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assignment :01

Data structure and algorithm



**roll no: 14670**

**name :urooj mustafa**

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**CHAPTER NO:01**

**EXERCISE 1.1**

***Question#1***

Describe your own real-world example that requires sorting. Describe one that requires ûnding the shortest distance between two points.

***Answer:***

**Sorting** is the process of arranging data or elements in a specific order, typically either ascending or descending. This can apply to numbers, strings, or other comparable data types. Sorting is commonly used to improve search efficiency, data organization, and user experience.

For example, sorting an array of numbers in ascending order would rearrange [5, 2, 8, 1] to become [1, 2, 5, 8].

Different sorting algorithms (such as Bubble Sort, Quick Sort, Merge Sort) are designed with varying levels of efficiency depending on the data set's size and structure.

 Sorting **example:** Organizing books in a library by title, author, or genre. This helps users quickly find the book they need.

 Shortest **distance example:** Finding the quickest route between two cities on a map, like navigating from your home to a specific destination using GPS.

***Sorting Example:***

* **Task:** Organizing online product listings by price.
* **Example:** When shopping online, users might want to see products sorted from the cheapest to the most expensive. For instance, if a user is browsing smartphones, they can sort the listings by price to compare the options within their budget.

***Shortest Distance Example:***

* **Task:** Finding the quickest route between two locations.
* **Example:** A navigation app like Google Maps needs to find the shortest distance between two points, such as from your home to your workplace, to provide the fastest driving route considering traffic conditions.

**QUESTION : # 02**

Q2.otherthan speed ,what other meaures of efficiency might you need to consider in a real-world settings?

**ANSWER:**

In a real-world setting, other than speed, several measures of efficiency might need to be considered:

1. **Resource Utilization**: Efficient use of resources such as materials, energy, and human labor. For example, minimizing waste and optimizing the use of raw materials in manufacturing processes.

2. **Cost Efficiency**: Balancing the cost with the benefits. This includes minimizing operational costs, transportation expenses, and any other financial expenditures while maintaining quality.

3**. Reliability and Accuracy**: Ensuring the process consistently produces correct and reliable results. This is crucial in contexts such as data processing, manufacturing, and service delivery.

4. **Scalability**: The ability of a process or system to handle increased workload or expand in capacity without significant loss of efficiency or performance.

5. **Sustainability**: Minimizing the environmental impact and ensuring that processes are environmentally friendly. This includes reducing carbon footprints, managing waste, and conserving energy.

6. **Flexibility:** The ability to adapt to changes or unforeseen circumstances without significant downtime or inefficiency. This is important in dynamic environments where requirements may change frequently.

7. **Customer Satisfaction:** Ensuring that the process meets or exceeds customer expectations in terms of quality, delivery time, and overall experience.

8. **Compliance and Safety:** Adhering to regulatory requirements and ensuring the safety of employees and customers. Efficient processes must also ensure compliance with laws and standards.

**QUESTION : # 03**

Q3.select a data structure that you have seen,and discuss its strength and limitations.

**ANSWER:**

### data Structure: **Array**

#### Strengths:

1. **Fast Random Access (O (1)):**
   * **Explanation:** Arrays allow constant time access to elements using an index. This makes retrieving any element very fast, regardless of the array's size.
   * **Example:** In a game, if you need to access the position of the 10th player from an array of player positions, you can do so instantly using the index, e.g., players [9].
2. **Efficient Iteration:**
   * **Explanation:** Since arrays store elements contiguously in memory, iterating over the array is efficient. It leverages CPU cache locality, meaning fewer cache misses, which speeds up processing.
   * **Example:** When calculating the total score from an array of game scores, looping through the array can be done quickly due to the array's memory layout.
3. **Simple to Implement:**
   * **Explanation:** Arrays are simple to understand and implement, and they work well for static lists or fixed-size datasets where the number of elements does not change.
   * **Example:** In a program that tracks the days of the week, an array of fixed size (7 elements) can be used since the number of days never changes.

#### Limitations:

1. **Fixed Size:**
   * **Explanation:** Arrays have a fixed size once they are created. You need to know the number of elements in advance, or you risk either running out of space or wasting memory.
   * **Example:** If you create an array to store 100 items but only use 50, the remaining 50 slots will still consume memory unnecessarily.
2. **Costly Insertions and Deletions (O(n)):**
   * **Explanation:** Inserting or deleting elements from an array is inefficient because it requires shifting elements to maintain order. In the worst case (inserting at the start), all elements must be shifted.
   * **Example:** If you need to insert a new value at the beginning of an array of 1,000 items, you would have to shift all other items one position to the right, which takes time proportional to the number of elements (O(n)).
3. **Inefficient Memory Usage for Dynamic Data:**
   * **Explanation:** If an array needs to grow dynamically, you often need to create a new, larger array and copy over the elements, which is computationally expensive and can waste memory if the new size is overestimated.
   * **Example:** If you're building a dynamic list of users and you initially allocate an array with 10 slots but end up needing 100 slots, resizing the array each time it fills up can slow down performance.
4. **No Built-in Flexibility for Complex Structures:**
   * **Explanation:** Arrays store elements of the same type in contiguous memory. They are not ideal for complex data structures where relationships between elements need to be dynamic or flexible.
   * **Example:** Arrays are not suitable for representing complex hierarchies like family trees, where the number of children for each node is not fixed and varies between elements.

### Example Use Case:

An **array** is ideal for storing data where you know the size in advance, and fast access to elements is a priority. For instance, in a **calendar application**, you can use an array to store the names of the months ([January, February, March, ...]). This allows constant-time access to any month by its index, which is useful when generating reports or scheduling events for specific months.

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**QUESTION : # 04**

Q4.how are the shortest-pathand travelling-salesperson problems given above similar?how are they different.

**ANSWER:**

The Shortest Path Problem and the Traveling Salesperson Problem (TSP) are both fundamental problems in graph theory and optimization, but they have different objectives and constraints.

**Similarities:**

1. **Graph Representation**: Both problems are often represented using graphs, where nodes represent locations or points and edges represent the paths or connections between these nodes.

2. **Optimization**: Both problems involve finding an optimal solution, typically minimizing the distance, cost, or time.

