9 Algorithm Design and Problem-solving

Refer to Pseudocode Guide **www.cambridgeinternational.org/support**

9.1 Computational Thinking Skills

Candidates should be able to:	Notes and guidance
Show an understanding of abstraction	Need for and benefits of using abstraction Describe the purpose of abstraction Produce an abstract model of a system by only including essential details
Describe and use decomposition	Break down problems into sub-problems leading to the concept of a program module (procedure / function)

9.2 Algorithms

Candidates should be able to:	Notes and guidance
Show understanding that an algorithm is a solution to a problem expressed as a sequence of defined steps	
Use suitable identifier names for the representation of data used by a problem and represent these using an identifier table	
Write pseudocode that contains input, process and output	
Write pseudocode using the three basic constructs of sequence, selection and iteration (repetition)	
Document a simple algorithm using a structured English description, a flowchart or pseudocode	
Write pseudocode from: • a structured English description • a flowchart	
Draw a flowchart from: • a structured English description • pseudocode	

9.2 Algorithms continued

Describe and use the process of stepwise refinement to express an algorithm to a level of detail from which the task may be programmed

Use logic statements to define parts of an algorithm solution

Computational Thinking Skills

Abstraction

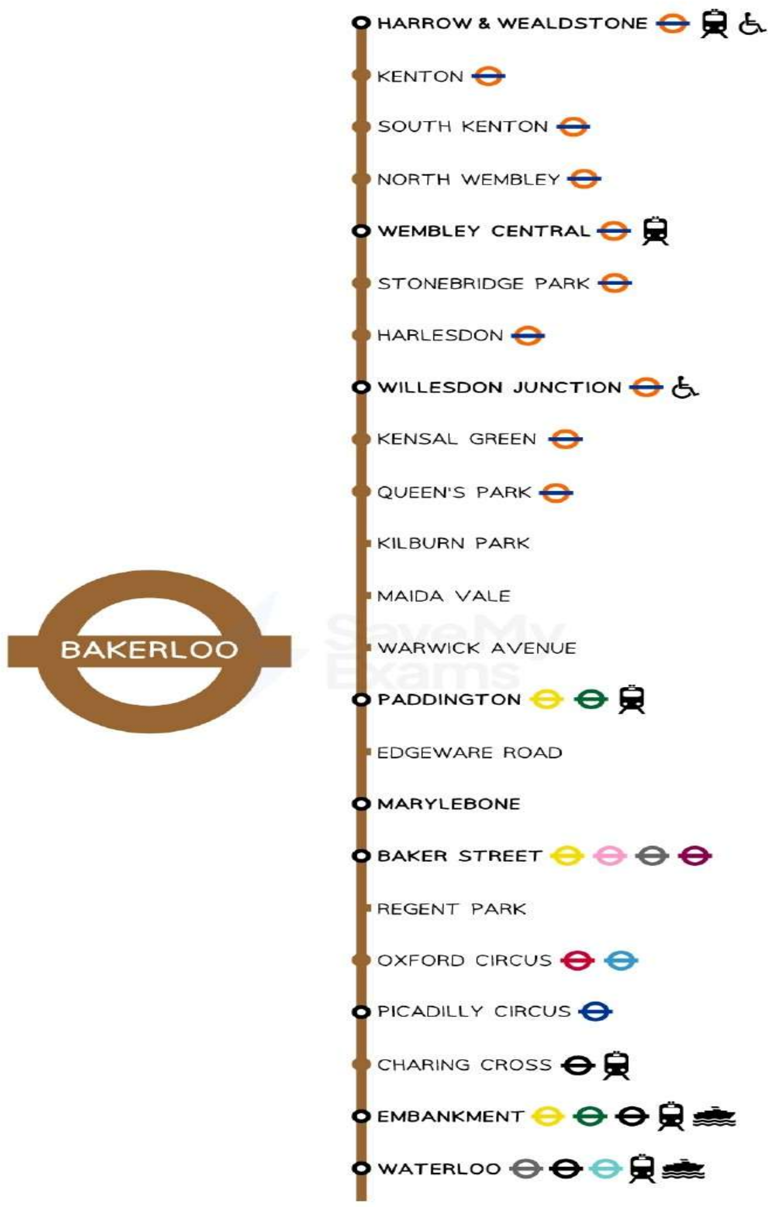
What is abstraction?

