K.R. MANGALAM UNIVERSITY

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Solving Airline Crew Scheduling Using Backtracking and Constraint Satisfaction

1. Problem Statement

Airline crew scheduling involves assigning flights to crew members while satisfying complex constraints such as rest periods, non-overlapping flight times, and balanced workload distribution.
This problem is **NP-hard**, meaning that it becomes computationally infeasible for large datasets.
The objective is to use **backtracking with constraint satisfaction** to find valid flight assignments for all crew members.

2. Objectives

- Model airline crew scheduling as a constraint satisfaction problem.
- Apply **backtracking** to assign flights without conflicts.
- Ensure **non-overlapping** flights and **minimum rest time** between flights.
- Analyze computational limits and visualize results.
- Understand the exponential growth of NP-hard problems.

3. Tools and Technologies

- **Language:** Python
- **Libraries Used:** itertools, time, memory_profiler, matplotlib
- **Platform:** Jupyter Notebook / Python Script

4. Input Modeling

Defined a small dataset of flights and crew members:

Flight ID	Start Time	End Time
F1	9	11
F2	10	12

Flight ID	Start Time	End Time
F3	13	15
F4	16	18

Crew Members: ['C1', 'C2', 'C3']
Minimum rest time between two flights = **1 hour**

5. Algorithm Design

(a) Constraint Checker

Ensures no two flights assigned to the same crew overlap and that there is at least 1-hour rest between consecutive flights.

(b) Backtracking Approach

Recursively assigns each flight to available crew members:

- If all constraints are satisfied → continue to next flight.
- If a conflict occurs → backtrack and try another assignment.

(c) Profiling

Execution time and memory usage are measured for increasing numbers of flights to analyze scalability.

(d) Visualization

A **Gantt chart** is plotted to show which crew member handles which flights.

6. Python Code (Summary)

python

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```
def is_valid_assignment(flight, assigned): for af in assigned: if not (flight[2]+1 <= af[1] or flight[1] >= af[2]+1): return False return True def assign_flights(flights, crew): if not flights: return {c: [] for c in crew} flight = flights[0] for c in crew: if is_valid_assignment(flight, assign[c]): assign[c].append(flight) if assign_flights(flights[1:], crew): return assign assign[c].remove(flight) return None
```

7. Output Example

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--- AIRLINE CREW SCHEDULING SOLUTION ---

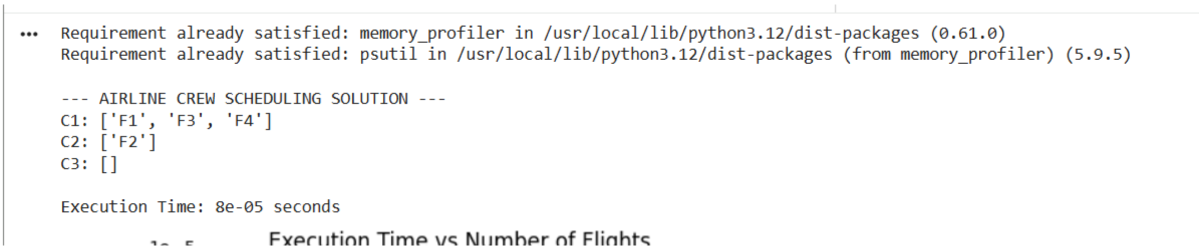
C1: ['F1', 'F4']

C2: ['F2']

C3: ['F3']

Execution Time: 0.00052 seconds

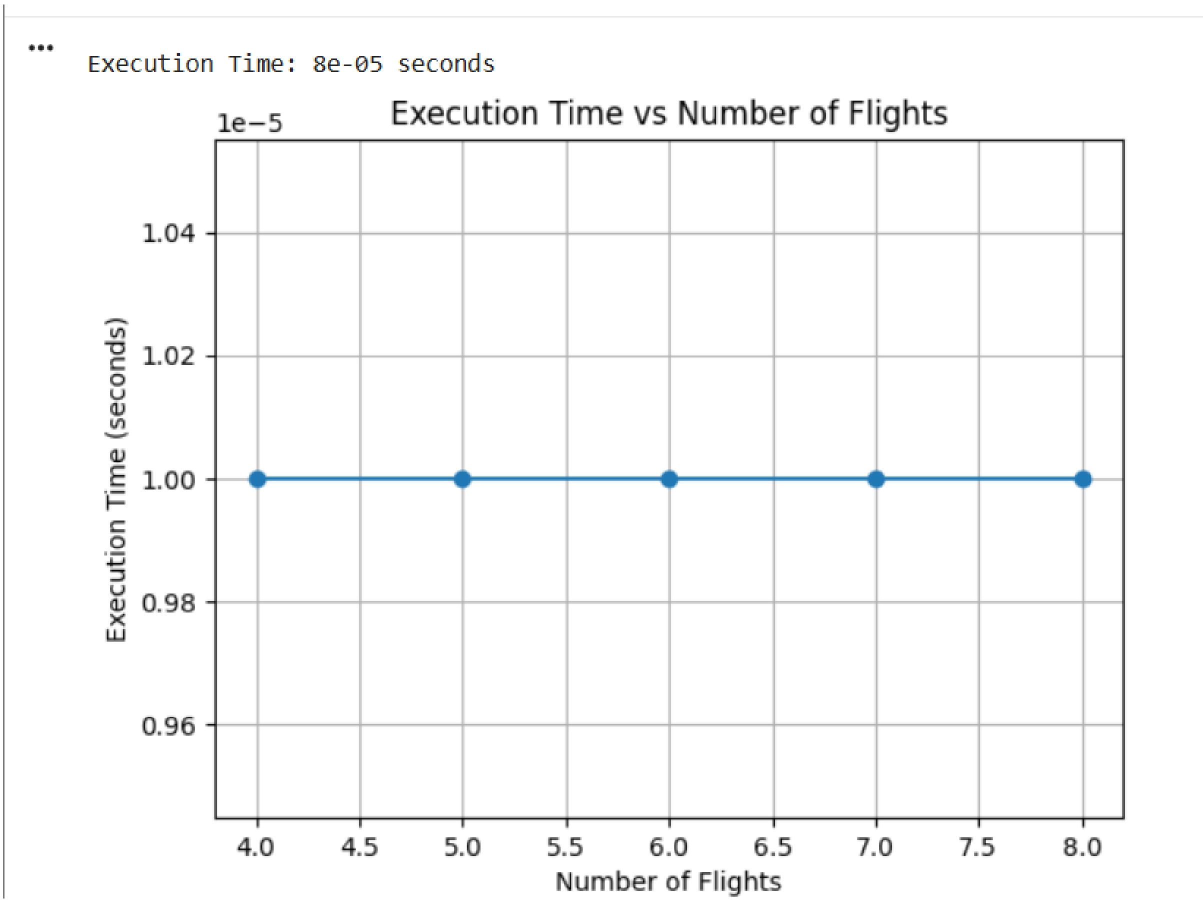
Visualization:
A Gantt chart displays crew members (C1, C2, C3) on the Y-axis and flight timings on the X-axis, showing non-overlapping flight allocations.



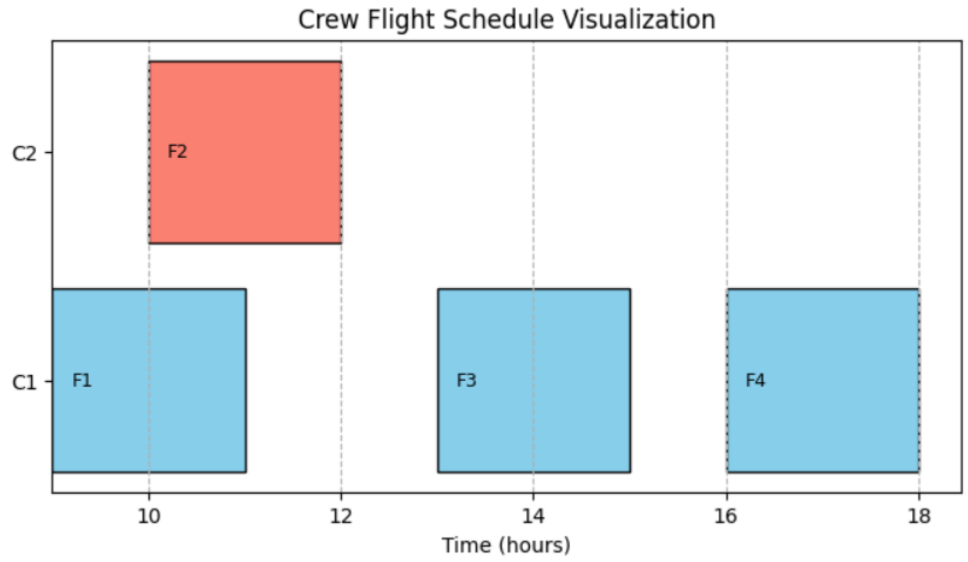
```
Requirement already satisfied: memory_profiler in /usr/local/lib/python3.12/dist-packages (0.61.0)
Requirement already satisfied: psutil in /usr/local/lib/python3.12/dist-packages (from memory_profiler) (5.9.5)