**Differences:**

1**. Objective**:

**Shortest Path Problem:** The goal is to find the shortest path between two specific nodes (source and destination) in a graph.

**Traveling Salesperson Problem (TSP):** The goal is to find the shortest possible route that visits each node exactly once and returns to the starting node.

2. **Constraints:**

**Shortest Path Problem**: The path must go from the source to the destination, and intermediate nodes do not have to be visited.

**Traveling Salesperson Problem**: Every node must be visited exactly once before returning to the starting point.

3**. Solution Complexity**:

**Shortest Path Problem**: It can be solved efficiently using algorithms like Dijkstra's or Bellman-Ford, which are polynomial-time algorithms.

**Traveling Salesperson Problem**: It is an NP-hard problem, meaning there is no known polynomial-time algorithm to solve it. Solutions often require heuristic or approximation methods for large instances.

4**. Use Cases:**

**Shortest Path Problem**: Often used in routing and navigation applications where the interest is in finding the best way to travel between two points.

**Traveling Salesperson Problem:** Common in logistics and planning, where the goal is to minimize travel distance or time for a tour that must visit multiple locations.

Understanding these differences and similarities can help in choosing the right approach and algorithms for solving specific problems in real-world scenarios.

**QUESTION : # 05**

Q5.suggest a real-world problem in which only the best solution will do .then come up with one in which “approximately” the best solution is good enough.

**ANSWER:**

Real-World Problem Requiring the Best Solution

**Air Traffic Control Routing**

In air traffic control, ensuring the safest and most efficient routes for airplanes is critical. The shortest path problem can be applied here to determine the most optimal route for an aircraft from its origin to its destination while considering factors like weather conditions, air traffic, and fuel efficiency. Any deviation from the optimal route can lead to safety risks, increased fuel consumption, and potential delays. Thus, in this scenario, only the best solution will do to maintain safety and efficiency.

Real-World Problem Where an Approximate Solution is Good Enough

**Delivery Route Planning for E-commerce**

In the context of delivering packages for an e-commerce company, solving the Traveling Salesperson Problem (TSP) can help minimize the total travel distance or time for delivering packages. However, given the complexity and size of real-world delivery networks, finding the exact optimal solution may not be feasible within a reasonable time frame. Instead, an approximate solution that is close to the best can still provide significant cost and time savings. Algorithms like genetic algorithms, simulated annealing, or nearest neighbor heuristics can offer solutions that are good enough for practical purposes, balancing efficiency and computational effort.

**QUESTION : # 06**

Q6.describe a real-world problem in which sometime the entire input is available before you need to solve the problem, but other times the input is not entirely available in advance and arrives over time.

**ANSWER:**

Real-World Problem with Varying Input Availability

**Ride-Sharing Route Optimization**

In ride-sharing services like Uber or Lyft, optimizing the routes for drivers can face two different scenarios regarding input availability:

1. **Entire Input Available in Advance**: During peak hours or scheduled events (like airport runs or concerts), a large number of ride requests may be pre-booked. In these cases, the system has the entire set of ride requests in advance and can optimize the routes for drivers to maximize efficiency and minimize wait times. Advanced algorithms can be employed to batch these requests and plan optimal routes for multiple drivers, considering factors like traffic, pickup, and drop-off locations.

2**. Input Arrives Over Time**: In normal operating conditions, ride requests come in continuously and unpredictably. The system must handle real-time input and dynamically update routes for drivers as new requests arrive. This requires on-the-fly optimization where algorithms must quickly adapt to new data and re-optimize routes to balance driver availability, minimize passenger wait times, and ensure efficient ride completion.

**EXERCISE 1.2**

**QUESTION : # 01**

Q1. Give an example of an application that requires algorithmic content at the application level, and discuss the function of the algorithm involved.

**ANSWER:**

One example of an application that requires algorithmic content at the application level is a recommendation system used by streaming services like Netflix or Spotify.

**Application Overview**

A recommendation system suggests content (such as movies, TV shows, or music) to users based on their preferences and behaviors. These systems enhance user experience by helping users discover new content they are likely to enjoy, thereby increasing user engagement and satisfaction.

**Functions of the Algorithms Involved**

**1. Collaborative Filtering:**

**Function**: Identifies patterns in user behavior to recommend items that similar users have liked.

**Algorithm:** User-based collaborative filtering or item-based collaborative filtering. These algorithms compute similarities between users or items using techniques such as cosine similarity, Pearson correlation, or matrix factorization methods like Singular Value Decomposition (SVD).

**2. Content-Based Filtering:**

**Function**: Recommends items that are similar to those a user has shown interest in based on item attributes.

**Algorithm**: Uses machine learning algorithms such as Naive Bayes, decision trees, or neural networks to analyze item features and user profiles, and then predict which items a user might like.

3**. Hybrid Methods:**

Function: Combines collaborative filtering and content-based filtering to leverage the strengths of both approaches and mitigate their weaknesses.

Algorithm: Implements a combination of techniques, such as a weighted hybrid model that assigns different weights to recommendations from collaborative and content-based filters, or a switching hybrid model that chooses the best approach based on context.

4**. Matrix Factorization**:

**Function:** Decomposes the user-item interaction matrix into lower-dimensional matrices to uncover latent factors influencing user preferences.

**Algorithm**: Techniques like Singular Value Decomposition (SVD), Non-negative Matrix Factorization (NMF), or Alternating Least Squares (ALS) help in capturing the underlying structure of the data, making predictions more accurate.

**5. Deep Learning Models**:

**Function:** Captures complex patterns and non-linear relationships in the data, improving recommendation quality.

**Algorithm:** Utilizes deep neural networks, such as Convolutional Neural Networks (CNNs) or Recurrent Neural Networks (RNNs), to model intricate user-item interactions and content features.

6. **Association Rule Learning:**

**Function**: Identifies associations between items frequently co-considered or co-purchased.

**Algorithm**: Uses algorithms like Apriori or Eclat to discover frequent itemsets and generate association rules, which can be used to recommend items that are often bought or viewed together.

**Example Workflow**

1**. Data Collection**: The system collects data on user interactions, such as viewing history, ratings, search queries, and demographic information.