- Abstraction is the process of **removing unnecessary details** from a problem to **focus on the important features** for implementing a solution
- Examples of abstraction include modelling a:
  - **real-life object**
  - **environment**
  - **action**
  - **sequence of actions**
  - **concept**
- Implementations of these include:
  - **a computer game that simulates playing a sport**
  - **a simulator such as a car or flight simulator,**
  - **a map of a bus or train route in a city**
- When creating a program, developers must **identify important features** that will contribute to solving the problem or have a role to play in the solution

Computer games

- Computer games use a large amount of abstraction, **removing the elements that a user does not need to consider** in order to enjoy playing the game
- When using abstraction in computer games which are designed to simulate real life, the aim is to make the game realistic and visually appealing whilst keeping the game fun to play
- In a game that simulates a sport, it is important to the user that visually they recognise the environment and when they perform an action, they see a response
- However, users do not need to know the complex algorithms used to control the non player characters (NPCs)

Train map

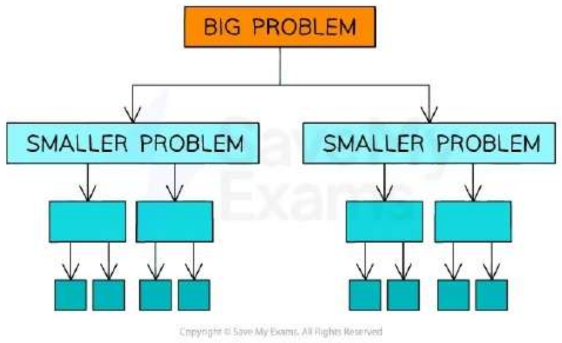


- Another specific example of abstraction would be the London underground train route map; travellers **do not need to know the geographical layout** of the routes, only that getting on at stop A will eventually transport you to stop B

Decomposition

What is decomposition?

- Decomposition is **breaking down a big problem** into smaller problems so that they can be **solved independently**
- Programmers use decomposition to:
    - **Break** problems down
    - **Identify** the steps, parts or processes involved in a problem
    - **Identify** reusable components
    - **Split** tasks between programmers
- In the case of slow appointment booking, you could **decompose** the problem into issues such as server limitations during peak hours, inefficient backend algorithms, and user interface delays



Process of decomposition to break problems down

Using abstraction to design a solution

- Before we start to break problems down, it is often useful to **apply the rules of abstraction** to the problem
- Applying abstraction will remove **non-essential elements** and that programmers can **focus on critical aspects** for problem-solving

- When addressing a slow booking system, a programmer could ignore elements like the system's colour scheme or graphics and focus on critical performance metrics such as server response time and database query efficiency

Decomposing slow response times problem

1. **Big problem**: Slow response times during the online appointment booking process
2. **Decompose** into sub-problems:
    - Server limitations causing **bottlenecks** during peak hours
    - Inefficient algorithms leading to **delayed confirmation** screens
    - Poor user interface contributing to an overall **bad user experience**
3. **Prioritise** sub-problems:
    1. Address **server limitations**, as solving this could have a broad impact on system performance
    2. Look into **optimising algorithms** to speed up the booking and confirmation process
    3. Lastly, make **user interface improvements** to enhance user experience, possibly mitigating some of the frustration caused by slow response times

Algorithm basics

Definition of algorithm

What is an algorithm?

- An algorithm is a **solution to a problem** expressed as a **sequence of defined steps**
- Methods of writing an algorithm before attempting to program a solution include:
  - **Structured English**
  - **Pseudocode**
  - **Flowcharts**

Structured English

- Structured English is a **human-readable method** for describing algorithms using a combination of **natural English language** and **programming logic**
  - It uses clear English phrases to describe each step
  - Logic structures like **IF...THEN**, **REPEAT**, and **WHILE** may appear, but without strict syntax rules
  - Often used in the early planning stages before converting to pseudocode

```
Ask the user to enter their age
If the age is 18 or over
→ Display a welcome message
Otherwise
→ Display an access denied message
```

