): what happened, then what the system does as it changes state. A question gives a table of *current state, input, output, next state* and asks for the diagram, or the reverse — every row of the table is exactly one arrow. Check that every state has

an arrow leaving it for every input that can occur, including the ones that leave the state unchanged (an arrow that loops back to the same state).

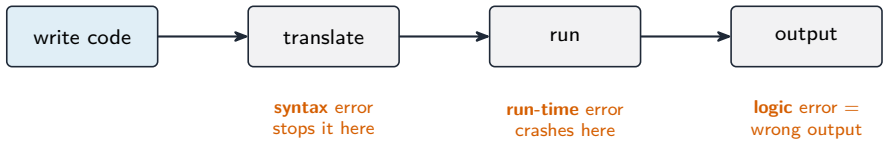
Worked example. A pump controller has states *pump off* and *pump on*. In *pump off*, the input *low level detected* produces the output *activate pump* and moves to *pump on*; in *pump on*, *normal level detected* produces *deactivate pump* and moves to *pump off*. Any other input leaves the state unchanged. Draw the table.

Current state	Input	Output	Next state
pump off	low level detected	activate pump	pump on
pump off	normal level detected	—	pump off
pump on	normal level detected	deactivate pump	pump off
pump on	low level detected	—	pump on

The two "no change" rows become loop arrows on the diagram; leaving them out loses the mark for completeness.

Errors

- **syntax error** 语法错误 — breaks the language's grammar (missing bracket, misspelled keyword). Caught at translation time; the program won't run until fixed.
- **run-time error** 运行时错误 — happens while running (divide by zero, file not found, array index out of range). The program crashes or raises an exception; fix by adding checks.
- **logic error** 逻辑错误 — the program runs but gives **wrong results** (using `+` for `-`, an off-by-one loop, conditions in the wrong order). The hardest to find; the only sign is wrong output, so use careful testing and tracing.



When each error shows up: syntax at translation, run-time during the run, logic in the output

Exposing and avoiding faults. Faults are *exposed* by testing against a test plan, by a dry run or trace table, by a walkthrough with colleagues, and by the IDE's debugger (breakpoints, single stepping, watching variables). They are *avoided* by designing before coding (structure chart, pseudocode), by modular code with meaningful identifiers and comments, by **validation** of every input, by handling exceptions rather than letting a run-time error crash the program, and by the IDE's dynamic syntax checks as you type.

Worked example. State the type of error in each case and how it shows itself. (a) `Result <- STR_TO_NUM(x) / STR_TO_NUM(y)` is run with `y = "0"`. (b) The same line is run with `x = "12a"`. (c) A loop written as `FOR i <- 1 TO 9` processes a ten-element array. (d) `OUTPUT "Total: " Total` is missing a comma.

(a) **Run-time error** — division by zero; the program crashes when this line is executed with that data. (b) **Run-time error** — the string cannot be converted to a number. (c) **Logic error** — the program runs but the tenth element is never processed, so the output is wrong. (d) **Syntax error** — the statement breaks the language's rules and is reported by the translator before the program runs.

Worked example. Correct the errors in this pseudocode, which should output the average of ten marks.

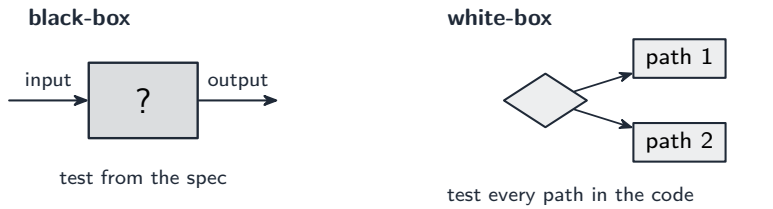
```
Total <- 0
FOR i <- 1 TO 10
    INPUT Mark
    Total <- Total + Mark
NEXT i
Average <- Total / 9
OUTPUT "Average" Average
```

The division should be by 10, not 9 (a logic error); the output line needs a comma or an `&` between the string and the value (a syntax error); and `Average` is never declared as REAL (a syntax or run-time error, depending on the language). Say which line and what the corrected line is: `Average <- Total / 10`.

Testing methods

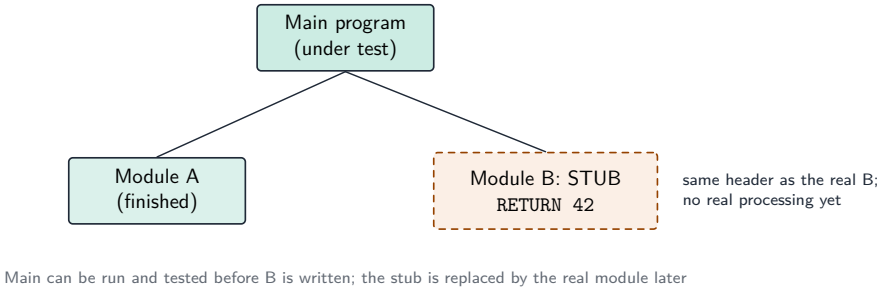
- **dry run** 手工跟踪 — trace the code on paper, writing each variable's value in a table.
- **walkthrough** 走查 — a team review of the code.
- **white-box testing** 白盒测试 — designed from the code's internal structure, covering every statement, branch and loop.
- **black-box testing** 黑盒测试 — designed from the specification only: feed inputs, check outputs.
- **integration testing** 集成测试 — combine modules and test the interfaces between them.
- **alpha testing** α 测试 — by the developers/in-house before release; **beta testing** β 测试 — by a limited group of real users in their own environment.