2. **Data Preprocessing**: Cleans and transforms the raw data into a suitable format for analysis, handling missing values and normalizing attributes.

3. **Feature Extraction**: Extracts relevant features from the data, such as user preferences, item attributes, and contextual information.

4. **Model Training:** Trains the chosen recommendation algorithms using the processed data and extracted features.

5. **Recommendation Generation:** The trained models generate recommendations for each user based on their profile and interaction history.

6. **Evaluation and Feedback**: The system evaluates the recommendations using metrics like precision, recall, and F1-score, and incorporates user feedback to continuously improve the models.

**QUESTION : # 02**

Q2.suppose that for inputs of size n on a particular computer ,insertion sort runs in steps and merge sort runs in 64nlogn steps.for which value of n does insertion sort beat merge sort?

**ANSWER:**

We are given:

- Insertion sort runs in ( 8n^2 ) steps.

- Merge sort runs in ( 64n log n ) steps.

We want to find when the running time of insertion sort is less than the running time of merge sort, i.e., when:

[8n^2 < 64n log n]

Divide both sides of the inequality by 8:

[n^2 < 8n log n]

Divide both sides by ( n ) (assuming ( n > 0 )):

[n < 8 log n]

This inequality needs to be solved numerically because of the logarithmic term. You can graph or check values of ( n ) to find the point where ( n ) is less than ( 8 log n ).

Numerical check:

Let's try some values of ( n ):

1. **For ( n = 16 ):**

* ( log 16 = 4 ) (base 2).
* -( 8 log 16 = 8 times 4 = 32 ).
* -( 16 < 32 ) is true.

2**. For ( n = 64 ):**

* ( log 64 = 6 ).
* ( 8 log 64 = 8 times 6 = 48 ).
* ( 64 < 48 ) is false.

Thus, the inequality holds true for ( n = 16 ) and smaller values of ( n ), but not for larger values. So, insertion sort beats merge sort for \( n <= 16 )

**QUESTION : # 03**

Q3. What is the smallest value of n such that an algorithm whose running time is 100n2 runs faster than an algorithm whose running time is 2 n on the same machine?

**ANSWER**:

We are given:

- One algorithm has a running time of ( 100n^2 ).

- Another algorithm has a running time of ( 2^n ).

We need to find the smallest ( n ) such that:

[100n^2 < 2^n]

This inequality can also be solved numerically by testing different values of ( n ):

1. For ( n = 10 ):

* ( 100n^2 = 100 times 10^2 = 100 times 100 = 10000 ).
* ( 2^n = 2^{10} = 1024 ).
* ( 10000 > 1024 ) is false.

2. For ( n = 15 ):

* ( 100n^2 = 100 times 15^2 = 100 times 225 = 22500 ).
* ( 2^n = 2^{15} = 32768 ).
* ( 22500 < 32768 ) is true.

Thus, the smallest value of n such that 100n^2 runs faster than 2^n is 15.

**EXERCISE 2.1**

exercises 2.1-1 Using Figure 2.2 as a model, illustrate the operation of I NSERTION-SORT on an array initially containing the sequence h31; 41; 59; 26; 41; 58i.

To illustrate the operation of **INSERTION-SORT** on the array ⟨31,41,59,26,41,58⟩, let’s walk through each step of the algorithm. The algorithm starts with the first element as a "sorted" section and then inserts each subsequent element into its correct position within this sorted section.

### i****nitial Array****:

⟨31,41,59,26,41,58⟩

### Step-by-Step Execution:

1. **Iteration 1**: j=2j
   * **Key**: 41
   * **Sorted Portion**: ⟨31⟩
   * **Comparison**: 41 ≥ 31 (no need to move)
   * **Result**: ⟨31,41,59,26,41,58⟩
2. **Iteration 2**: j=3j
   * **Key**: 59
   * **Sorted Portion**: ⟨31,41⟩
   * **Comparison**: 59 ≥ 41 (no need to move)
   * **Result**: ⟨31,41,59,26,41,58⟩
3. **Iteration 3**: j=4j
   * **Key**: 26
   * **Sorted Portion**: ⟨31,41,59⟩
   * **Comparison**: 26 < 59 (move 59 one position right)
   * **Comparison**: 26 < 41 (move 41 one position right)
   * **Comparison**: 26 < 31 (move 31 one position right)
   * **Result**: ⟨26,31,41,59,41,58⟩
4. **Iteration 4**: j=5j
   * **Key**: 41
   * **Sorted Portion**: ⟨26,31,41,59⟩
   * **Comparison**: 41 < 59 (move 59 one position right)
   * **Comparison**: 41 ≥ 41 (insert 41 in this position)
   * **Result**: ⟨26,31,41,41,59,58⟩
5. **Iteration 5**: j=6j
   * **Key**: 58
   * **Sorted Portion**: ⟨26,31,41,41,59⟩
   * **Comparison**: 58 < 59 (move 59 one position right)
   * **Comparison**: 58 > 41 (insert 58 in this position)
   * **Result**: ⟨26,31,41,41,58,59⟩

### ****Final Sorted Array****:

⟨26,31,41,41,58,59⟩

Each iteration moves the "key" element into the correct position within the sorted portion, resulting in a fully sorted array.

2.1-2 Consider the procedure SUM-ARRAY on the facing page. It computes the sum of the n numbers in array A[i:n]. State a loop invariant for this procedure, and use its initialization, maintenance, and termination properties to show that the SUMARRAY procedure returns the sum

Sum-Array(a,n)

* 1. Sum=0
  2. For i=1 to n
  3. Sum=sum + A[I]
  4. Return sum
* To analyze the **SUM-ARRAY** procedure and prove its correctness using a loop invariant, let’s go through the steps to state and verify an appropriate invariant for this procedure.
* The **SUM-ARRAY** procedure, given below, calculates the sum of nan elements in an array AAA:

Input:

def. SUM\_ARRAY (A, n):

sum = 0

for I in range(n): # Start from 0 and go up to n-1

sum += A[i]

return sum

# Example usage

A = [31, 41, 59, 26, 41, 58]

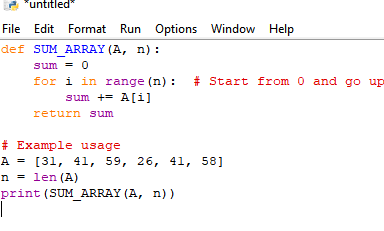
n = len(A)

print(SUM\_ARRAY(A, n))

output:

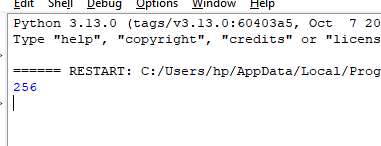
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Input:



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Output:



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2.1-4 Consider the searching problem:

Input: A sequence of n numbers( a1; a2; : : : ; an) stored in array A[1:n] and a value x.