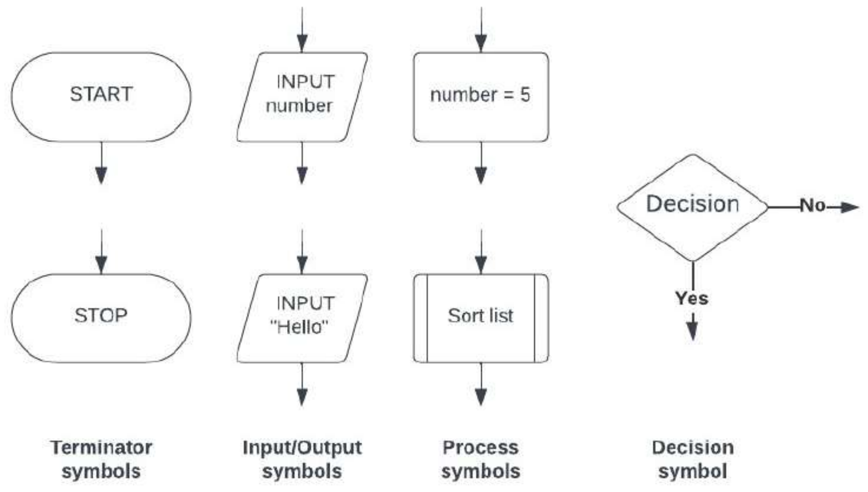
Pseudocode

- Pseudocode is a **precise, structured, and language-independent way** of describing an algorithm that resembles a programming language
- It **follows specific exam-board-defined syntax**
  - It includes formal elements like IF, THEN, ELSE, WHILE, REPEAT, DECLARE, and ← for assignment
  - Students must follow **CIE's pseudocode format** in exams

```
INPUT Age
IF Age >= 18 THEN
   OUTPUT "Welcome to the site"
ELSE
   OUTPUT "Sorry, this site is for users 18 and over"
ENDIF
```

Flowcharts

- Flowcharts are a **visual tool** that uses **shapes to represent different functions** to **describe an algorithm**
- Used to **visualise the flow of control** in a system
- Standard symbols include:
  - **Oval** for Start/End
  - **Parallelogram** for Input/Output
  - **Rectangle** for Processes
  - **Diamond** for Decisions
- Arrows show the **sequence of operations**



Identifier tables

What is an identifier table?

- An identifier table is used when writing **pseudocode** to keep track of all the **identifier names** used in an algorithm
- An **identifier** is the **name given to a variable, constant, array, procedure**, or any other named element in the pseudocode

Why use an identifier table?

- It helps you stay **organised** when designing an algorithm
- Ensures **consistent naming**
- Makes it easier to understand what each identifier stores or does

- Useful in **exam questions** when you are asked to declare variables clearly

Identifier naming rules

- Must start with a **letter** (A–Z or a–z)
- Can include **letters**, **digits (0–9)**, and **underscores (_)**
- **Accented characters** and **symbols** are not allowed
- Identifiers are **case sensitive** (e.g. `Total` and `total` are **NOT** treated the same)

Identifier	**Description**
`StudentName`	Stores a student's full name
`TestScore`	Holds a test score value
`MAX_SCORE`	Maximum score allowed
`FormList`	Stores names in a form group

Pseudocode

Input, process, output

What is an input?

- An input is **data or information being entered/taken into a program** before it is processed in the algorithm
- An input can come from a variety of sources, such as:
  - **User** - keyboard, mouse, controller, microphone
  - **Sensors** - temperature, pressure, movement
- Values are input using the INPUT command

```
INPUT <identifier>
```

What is a process?

- A process is **a doing action performed in the algorithm** that transforms inputs into the desired output. The central processing unit (**CPU**) executes the instructions that define the process
- An example would be:
  - **Comparing two numbers**
  - **Calculating an average**

What is an output?

