Intro: Coin Changing

Coin Changing

Goal. Given currency denominations: 1, 5, 10, 25, 100, give change to customer using *fewest* number of coins.

Ex: 34¢.

Algorithm is "Greedy": One large coin better than two or more smaller ones

Cashier's algorithm. At each iteration, give the *largest* coin valued ≤ the amount to be paid.

Ex: $2.89.

Coin-Changing: Does Greedy Always Work?

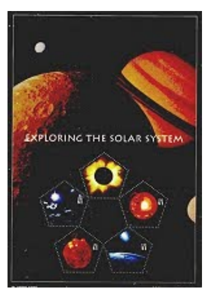
Observation. Greedy algorithm is sub-optimal for US postal denominations: 1, 10, 21, 34, 70, 100, 350, 1225, 1500.

Counterexample. 140¢.

- Greedy: 100, 34, 1, 1, 1, 1, 1, 1.
- Optimal: 70, 70.

Algorithm is "Greedy", but also short-sighted – attractive choice now may lead to dead ends later.

Correctness is key!



Outline & Goals

"Greedy Algorithms"

- what they are

Pros

- intuitive
- often simple
- often fast

Cons

- often incorrect!

Proof techniques

- stay ahead
- structural
- exchange arguments

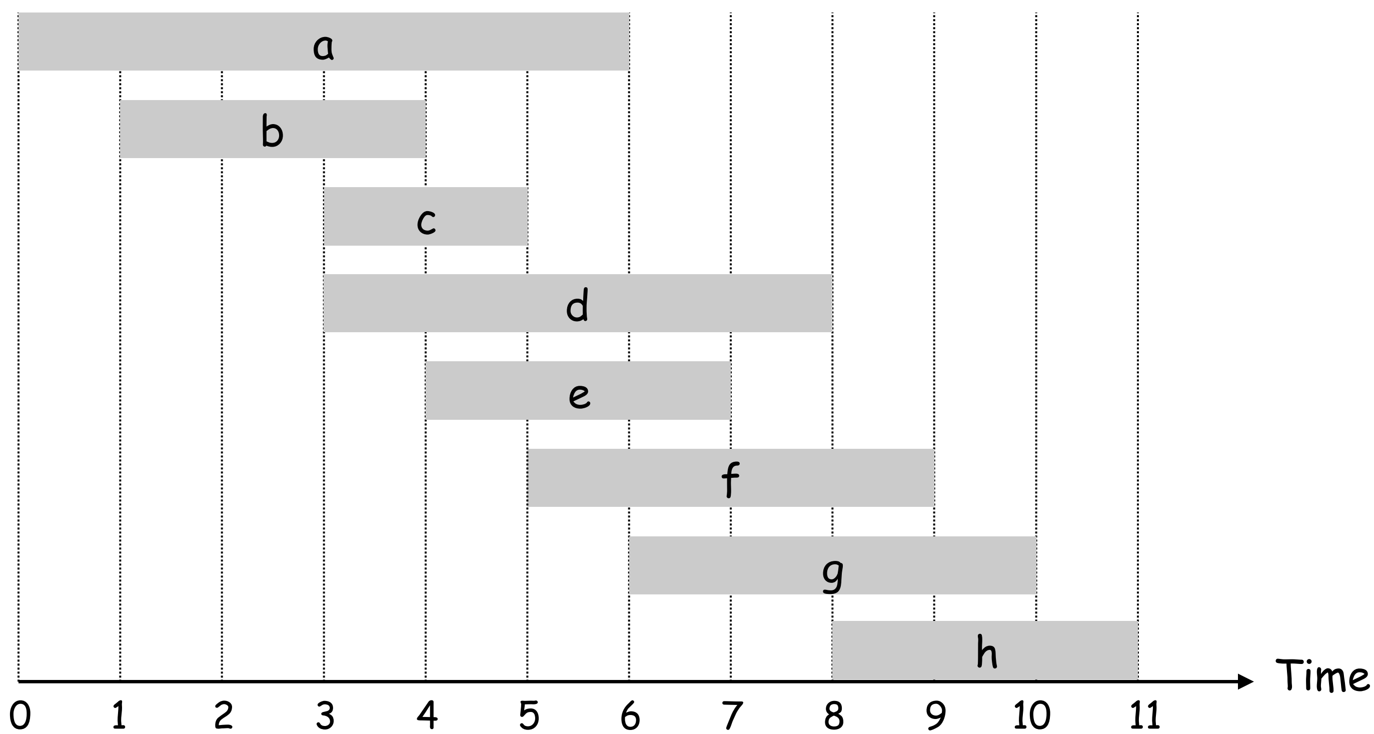
4.1 Interval Scheduling

Proof Technique 1: “greedy stays ahead”

Interval Scheduling

Interval scheduling.