Output: An index i such that x equals A[i] or the special value NIL if x does not appear in A.

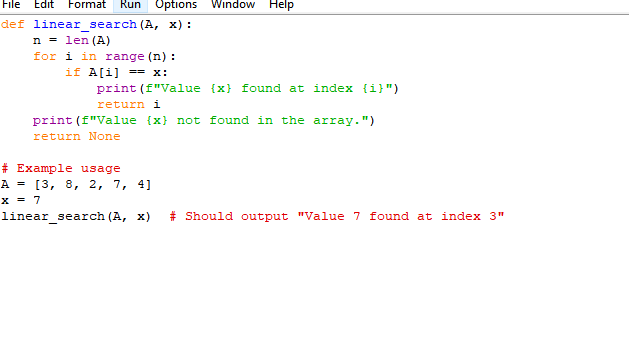
Write pseudocode for linear search, which scans through the array from beginning to end, looking for x. Using a loop invariant, prove that your algorithm is correct. Make sure that your loop invariant fulûlls the three necessary properties.

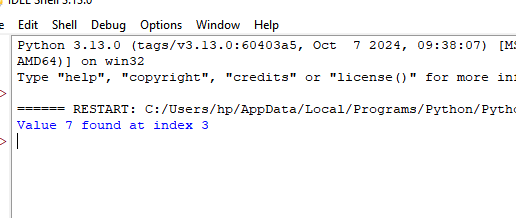
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**Pseudocode for Linear Search**

Here's the pseudocode for a linear search algorithm that scans through an array A from beginning to end looking for a value x:

Input:

output:



### Explanation of Code Execution

1. **Initialization**: The function linear\_search takes an array A and a value x.

**Loop**: It iterates through each element of A.

* + If it finds an element that matches x, it prints the index where x is found and returns that index.
  + If the loop completes without finding x, it prints that x is not found and returns None.

### Proof of Correctness Using a Loop Invariant

To prove the correctness, we use a loop invariant as explained:

#### Loop Invariant

For the loop on line 4 (for i in range(n)), the loop invariant is:

**At the start of each iteration, x is not found in any position of the array A before index i.**

#### Properties of the Loop Invariant

1. **Initialization**: Before the first iteration, no elements are checked, so it’s trivially true that x is not found in any position before index i = 0.
2. **Maintenance**: If A[i] matches x, it immediately returns i. If A[i] does not match x, the loop proceeds to the next index. Thus, if x is not found before index i + 1, the invariant holds.
3. **Termination**: When the loop terminates (i.e., i == n), the function has checked every element. If x has not been found, it correctly prints and returns None, as x is not present in A.

This ensures the function is correct, outputting the index if x is found, or None otherwise.

2.1-5 Consider the problem of adding two n-bit binary integers a and b, stored in two n-element arrays A[0: n-1] and B[0:n-1], where each element is either 0 or 1, a=∑. Write a procedure ADD-BINARY-INTEGERS that takes as input arrays A and B, along with the length n, and returns array C holding the sum.

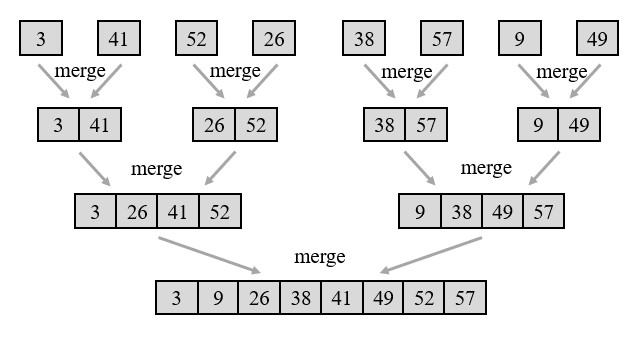
Exercises 2.2-1 Express the function 100n2  100n C 3 in terms of ‚-notation.

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Using Figure 2.4 as a model, illustrate the operation of merge sort on the array A=⟨3,41,52,26,38,57,9,49⟩*A*=⟨3,41,52,26,38,57,9,49⟩.



The figure is slightly different than the one in the book. The figure in the book was showing sorting progress from bottom to up. Here it is shown from top to bottom, which I feel will be more intuitive to understand.

The test in line 1 of the mergeSort procedure reads if p >= r rather than if p == r. If mergeSort is called with p > r, then the subarray A[p:r] is empty. Argue that as long as the initial call of mergeSort(A, 1, n) has n >= 1, the test if p == r suffices to ensure that no recursive call has p > r.

In Python, let’s analyze why the condition if p == r suffices to prevent any recursive calls with p>rp > rp>r in the mergeSort algorithm, as long as the initial call mergeSort(A, 1, n) has n≥1n \geq 1n≥1.