- An output is **the result of the processing in an algorithm** and usually the way a user can see if an algorithm works as intended
- An output can take various forms, such as:
  - **Numbers** - result of calculations
  - **Text**
  - **Images**
  - **Actions** - triggering events
- Values are output using the OUTPUT command

```
OUTPUT <value(s)>
```

More than one value can be output in the same command when separated by commas

```
OUTPUT "First name: ", Fname, "Surname: ", Sname
```

Example 1 - Area of a shape

- A user wants to write a program to calculate the area of a shape

Input	Process	Output
▪ Length ▪ Width	▪ Length X width	▪ Area

```
// Calculate the area of a rectangle

INPUT Length
INPUT Width

Area ← Length * Width

OUTPUT "The area is ", Area
```

Example 2 – Average test score

- A teacher wants to calculate the average mark achieved on a test amongst students in a class
- The teacher needs to enter how many students in the class and for each students a score out of 50

Input	Process	Output
▪ Number of students ▪ Score per student	▪ TotalScore = TotalScore + score per student ▪ Average = TotalScore / Number of students	▪ Average mark

```
// Calculate the average test score for a class

DECLARE TotalScore : INTEGER
DECLARE Score : INTEGER
DECLARE NumberOfStudents : INTEGER
DECLARE Average : REAL

TotalScore ← 0

INPUT NumberOfStudents

FOR StudentIndex ← 1 TO NumberOfStudents
   OUTPUT "Enter score for student ", StudentIndex
   INPUT Score
   TotalScore ← TotalScore + Score
NEXT StudentIndex

Average ← TotalScore / NumberOfStudents

OUTPUT "The average score is ", Average
```

Programming constructs

What is sequence?

- Sequence refers to lines of code which are run **one line at a time**
- The lines of code are run in the **order** that they written from the first line of code to the last line of code
- Sequence is **crucial to the flow** of a program, any instructions out of sequence can lead to **unexpected behaviour or errors**

Example

- A simple program to ask a user to input two numbers, number two is subtracted from number one and the result is outputted

Line	Pseudocode
01	INPUT NumberOne
02	INPUT NumberTwo
03	Result ← NumberOne - NumberTwo
04	OUTPUT "The result is ", Result

What is selection?

- Selection is when the **flow of a program is changed,** depending on a **set of conditions**
- The outcome of this condition will then determine **which lines or block of code is run next**
- Selection is used for **validation**, **calculation** and making sense of a **user's choices**
- There are two ways to write selection statements:
  - **if**... **then**... **else**...
  - **case**...

Structure	IF...THEN...ELSE example	CASE statement example
Purpose	Used for **binary decisions** (true/false)	Used for **multiple specific options**
Scenario	Check if a user is old enough to vote	Perform an action based on the direction entered

Pseudocode example	INPUT Age
	IF Age >= 18 THEN
	  OUTPUT "You can vote"
	ELSE
	  OUTPUT "You cannot vote"
	ENDIF
		INPUT Direction
		CASE OF Direction
		  "N" : OUTPUT "North"
		  "S" : OUTPUT "South"
		  "E" : OUTPUT "East"
		  "W" : OUTPUT "West"
		  OTHERWISE : OUTPUT "Invalid direction"
		ENDCASE

What is iteration?

- Iteration means **repeating a line or block of code** using a **loop**
- It allows a program to perform a task **multiple times** until a condition is met