- Job j starts at s_j and finishes at f_j.
- Two jobs compatible if they don't overlap.
- Goal: find maximum subset of mutually compatible jobs.



Interval Scheduling: Greedy Algorithms

Greedy template. Consider jobs in some order. Take each job provided it's compatible with the ones already taken.

- What order?
- Does that give best answer?
- Why or why not?
- Does it help to be greedy about order?

Interval Scheduling: Greedy Algorithms

Greedy template. Consider jobs in some order. Take each job provided it's compatible with the ones already taken.

[Earliest start time] Consider jobs in ascending order of start time s_j.

[Earliest finish time] Consider jobs in ascending order of finish time f_j.

[Shortest interval] Consider jobs in ascending order of interval length $f_j - s_j$.

[Fewest conflicts] For each job, count the number of conflicting jobs c_j. Schedule in ascending order of conflicts c_j.

Interval Scheduling: Greedy Algorithm

Greedy algorithm. Consider jobs in increasing order of finish time. Take each job provided it's compatible with the ones already taken.

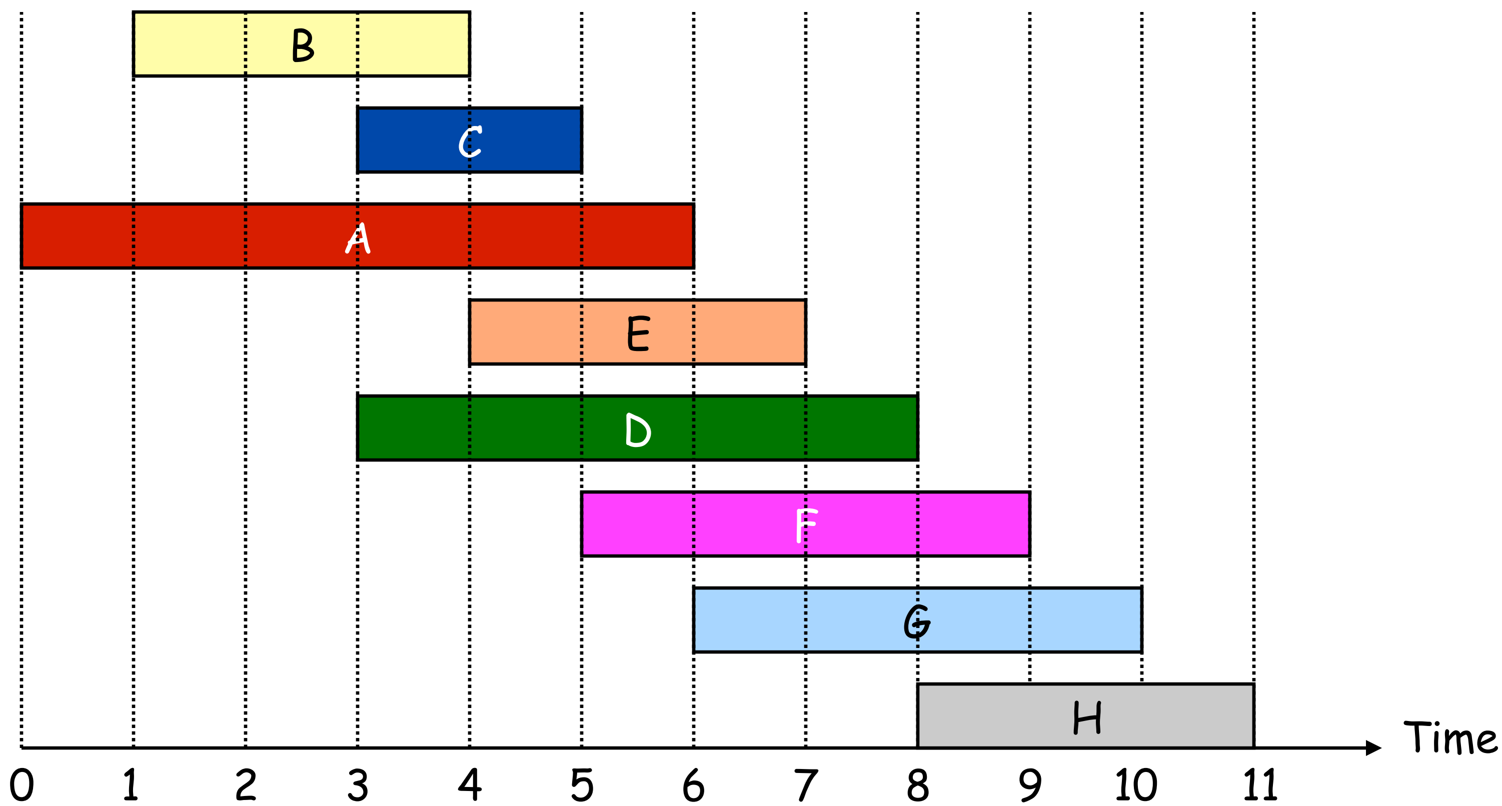
jobs selected

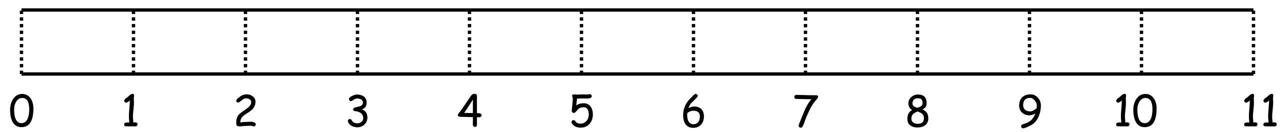
```
Sort jobs by finish times so that f1 ≤ f2 ≤ ... ≤ fn.

A = {}
for j = 1 to n {
   if (job j compatible with A)
      A = A ∪ {j}
}
return A
```

Implementation. O(n log n).

- Remember job j* that was added last to A.
- Job j is compatible with A if $s_j \geq f_{j^*}$.