- **acceptance testing** 验收测试 — by the customer, to decide if the product is fit for purpose.
- **stub** 桩 — a placeholder for a module that does not exist yet, so the structure can be tested top-down.



Black-box tests the specification; white-box tests the code paths

Which method, when. A **dry run** and a **walkthrough** need no computer — the dry run is you, tracing the algorithm with a **trace table** 跟踪表; the walkthrough is a meeting in which the author explains the code line by line and colleagues look for faults, so it also spreads knowledge of the code through the team and checks it against the design. **White-box** tests are written by someone who can see the code and aims to exercise every path; **black-box** tests are written from the specification and check only inputs against expected outputs, so a user or a separate tester can do them. **Integration** testing follows module testing: modules that pass alone can still fail when the data passed between them is the wrong type or in the wrong order. **Alpha** testing is in-house; **beta** testing gives a release candidate to a sample of real users, who report faults from real use; **acceptance** testing is the customer checking the finished product against the requirements before paying for it. A **stub** lets top-down testing start before every module exists.



A stub stands in for a module that is not written yet, so the modules above it can be tested now

Worked example. After the program passed its in-house tests it was given to a group of users to try before release. Name this type of testing, and state what happens next.

Beta testing — real users in their own environment, reporting faults the developers did not find. The faults are corrected, then the customer carries out **acceptance testing** against the requirements and the program is released; faults found in live use are then handled by corrective maintenance.

Worked example. Give three benefits of testing a program by walkthrough.

Errors are found by people who did not write the code and so read it without assumptions; the logic is checked against the design and specification, not only against test data; several people learn how the code works, which helps later maintenance; and no test data or working computer is needed, so it can be done early.

Test strategy and test plan

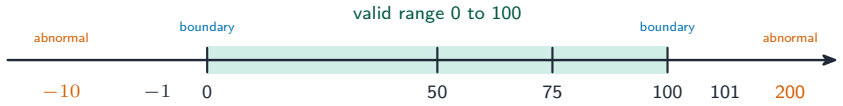
A **test strategy** 测试策略 is the **high-level approach** — which kinds of testing, who does them, when, and the criteria to move on. A **test plan** 测试计划 is the **detailed list of tests** — each with input data, expected output, and a column for the actual output.

What each contains. A *test strategy* states which testing methods will be used at which stage (module testing by the programmer, then integration, alpha, beta, acceptance), who is responsible for each, what test data is required, and the criteria for passing to the next stage. A *test plan* lists the individual tests: for each, the module or feature under test, the input data, the **reason** the data was chosen (normal, abnormal, extreme, boundary), the **expected** result, a space for the **actual** result, and what to do if they differ. The plan is written at the **design** stage, from the specification, so that it tests what the program *should* do rather than what it happens to do.

Choosing test data

For each field or condition, include three kinds:

- **normal data** 正常数据 — typical values inside the valid range (for marks 0–100: `50`, `75`).
- **abnormal data** 异常数据 — values that should be rejected (`-10`, `200`, `"abc"`).
- **extreme data** 极端数据 — the largest and smallest values still **accepted** (`0` and `100`).
- **boundary data** 边界数据 — values at the edges, where off-by-one errors hide (each accepted extreme and the rejected value just outside it: `0`/`-1`, `100`/`101`).



normal (50, 75) inside; extremes (0, 100) the accepted edges; abnormal (−1, 101, −10, 200) rejected

Test data for a 0–100 field: normal inside, extremes at the boundaries, abnormal outside

Worked example. A field accepts an exam mark from 0 to 100. Give test data of each kind with its expected result. **Normal**: `50` - accepted, a typical value inside the range. **Abnormal**: `-10`, `200`, `"abc"` - all rejected, being out of range or the wrong data type. **Extreme**: `0` and `100` - the largest and smallest values that are still **accepted**. **Boundary**: the pairs straddling each edge - `-1` rejected alongside `0` accepted, and `100` accepted alongside `101` rejected. Every value must carry its **expected result**, or the test plan proves nothing. Extreme and boundary are the pair most often confused: an extreme value sits **inside** and is accepted, while a boundary test is always a **pair** either side of the edge - which is exactly where off-by-one errors hide.

Worked example. A component passes if its weight, measured to the nearest gram, is within 3 g of the target of 50 g, i.e. from 47 g to 53 g inclusive. Draw up the test-plan rows for the check.

Test data	Type	Reason	Expected result
50	normal	a typical value well inside the range	accepted
47, 53	extreme (boundary)	the smallest and largest values that must still be accepted	accepted
46, 54	boundary	the values just outside the range, where an off-by-one error would accept them	rejected
20, 90	abnormal	values far outside the range	rejected
“abc”, −5	abnormal	the wrong type, a negative weight	rejected

Each row must say **why** the value was chosen and **what should happen**; a bare list of numbers earns nothing.