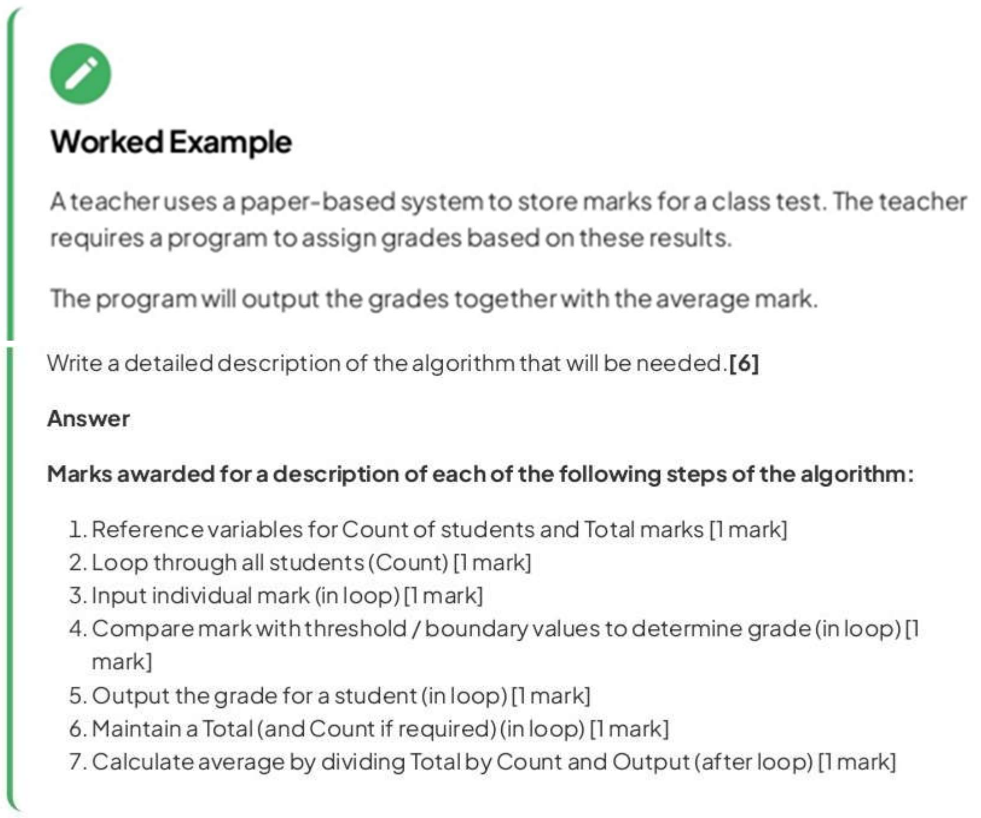
Types of iteration

Type	Description	Pseudocode Format
Count-controlled	Repeats a fixed number of times	FOR ... TO ... NEXT
Post-condition	Repeats **at least once**, checks the condition **after** running the block	REPEAT ... UNTIL
Pre-condition	Checks the condition **before** running the block	WHILE ... ENDWHILE

```
// Count-controlled
FOR i ← 1 TO 5
  OUTPUT i
NEXT i

// Post-condition
REPEAT
  INPUT Password
UNTIL Password = "Secret123"

// Pre-condition
WHILE Score < 100
  Score ← Score + 10
ENDWHILE
```



Worked Example

A teacher uses a paper-based system to store marks for a class test. The teacher requires a program to assign grades based on these results.

The program will output the grades together with the average mark.

Write a detailed description of the algorithm that will be needed.**[6]**

Answer

Marks awarded for a description of each of the following steps of the algorithm:

1. Reference variables for Count of students and Total marks [1 mark]
2. Loop through all students (Count) [1 mark]
3. Input individual mark (in loop) [1 mark]
4. Compare mark with threshold / boundary values to determine grade (in loop) [1 mark]
5. Output the grade for a student (in loop) [1 mark]
6. Maintain a Total (and Count if required) (in loop) [1 mark]
7. Calculate average by dividing Total by Count and Output (after loop) [1 mark]

Translation skills

Structured English/Flowchart to Pseudocode

Example – Structured English

A customer is buying an item. If the customer has a discount code, they receive 10% off the price. Otherwise, they pay the full amount. The program should ask for the item price and whether they have a discount code, then calculate and display the final price.

Step 1 – Structured English

1. Ask the user to enter the price of the item
2. Ask the user if they have a discount code
3. If they do have a discount code
   → Calculate 10% off the price
   → Subtract the discount from the original price
4. Otherwise
   → The price stays the same
5. Output the final price

Step 2 – Identifier table

Identifier	Description
ItemPrice	Original price of the item
HasDiscount	TRUE if user has a discount code
DiscountAmount	Amount taken off the original price
FinalPrice	Price after discount is applied

Step 3 – Pseudocode

```
// Ask for item price
INPUT ItemPrice

// Ask if user has a discount code
INPUT HasDiscount

IF HasDiscount = TRUE THEN
   DiscountAmount ← ItemPrice * 0.10
   FinalPrice ← ItemPrice - DiscountAmount
ELSE
```

```
    FinalPrice ← ItemPrice
ENDIF

// Output the final price
OUTPUT "The final price is ", FinalPrice
```

Structured English/Pseudocode to Flowchart

Example – Pseudocode

```
INPUT Number

IF Number MOD 2 = 0 THEN
    OUTPUT "Even"
ELSE
    OUTPUT "Odd"
ENDIF
```