Interval Scheduling





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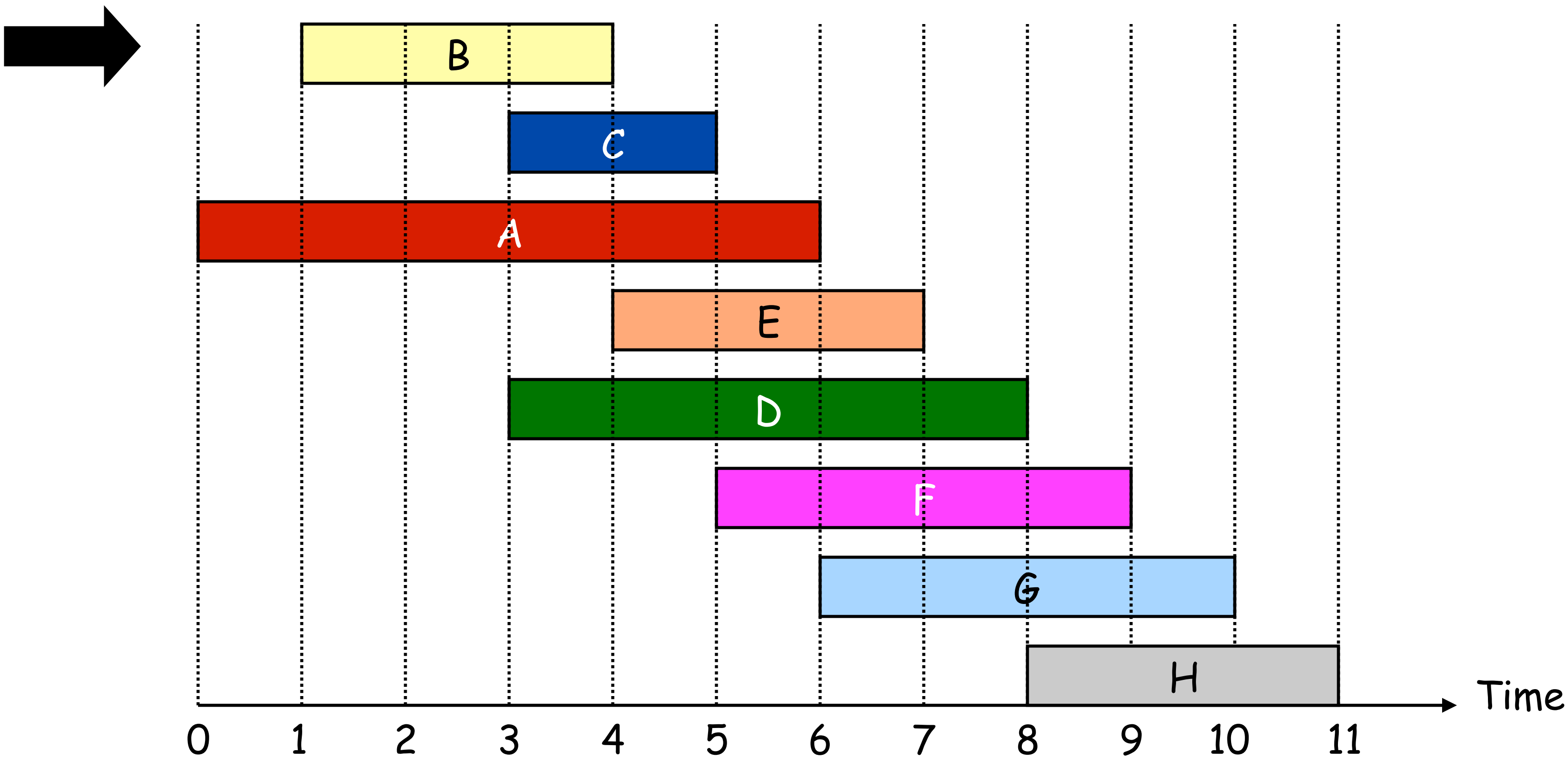