### Python Code for mergeSort

Here's a simplified version of the mergeSort function in Python:

python

Copy code

def mergeSort(A, p, r):

if p == r: # Base case: single element (no further division needed)

return

else:

q = (p + r) // 2 # Calculate the midpoint

mergeSort(A, p, q) # Recursively sort the left half

mergeSort(A, q + 1, r) # Recursively sort the right half

merge(A, p, q, r) # Merge the sorted halves

Here’s why if p == r is enough to prevent recursive calls with p>rp > rp>r:

### Explanation

1. **Initial Call**:
   * The algorithm is initially called as mergeSort(A, 1, n), where n≥1n \geq 1n≥1. This means we have at least one element, so the range [p,r]=[1,n][p, r] = [1, n][p,r]=[1,n] guarantees p≤rp \leq rp≤r at the start.
2. **Recursive Subdivision**:
   * Each recursive call splits the array into two halves by calculating the midpoint q=p+r2q = \frac{p + r}{2}q=2p+r​, which divides the range [p,r][p, r][p,r] as follows:
     + mergeSort(A, p, q) covers the left half of the range [p,q][p, q][p,q], where p≤q≤rp \leq q \leq rp≤q≤r.
     + mergeSort(A, q + 1, r) covers the right half of the range [q+1,r][q + 1, r][q+1,r], ensuring q+1≤rq + 1 \leq rq+1≤r.
3. **Base Case**:
   * The recursion stops when p == r, meaning the subarray has only one element.
   * Since the division always ensures that p≤rp \leq rp≤r, we avoid any calls where p>rp > rp>r. Consequently, there are no empty subarrays created, and a check for p > r isn’t necessary.
4. **Guaranteed Termination**:
   * The midpoint calculation and range constraints ensure that each recursive call reduces the subarray until it reaches a single element (p == r), at which point the recursion terminates.

### Why if p == r is Sufficient

Since the algorithm only makes recursive calls for valid subarrays where p≤rp \leq rp≤r, and the base case checks p == r to stop further recursion, the structure of mergeSort ensures that p > r is never encountered. This makes if p == r sufficient to prevent empty subarray cases.

### Final Conclusion

Thus, using if p == r in Python ensures no recursive calls with p>rp > rp>r as long as the initial call mergeSort(A, 1, n) starts with n≥1n \geq 1n≥1, and an additional check if p >= r is unnecessary.

2.3-3 State a loop invariant for the while loop of lines 12318 of the MERGE procedure. Show how to use it, along with the while loops of lines 20323 and 24327, to prove that the MERGE procedure is correct.

To prove the correctness of the MERGE procedure, we’ll use loop invariants to demonstrate that each while loop maintains a specific condition. This involves ensuring that each part of the merge function works as expected.

### The MERGE Procedure

The MERGE procedure is typically used as a subroutine in merge sort to combine two sorted subarrays into a single sorted array. Here’s a high-level outline of the standard merge function:

python

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def merge(arr, left, mid, right):

# Create copies of the left and right subarrays

n1 = mid - left + 1

n2 = right - mid

L = arr[left:left + n1]

R = arr[mid + 1:mid + 1 + n2]

# Initialize pointers for L, R, and arr

i = 0 # Initial index of L

j = 0 # Initial index of R

k = left # Initial index of merged subarray in arr

# Merge subarrays

while i < n1 and j < n2: # loop 12318

if L[i] <= R[j]:

arr[k] = L[i]

i += 1

else:

arr[k] = R[j]

j += 1

k += 1

# Copy any remaining elements of L

while i < n1: # loop 20323

arr[k] = L[i]

i += 1

k += 1

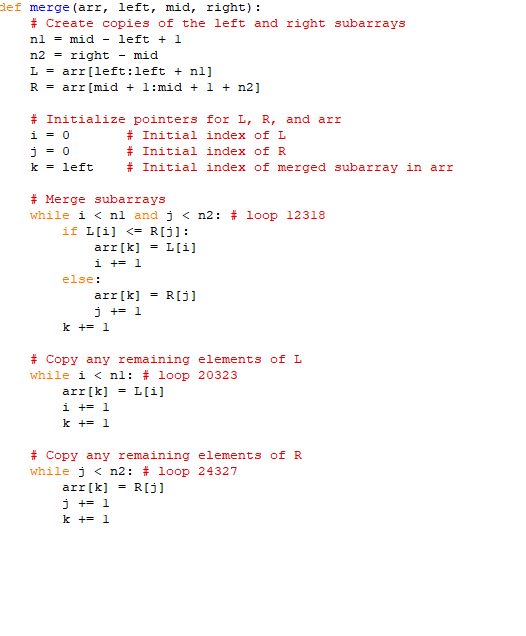
# Copy any remaining elements of R

while j < n2: # loop 24327

arr[k] = R[j]

j += 1

k += 1



### Loop Invariants

1. **Loop 12318 (Main Merging Loop)**
   * **Invariant**: At the start of each iteration, the elements in arr[left:k] are sorted and consist of the smallest elements from L and R that have not yet been merged.
   * **Proof of Invariant**:
     + **Initialization**: Before the loop starts, arr[left:k] is empty, so it is trivially sorted.
     + **Maintenance**: At each iteration, we place the smallest unmerged element from L or R into arr[k]. This ensures that arr[left:k] remains sorted.
     + **Termination**: The loop terminates when either L or R has been completely merged into arr. At this point, arr[left:k] contains the sorted elements from both subarrays that have been processed up to k.
2. **Loop 20323 (Copy Remaining Elements of L)**
   * **Invariant**: At the start of each iteration, all elements in L[i:n1] are greater than or equal to the elements in arr[left:k], which is already sorted.
   * **Proof of Invariant**:
     + **Initialization**: Before this loop starts, the main merging loop has completed, and any remaining elements in L are greater than or equal to those in arr[left:k].
     + **Maintenance**: Each iteration copies the next element from L into arr[k], preserving the sorted order in arr.
     + **Termination**: The loop terminates when all elements of L are copied into arr, so all elements from L have been merged in sorted order.
3. **Loop 24327 (Copy Remaining Elements of R)**
   * **Invariant**: At the start of each iteration, all elements in R[j:n2] are greater than or equal to the elements in arr[left:k], which is already sorted.
   * **Proof of Invariant**:
     + **Initialization**: Before this loop starts, the main merging loop has completed, and any remaining elements in R are greater than or equal to those in arr[left:k].
     + **Maintenance**: Each iteration copies the next element from R into arr[k], preserving the sorted order in arr.
     + **Termination**: The loop terminates when all elements of R are copied into arr, so all elements from R have been merged in sorted order.

### Conclusion

Since each loop maintains its invariant and upon termination, all elements from L and R have been placed in arr[left:right + 1] in sorted order, we can conclude that the MERGE procedure correctly merges two sorted subarrays into a single sorted array.