Maintenance

Most of a program’s lifetime cost is in maintenance. Three kinds:

Three kinds of maintenance: perfective, adaptive and corrective

- **perfective maintenance** 完善性维护 — improving performance or features even though it works (a faster query, a new option).
- **adaptive maintenance** 适应性维护 — keeping it working in a changing environment (a new OS, a new API, a legal change).
- **corrective maintenance** 纠正性维护 — fixing bugs found in use.

A program may need all three throughout its life.

Why each is needed — the reasons the mark scheme lists. *Corrective*: a fault is reported by a user after release, or an incorrect output is noticed in particular circumstances that testing did not cover. *Adaptive*: the operating system, hardware or browser is upgraded; a law or company rule changes (tax rates, data-protection requirements); the program must work with a new external system or file format. *Perfective*: users ask for extra features or a better interface; the program is made faster or made to use less memory; the code is tidied to make future changes easier.

Worked example. (a) A released program outputs a wrong value under certain circumstances. (b) The hardware that runs a program is replaced. (c) Customers ask for the coffee-shop loyalty program to send a message on a customer’s birthday. Name the maintenance type in each case.

(a) **Corrective** — a fault in the delivered program is being fixed. (b) **Adaptive** — the program is changed to run in its new environment. (c) **Perfective** — a feature is added to a program that already works.

Amending an existing program

When asked to add a feature or fix a bug:

1. **read the existing code** until you understand the algorithm and data flow.
2. **find where the change goes** — which subroutine, which lines.
3. **make the change as small as possible** — don’t rewrite working code.

4. **update related parts** — every caller of a changed parameter list, every routine using a changed data structure.
5. **test** the new behaviour **and** the old (**regression testing** 回归测试 — check you broke nothing).
6. **document** the change.

Clear comments, meaningful names, decomposed subroutines and a structure chart make a program much easier to amend — which is why the design tools matter even after the first release.

Analysing a program you did not write. Start from the identifier table and the module headers: they tell you what each module receives and returns before you read a line of its body. Then trace the algorithm with a trace table for one small input, noting where each output value comes from. Only then decide where the enhancement goes — usually a new module called from the existing one, so the working code is disturbed as little as possible — and write the pseudocode for the change and the test data that proves it.

Definitions the examiner accepts

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

Term	Definition
development life cycle	the sequence of stages, from analysis to maintenance, followed to produce and support a program
waterfall model	a life cycle in which the stages are carried out in a fixed order, each completed before the next begins
iterative model	a life cycle in which a working version is produced and then repeatedly refined until it is complete
rapid application development	a life cycle that builds prototypes quickly, refining them with user feedback until they are accepted
structure chart	a diagram that shows how a program is decomposed into modules, the order in which they are called and the parameters passed between them
state-transition diagram	a diagram that shows the states a system can be in and the inputs that cause it to move between them
syntax error	an error in the way a statement is written, so it breaks the rules of the language and cannot be translated
logic error	an error in the algorithm, so the program runs but produces the wrong result
run-time error	an error that occurs while the program is running, such as division by zero, and stops it

Term	Definition
dry run	working through the algorithm by hand, recording the values of the variables in a trace table
walkthrough	a review in which the author steps through the code with colleagues who look for errors
stub	a placeholder module with the correct header that returns a fixed value, used so the modules that call it can be tested
test plan	a list of the tests to be carried out, each with its test data, the reason for the data and the expected result
boundary data	values at each edge of the valid range, both the last value accepted and the first value rejected
corrective / adaptive / perfective maintenance	fixing faults found in use / changing the program to suit a changed environment / improving a program that already works

Exam tips

- Compare development models (waterfall, iterative, RAD) by **principle, benefit, drawback**, and know the five stages of the **program development life cycle** and what each produces.
- Distinguish **syntax, logic and run-time** errors by *when* each shows itself: at translation, in the output, during the run.
- Choose **test data** of every kind — normal, abnormal, extreme and boundary — and give each value with its reason and expected result.
- Distinguish the types of **maintenance** (corrective, adaptive, perfective) by *why* the change is being made.
- On a structure chart, name every symbol: box, calling line, data couple, control couple, selection diamond, iteration arrow. Reading module headers off a chart, remember a function has `RETURNS`.

Common mistakes

- Describing a life cycle stage by its name only ("in the design stage the program is designed"). Say what is produced: structure chart, pseudocode, test plan.
- Calling a wrong output a "run-time error". If the program runs to the end, it is a logic error.
- Giving boundary data as just the extremes. The mark needs the values on **both** sides of the edge.

- Treating alpha and beta testing as the same. Alpha is in-house by the developers; beta is by real users outside.
- Confusing adaptive and perfective maintenance. Adaptive responds to a change *outside* the program; perfective improves a program nobody had to change.
- Drawing a structure chart with the modules in any order. They read left to right in the order they are called, and each parameter needs its arrow.