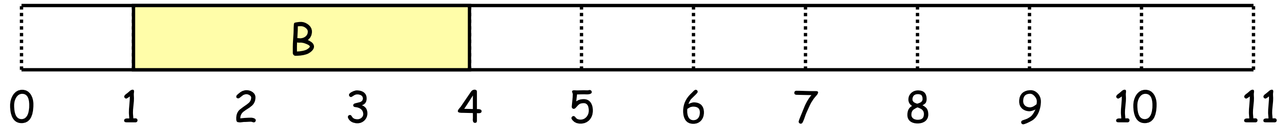
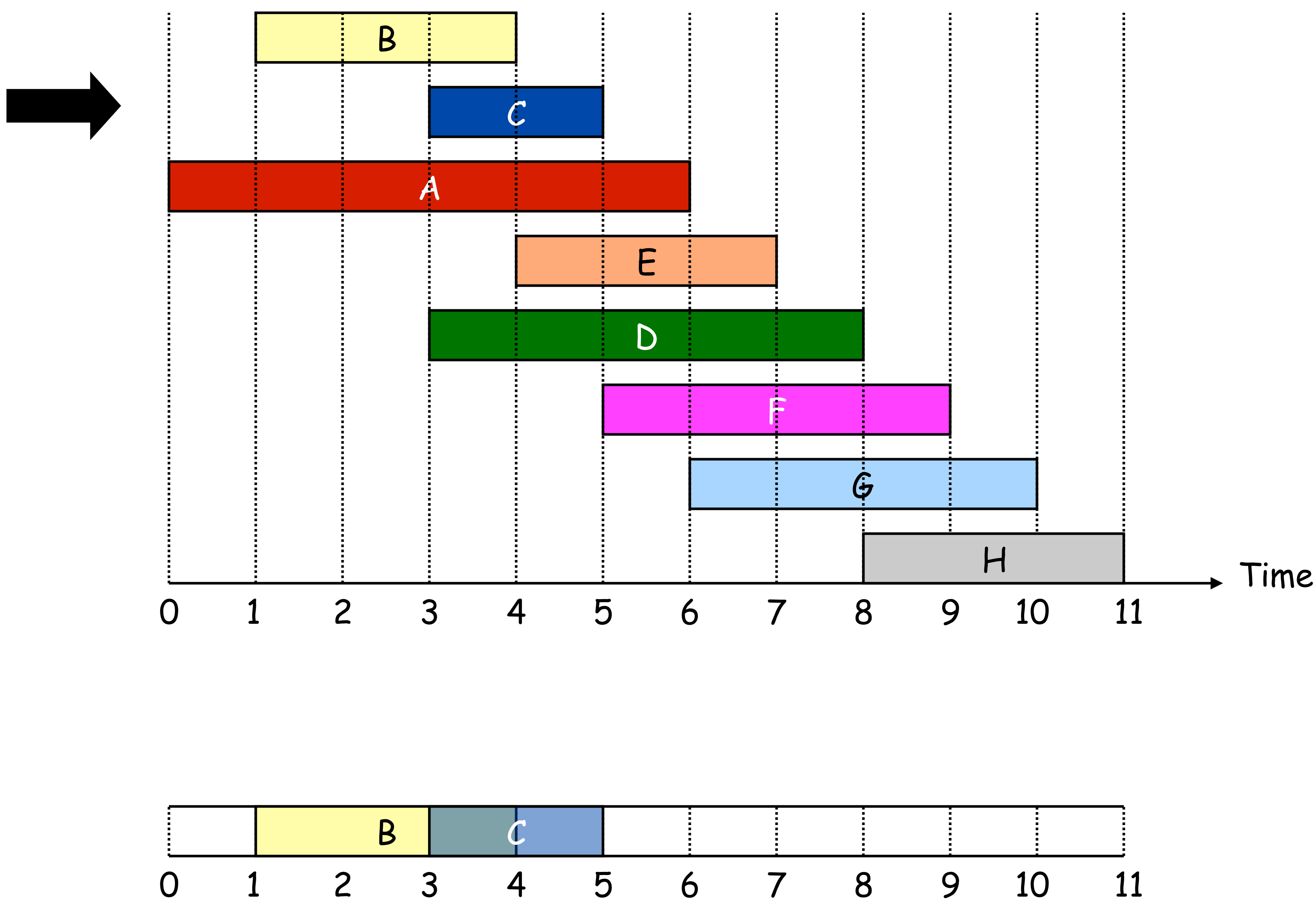