Use mathematical induction to show that when n*n* is an exact power of 22, the solution of the recurrence

T(n)={2if n=2,2T(n/2)+nif n=2k,for k>1.*T*(*n*)={22*T*(*n*/2)+*n*​if *n*=2,if *n*=2*k*,for *k*>1.​

is T(n)=nlg⁡n*T*(*n*)=*n*lg*n*

#### Base Case

When n=2*n*=2, T(2)=2=2lg⁡2*T*(2)=2=2lg2. So, the solution holds for the initial step.

#### Inductive Step

Let’s assume that there exists a k*k*, greater than 1, such that T(2k)=2klg⁡2k*T*(2*k*)=2*k*lg2*k*. We must prove that the formula holds for k+1*k*+1 too, i.e. T(2k+1)=2k+1lg⁡2k+1*T*(2*k*+1)=2*k*+1lg2*k*+1.

From our recurrence formula,

T(2k+1)=2T(2k+1/2)+2k+1=2T(2k)+2⋅2k=2⋅2klg⁡2k+2⋅2k=2⋅2k(lg⁡2k+1)=2k+1(lg⁡2k+lg⁡2)=2k+1lg⁡2k+1*T*(2*k*+1)​=2*T*(2*k*+1/2)+2*k*+1=2*T*(2*k*)+2⋅2*k*=2⋅2*k*lg2*k*+2⋅2*k*=2⋅2*k*(lg2*k*+1)=2*k*+1(lg2*k*+lg2)=2*k*+1lg2*k*+1​

This completes the inductive step.

Since both the base case and the inductive step have been performed, by mathematical induction, the statement T(n)=nlg⁡n*T*(*n*)=*n*lg*n* holds for all n*n* that are exact power of 2.

You can also think of insertion sort as a recursive algorithm. In order to sort A[1:n] , recursively sort the subarray A[1:n-1] and then insert A[n] into the sorted subarray A[1:n-1] Write pseudocode for this recursive version of insertion sort. . Give a recurrence for its worst-case running time.

Here’s the pseudocode for a recursive version of insertion sort:

Recursive-Insertion-Sort(A, n)

1. if n <= 1

2. return

3. Recursive-Insertion-Sort(A, n - 1)

4. key = A[n]

5. j = n - 1

6. while j > 0 and A[j] > key

7. A[j + 1] = A[j]

8. j = j - 1

9. A[j + 1] = key

### Explanation

1. The base case is when n≤1n \leq 1n≤1, in which case the array is already sorted.
2. The recursive call Recursive-Insertion-Sort(A, n - 1) sorts the subarray A[1:n-1].
3. After sorting A[1:n-1], the algorithm inserts A[n] into its correct position in the sorted subarray by shifting elements to the right until the correct position is found.

### Recurrence for Worst-Case Running Time

Let T(n)T(n)T(n) be the worst-case running time for Recursive-Insertion-Sort on an array of size nnn.

1. **Base Case**: When n=1n = 1n=1, the array is already sorted, so T(1)=O(1)T(1) = O(1)T(1)=O(1).
2. **Recursive Case**: For n>1n > 1n>1, the recurrence can be given by: T(n)=T(n−1)+O(n).T(n) = T(n - 1) + O(n).T(n)=T(n−1)+O(n).
   * T(n−1)T(n - 1)T(n−1) accounts for the time to sort the subarray A[1:n−1]A[1:n-1]A[1:n−1].
   * O(n)O(n)O(n) accounts for the time to insert A[n] into the sorted subarray A[1:n-1] by potentially shifting up to n−1n - 1n−1 elements.

### Solution to the Recurrence

The recurrence T(n)=T(n−1)+O(n)T(n) = T(n - 1) + O(n)T(n)=T(n−1)+O(n) expands to:

T(n)=O(1)+O(2)+⋯+O(n)=O(n(n+1)2)=O(n2).T(n) = O(1) + O(2) + \cdots + O(n) = O\left(\frac{n(n + 1)}{2}\right) = O(n^2).T(n)=O(1)+O(2)+⋯+O(n)=O(2n(n+1)​)=O(n2).

Thus, the worst-case running time for this recursive version of insertion sort is O(n2)O(n^2)O(n2), which is the same as the iterative version of insertion sort.

2.3-6 Referring back to the searching problem (see Exercise 2.1-4), observe that if the subarray being searched is already sorted, the searching algorithm can check the midpoint of the subarray against v and eliminate half of the subarray from further Problems for Chapter 2 45 consideration. The binary search algorithm repeats this procedure, halving the size of the remaining portion of the subarray each time. Write pseudocode, either iterative or recursive, for binary search. Argue that the worst-case running time of binary search is ‚.lg n/.

Binary search is an efficient algorithm for finding an element in a sorted array. By repeatedly dividing the search interval in half, it eliminates half of the elements each step, achieving a logarithmic running time in the worst case.

### Binary Search Pseudocode (Iterative)

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Binary-Search(A, v)

1. low = 0

2. high = len(A) - 1

3. while low ≤ high

4. mid = (low + high) // 2

5. if A[mid] == v

6. return mid # Element found

7. elif A[mid] < v

8. low = mid + 1

9. else

10. high = mid - 1

11. return -1 # Element not found

### Binary Search Pseudocode (Recursive)

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Binary-Search(A, v, low, high)

1. if low > high

2. return -1 # Element not found

3. mid = (low + high) // 2

4. if A[mid] == v

5. return mid # Element found

6. elif A[mid] < v

7. return Binary-Search(A, v, mid + 1, high)

8. else

9. return Binary-Search(A, v, low, mid - 1)

### Explanation

1. **Iterative Version**:
   * Start with the entire array as the search range (low = 0, high = len(A) - 1).
   * In each iteration, check the middle element A[mid].
   * If A[mid] == v, return mid (found).
   * If A[mid] < v, adjust the search to the right half (low = mid + 1).
   * If A[mid] > v, adjust the search to the left half (high = mid - 1).
   * Repeat until low > high, indicating that v is not in the array.
2. **Recursive Version**:
   * If low > high, return -1 (not found).
   * Calculate the middle index mid = (low + high) // 2.
   * If A[mid] == v, return mid (found).
   * If A[mid] < v, search the right half by calling Binary-Search(A, v, mid + 1, high).
   * If A[mid] > v, search the left half by calling Binary-Search(A, v, low, mid - 1).