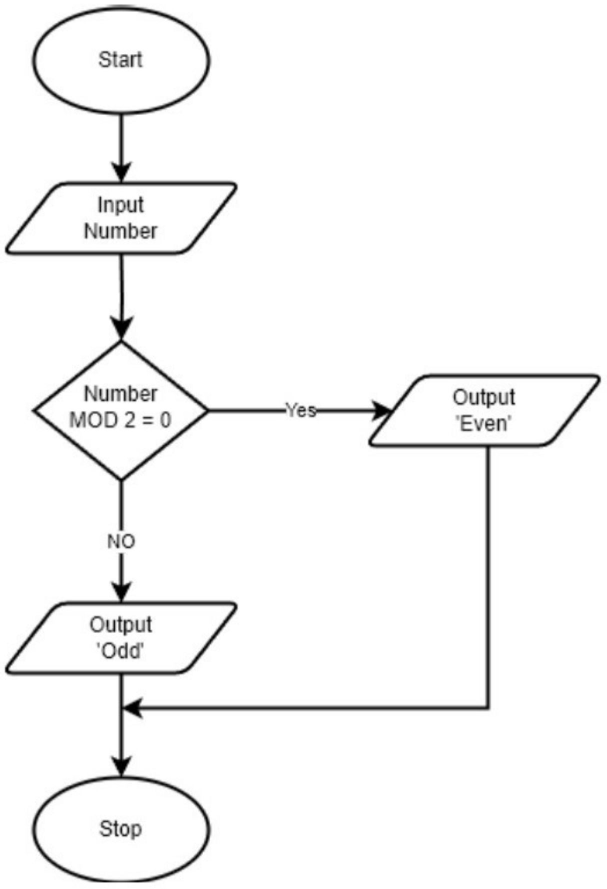
Step 1 – Identifier table

Identifier	Description
Number	The number entered by the user

Step 2 – Flowchart structure

Pseudocode statement	Flowchart symbol	Purpose
INPUT Number	Parallelogram (Input/Output)	User enters a number
IF Number MOD 2 = 0	Diamond (Decision)	Checks if the number is divisible by 2
OUTPUT "Even"	Parallelogram (Input/Output)	Displays message if the condition is true
OUTPUT "Odd"	Parallelogram (Input/Output)	Displays message if the condition is false
Start/End	Oval	Denotes beginning and end of the process
Arrows	Lines with arrows	Indicate flow of control

Step 4 – Flowchart



Refinement & logic

Stepwise refinement

What is stepwise refinement?

- Stepwise refinement is the process of **breaking down a complex problem** into smaller, more manageable sub-problems in a logical order
- Each sub-problem is **refined step by step** until it is simple enough to be solved with a single subroutine or module
- This method ensures that the overall problem can be solved by addressing each part individually, in a **structured and efficient** way

Relationship to decomposition and top-down design

- **Decomposition** is the general concept of breaking a problem down into smaller parts
- **Top-down design** is the strategy used to perform decomposition
- **Stepwise refinement** is the process used in top-down design to **gradually refine** each major task into simpler sub-tasks
- In other words, **stepwise refinement is how top-down design is implemented**

Benefits of stepwise refinement

- Helps developers **understand and organise** the structure of a program
- Makes **testing and debugging easier** through **unit testing** of individual subroutines
- Encourages **code reuse** by breaking tasks into reusable components
- Supports **collaborative development**, as tasks can be divided between team members
- Each subroutine should:
  - **Be clear and focused** on a single task
  - **Be simple** enough to implement directly
  - **Not need** further breakdown

Example: Calculating student grades

- Here's how stepwise refinement could be applied to a program designed to calculate student grades for a teacher's classes:

Top-level task:

- Calculate grades for all students in all classes

Stepwise refinement:

- **Step 1 – Calculate the grade for each assessment**

    - For each question:
        - Mark the question
        - Store the mark
    - Sum the marks for all questions in the assessment
- **Step 2 – Calculate the average grade for each student**
    - Add together grades from all assessments
    - Divide by the number of assessments
    - Store the average
- **Step 3 – Repeat for each class**
    - For every student in the class:
        - Perform Steps 1 and 2
- This structured breakdown allows each task to be turned into a subroutine, simplifying the design, implementation, and testing of the overall program