Interval Scheduling



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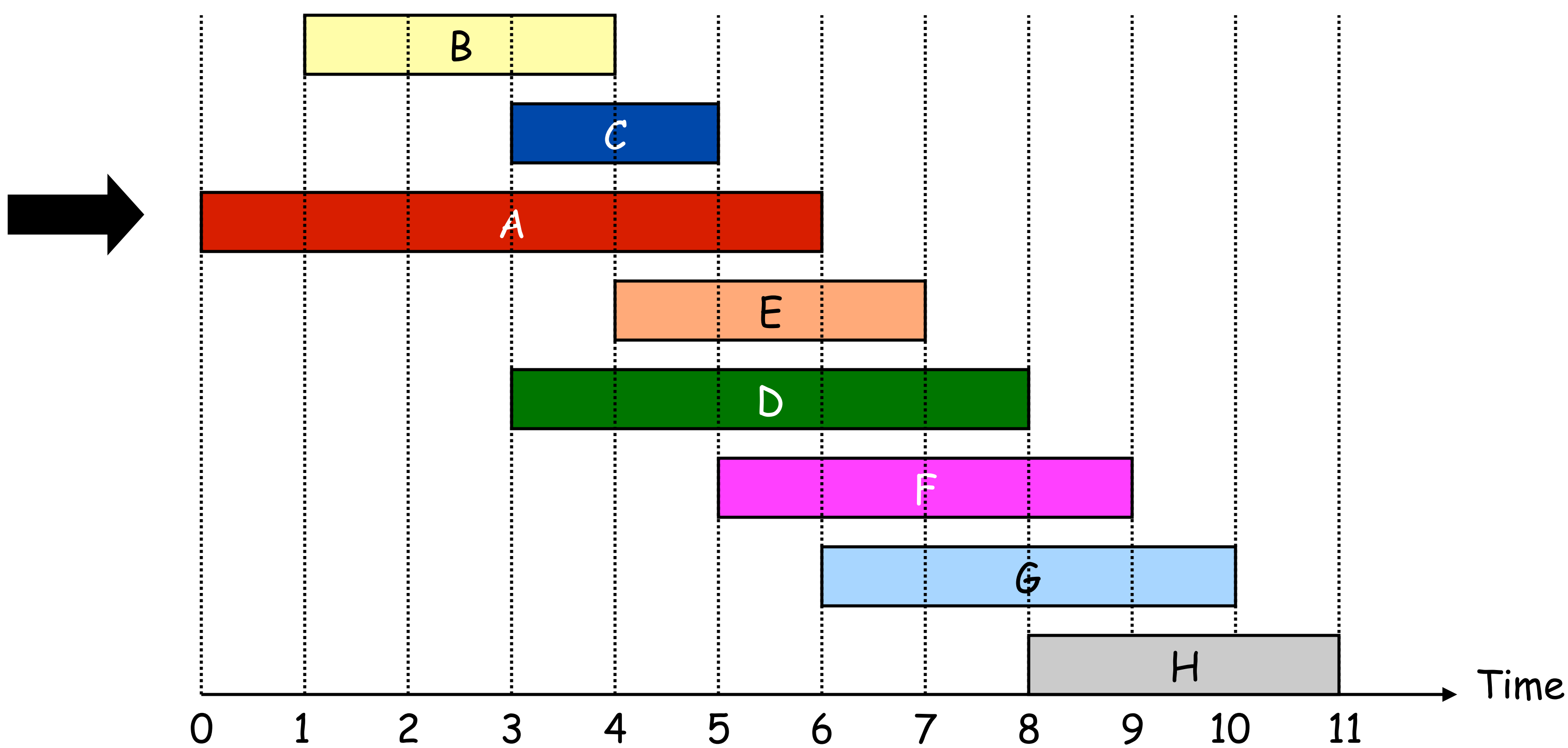