### Worst-Case Running Time Analysis

Each iteration or recursive call reduces the search range by half, so we can express the worst-case time complexity T(n)T(n)T(n) as:

T(n)=T(n2)+O(1).T(n) = T\left(\frac{n}{2}\right) + O(1).T(n)=T(2n​)+O(1).

The solution to this recurrence is T(n)=O(log⁡n)T(n) = O(\log n)T(n)=O(logn).

1. **Initial Problem Size**: Start with nnn elements.
2. **Divide**: Each step, reduce the size of the search range by half.
3. **Halving Process**: After kkk divisions, the search range is n2k\frac{n}{2^k}2kn​.
4. **Termination Condition**: The process continues until the range size becomes 1, which occurs when n2k=1\frac{n}{2^k} = 12kn​=1. Solving for kkk, we find k=log⁡2nk = \log\_2 nk=log2​n.

Therefore, the worst-case running time of binary search is O(log⁡n)O(\log n)O(logn), as it takes at most log⁡n\log nlogn steps to reach the base case in both the iterative and recursive versions.

The while loop of lines 5-7 of the insertion-sort procedure in section 2.1 uses a linear search to scan (backward) through the sorted subarray a[1:j-1] what if insertion sort used a binary search (see exercise 2.3-6) instead of a linear search? Would that improve the overall worst-case running time of insertion sort to o(n lg n)?

If insertion sort used binary search instead of a linear search to find the correct position for each element, it would indeed reduce the number of comparisons needed to find the insertion point. However, this optimization does not improve the overall worst-case time complexity of insertion sort to O(nlog⁡n)O(n \log n)O(nlogn).

### Analysis

1. **Binary Search for Finding the Insertion Point**:
   * In the standard insertion sort algorithm, to insert an element A[j]A[j]A[j] into the sorted subarray A[1:j−1]A[1:j-1]A[1:j−1], a **linear search** is used to find the correct position, which takes O(j)O(j)O(j) time in the worst case.
   * If we replace the linear search with a **binary search**, we can find the position in O(log⁡j)O(\log j)O(logj) time.
2. **Time Complexity of Shifting Elements**:
   * Although binary search reduces the time complexity of finding the insertion point to O(log⁡j)O(\log j)O(logj), the **shifting of elements** to insert A[j]A[j]A[j] in the correct position still takes O(j)O(j)O(j) time in the worst case.
   * This is because, even after finding the correct insertion index, we need to move all elements greater than A[j]A[j]A[j] to the right by one position to make space for A[j]A[j]A[j].
3. **Overall Time Complexity**:
   * Insertion sort has nnn passes, and for each pass jjj, finding the insertion point takes O(log⁡j)O(\log j)O(logj) with binary search, but shifting elements still takes O(j)O(j)O(j).
   * Therefore, the time complexity per pass remains O(j)O(j)O(j) because the shifting operation dominates.
   * Summing over all passes, we get: T(n)=∑j=1nO(j)=O(n2).T(n) = \sum\_{j=1}^{n} O(j) = O(n^2).T(n)=j=1∑n​O(j)=O(n2).

### Conclusion

Using binary search to find the insertion point in insertion sort **does not improve the overall worst-case time complexity** to O(nlog⁡n)O(n \log n)O(nlogn) because the shifting of elements still takes linear time per pass. Thus, the overall time complexity remains O(n2)O(n^2)O(n2) in the worst case, even with binary search.

### When Does Binary Search Help in Insertion Sort?

While it doesn’t improve the asymptotic time complexity, using binary search in insertion sort can:

* Reduce the number of comparisons to find the correct position for each element.
* Improve performance in practice, especially for partially sorted or smaller arrays, where the reduction in comparisons can yield some speedup. However, for large arrays, O(n2)O(n^2)O(n2) still becomes impractical compared to O(nlog⁡n)O(n \log n)O(nlogn) sorting algorithms like merge sort or quicksort.

2.3-8 Describe an algorithm that, given a set S of n integers and another integer x, determines whether S contains two elements that sum to exactly x. Your algorithm should take 0(n clg n) time in the worst case.

To solve this problem in O(noggin)O (n \log n) O(long) time, we can use sorting and the two-pointer technique. Here’s a step-by-step description of the algorithm:

### Algorithm: Two-Sum with Sorting and Two-Pointer Technique

1. **Sort the Array**:
   * Sort the array SSS of nan integers in O(noggin)O(n \log n)O(nlogn) time.
2. **Initialize Two Pointers**:
   * Use two pointers: one starting from the beginning (left = 0) and one starting from the end (right = n - 1) of the sorted array.
3. **Two-Pointer Search**:
   * While left < right:
     + Calculate the sum of the elements at the two pointers: sum = S[left] + S[right].
     + If sum == x, return True, as we have found two elements that add up to xxx.
     + If sum < x, move the left pointer to the right (left += 1) to increase the sum.
     + If sum > x, move the right pointer to the left (right -= 1) to decrease the sum.
4. **Return False if No Pair Found**:
   * If the loop completes without finding two elements that add up to xxx, return False.

### Pseudocode

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Two-Sum(S, x)

1. Sort S in ascending order

2. left = 0

3. right = len(S) - 1

4. while left < right

5. sum = S[left] + S[right]

6. if sum == x

7. return True

8. elif sum < x

9. left = left + 1

10. else

11. right = right - 1

12. return False

### Explanation of the Algorithm

* **Sorting**: Sorting the array takes O(nlog⁡n)O(n \log n)O(nlogn) time.
* **Two-Pointer Search**: The two-pointer technique only requires a single pass through the array, which takes O(n)O(n)O(n) time.

Since O(nlog⁡n)+O(n)=O(nlog⁡n)O(n \log n) + O(n) = O(n \log n)O(nlogn)+O(n)=O(nlogn), the overall time complexity is O(nlog⁡n)O(n \log n)O(nlogn).

### Why This Works

* Sorting the array allows us to efficiently check sums by leveraging the ordered nature of the array.
* The two-pointer approach exploits the sorted order to systematically explore potential pairs that might sum to xxx by either increasing or decreasing the current sum based on comparisons with xxx.