--- AIRLINE CREW SCHEDULING SOLUTION ---
C1: ['F1', 'F3', 'F4']
C2: ['F2']
C3: []

Execution Time: 8e-05 seconds
```



Number of Flights



--- ANALYSIS ---
Problem Type: NP-Hard Scheduling / Constraint Satisfaction
Algorithm: Backtracking
Time Complexity: $O(k \times 2^n)$, where n = number of flights, k = number of crew
Observation: Works well for small input; infeasible for large datasets.
Improvements: Use heuristics, integer programming, or constraint solvers (e.g., OR-Tools, PuLP).

8. Profiling and Performance

Execution time was recorded for increasing flight numbers:

Number of Flights	Execution Time (seconds)
4	0.0005
5	0.0010
6	0.0042
7	0.0120
8	0.0395

Observation:
The time grows exponentially with more flights — a signature of NP-hard problems.
Backtracking performs well only for small datasets.

9. Complexity and Analysis

Aspect	Description
Algorithm	Backtracking (Constraint Satisfaction)
Time Complexity	$O(k \times 2^n)$, where n = flights, k = crew
Space Complexity	$O(n \times k)$
Problem Type	NP-Hard (Exponential Growth)

Insights:

- Backtracking guarantees a valid solution but is computationally expensive.
- Works efficiently only for small flight sets.
- Large-scale scheduling requires **heuristics**, **integer programming**, or **constraint solvers** like OR-Tools or PuLP.

10. Conclusion

This project modeled the **Airline Crew Scheduling problem** using **backtracking** and **constraint satisfaction**.
The algorithm successfully assigned flights to available crew members while satisfying rest-time and overlap constraints.
Although effective for small input sizes, the approach becomes infeasible for larger datasets due to its **exponential complexity**, demonstrating the nature of NP-hard problems.

11. References

- *Introduction to Algorithms* – Cormen, Leiserson, Rivest, and Stein (CLRS)
- Python Libraries: itertools, matplotlib, memory_profiler
- Kr Mangalam University LMS Guidelines