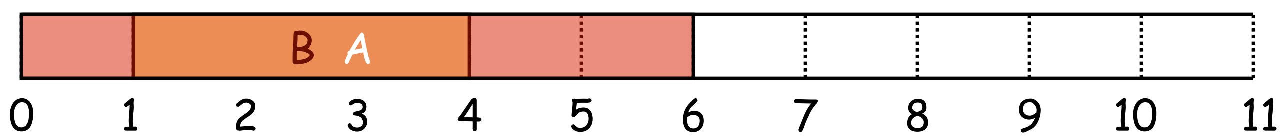

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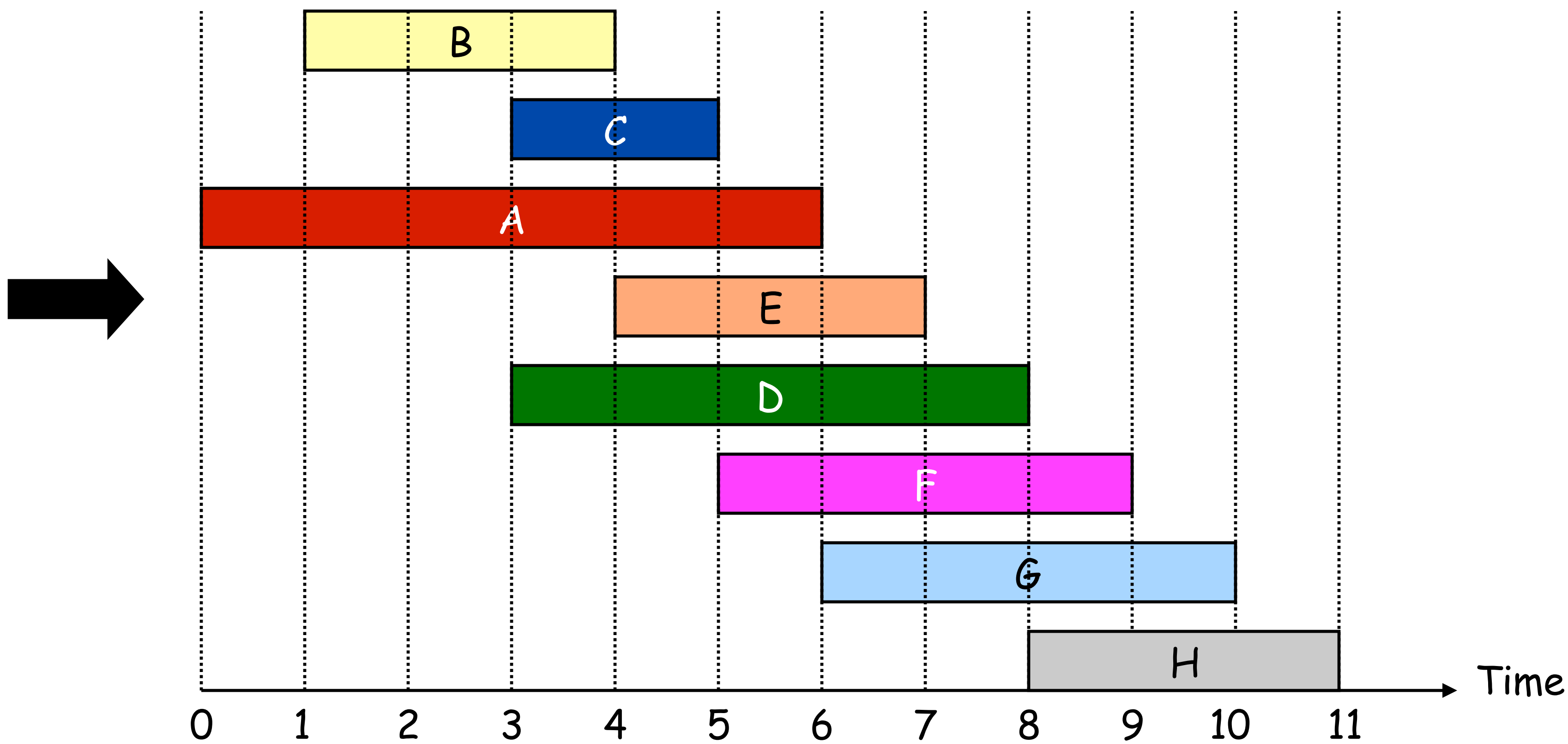