### Example Walkthrough

Suppose S=[3,1,4,5,9]S = [3, 1, 4, 5, 9]S=[3,1,4,5,9] and x=8x = 8x=8:

1. Sort SSS: S=[1,3,4,5,9]S = [1, 3, 4, 5, 9]S=[1,3,4,5,9].
2. Initialize left = 0 (pointing to 1) and right = 4 (pointing to 9).
3. Check S[left] + S[right] = 1 + 9 = 10 > x, so move right to the left (right = 3).
4. Now, S[left] + S[right] = 1 + 5 = 6 < x, so move left to the right (left = 1).
5. Now, S[left] + S[right] = 3 + 5 = 8 == x, so we return True.

This algorithm ensures we efficiently check each possible pair without needing a nested loop, achieving O(nlog⁡n)O(n \log n)O(nlogn) complexity.

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**EXERCISE 3.1**

**QUESTION : # 01**

Q1. Modify the lower-bound argument for insertion sort to handle input sizes that are not necessarily a multiple of 3.

**ANSWER:**

To modify the lower-bound argument for insertion sort, we need to analyze the comparison-based sorting algorithm in a way that accounts for input sizes that are not necessarily a multiple of 3.

**Original Lower-Bound Argument**

The classic lower bound for any comparison-based sorting algorithm is Ω(nlogn). This is derived from the decision tree model of sorting, where each comparison can be thought of as a binary decision that splits the input set into two parts. The height of the decision tree represents the worst-case number of comparisons needed to sort the array.

For insertion sort specifically, the worst-case scenario occurs when the input is sorted in reverse order, requiring O(n^2) comparisons. However, the lower bound for sorting in general is more broadly applicable.

**Modifying the Argument**

1. **Decision Tree Model**: In the decision tree model, each node represents a comparison between two elements. The leaves represent the different permutations of the input. The number of leaves (which corresponds to the number of different ways to order the input) for an array of size n is n!.
2. **Height of the Decision Tree**: The number of leaves of a binary tree with height h is at most 2^h. Thus, for the sorting algorithm to determine the correct order, we need:

n!≤ 2^h

Taking logarithms, we get:

h ≥ (n!)

Using Stirling's approximation n!≈, we can derive:

(n!) ≈ (e)+1/2 (2πn)

This simplifies to:

Θ(n(n))

1. **Handling Non-Multiples of 3**: The crux of the lower bound argument does not fundamentally change when the input size is not a multiple of 3. The decision tree still holds for any n, regardless of its relation to specific numbers. Thus, the height of the decision tree, and hence the number of comparisons required in the worst case, will still require Θ(n​(n)).
2. **Insertion Sort Specifically**: While insertion sort operates in O(n^2) in the worst case, it can be shown that for arbitrary n, the lower bound remains valid. For insertion sort, even if nnn is not a multiple of 3, the worst-case scenario still requires making at most n(n−1)/2 comparisons, confirming that insertion sort cannot perform better than Θ(n^2) in the worst case.

**QUESTION : # 02**

Q2. Using reasoning similar to what we used for insertion sort, analyze the running time of the selection sort algorithm from Exercise 2.2-2.

**ANSWER:**

**Running Time Analysis**

1. **Outer Loop**: The outer loop runs n−1 times, where n is the number of elements in the array.
2. **Finding the Minimum**: For each iteration of the outer loop at position iii:
   * The inner loop runs from i to n−1, checking each element to find the minimum. This takes O(n−i) time.
   * The total time spent finding the minimum across all iterations can be calculated as follows:
     + For i =0 : n−0 = n
     + For i =1 : n−1
     + For i =2 : n−2
     + ...
     + For i= n−2 : n−(n−2) = 2
     + For i= n−1 : n−(n−1) = 1

The total time for finding the minimum over all iterations is:

(n)+(n−1)+(n−2)+…+2+1 = n(n−1)/2

This simplifies to O(n^2).

1. **Swapping**: Each swap operation is constant time, O(1), and since we perform at most n−1 swaps, this contributes an O(n) factor, which is negligible compared to O(n^2).

**Conclusion**

Putting it all together, the dominant factor in the running time of selection sort is the process of finding the minimum element, which takes O(n^2) time. Thus, the overall time complexity of selection sort is:

O(n^2)

Selection sort, therefore, has a quadratic time complexity for all cases (best, average, and worst), making it inefficient for large lists compared to more advanced algorithms like quicksort or mergesort.

**QUESTION : # 03**

Q3. Suppose that α is a fraction in the range 0 < α < 1. Show how to generalize the lower-bound argument for insertion sort to consider an input in which the αn largest values start in the first αn positions. What additional restriction do you need to put on α? What value of α maximizes the number of times that the αn largest values must pass through each of the middle .(1 – 2α)n array positions?

**ANSWER:**

To analyze the lower bound for insertion sort with respect to the given scenario, we need to consider how insertion sort behaves with an input where the largest α n values are already positioned in the first α n slots.

### Generalizing the Lower-Bound Argument

1. **Insertion Sort Overview**: Insertion sort works by building a sorted portion of the array one element at a time. It takes each new element and inserts it into the correct position in the already sorted portion.
2. **Input Condition**: We have an array of size nnn where the largest α n elements are in the first α n positions and the remaining (1−α)n elements are in the last (1−α)n positions.
3. **Movement of Elements**: When sorting the array, insertion sort will have to consider where to place each of the α n largest elements. Since they are already positioned in the first α n slots, we need to examine how many times these elements will "pass through" the middle (1−2α)n positions, which are the elements from positions αn+1 to (1−α)n.

### Additional Restriction on alphaα

For the analysis to hold, we need α<1/2 . If α ≥1/2​, the largest values would occupy a significant portion of the array, which alters the dynamics of how they interact with the remaining elements.

### Maximizing the Pass-Through

To determine the value of α that maximizes the number of times the α n largest values must pass through the middle (1−2α)n positions, consider:

1. **Movement Mechanics**: Each time an element from the largest α n must be placed in the sorted section, it may have to traverse the unsorted section that includes the middle (1−2α)n.
2. **Effective Traversal**: Each of the α n largest elements will have to pass through potentially all elements in the (1−2α)n section if they are larger than those elements. The number of comparisons (and thus movements through the middle section) is affected by how many of the αn elements are greater than the elements in the unsorted section.