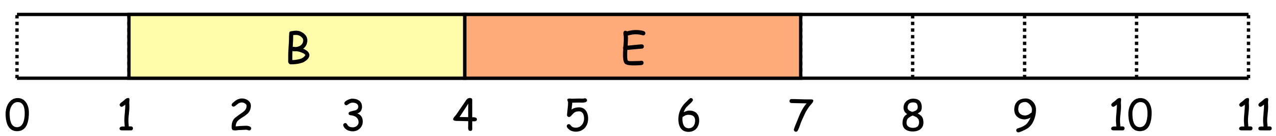

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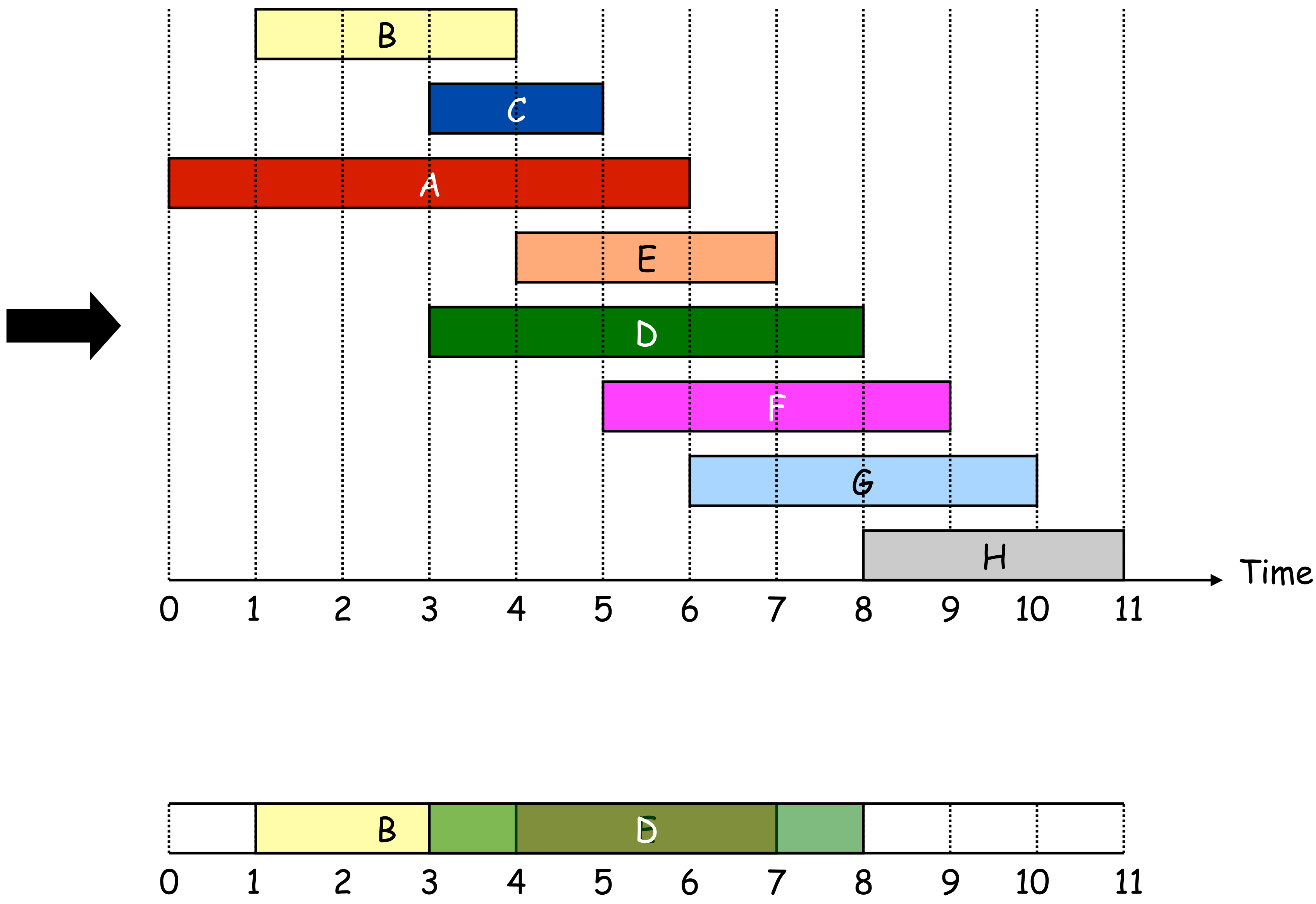

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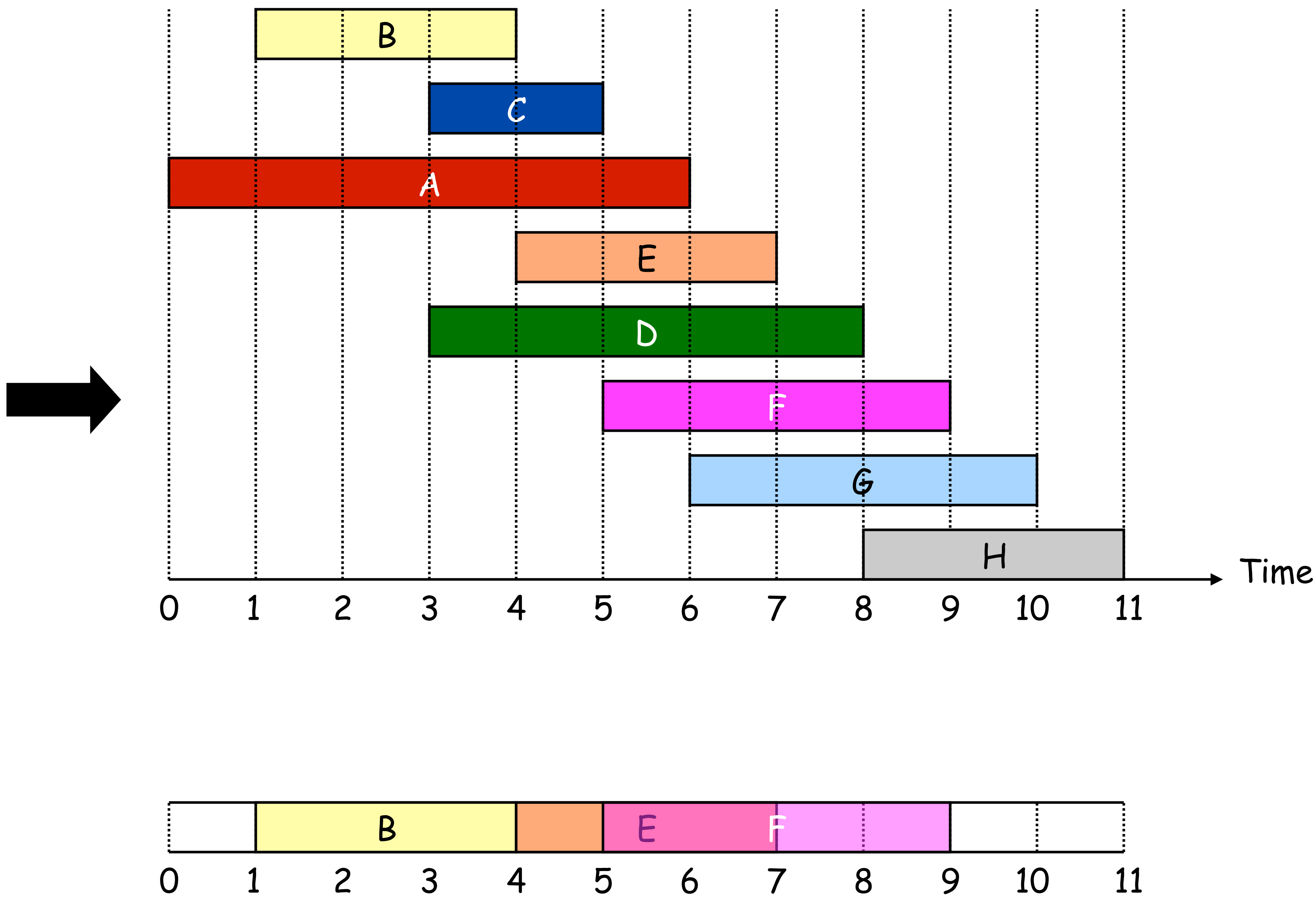

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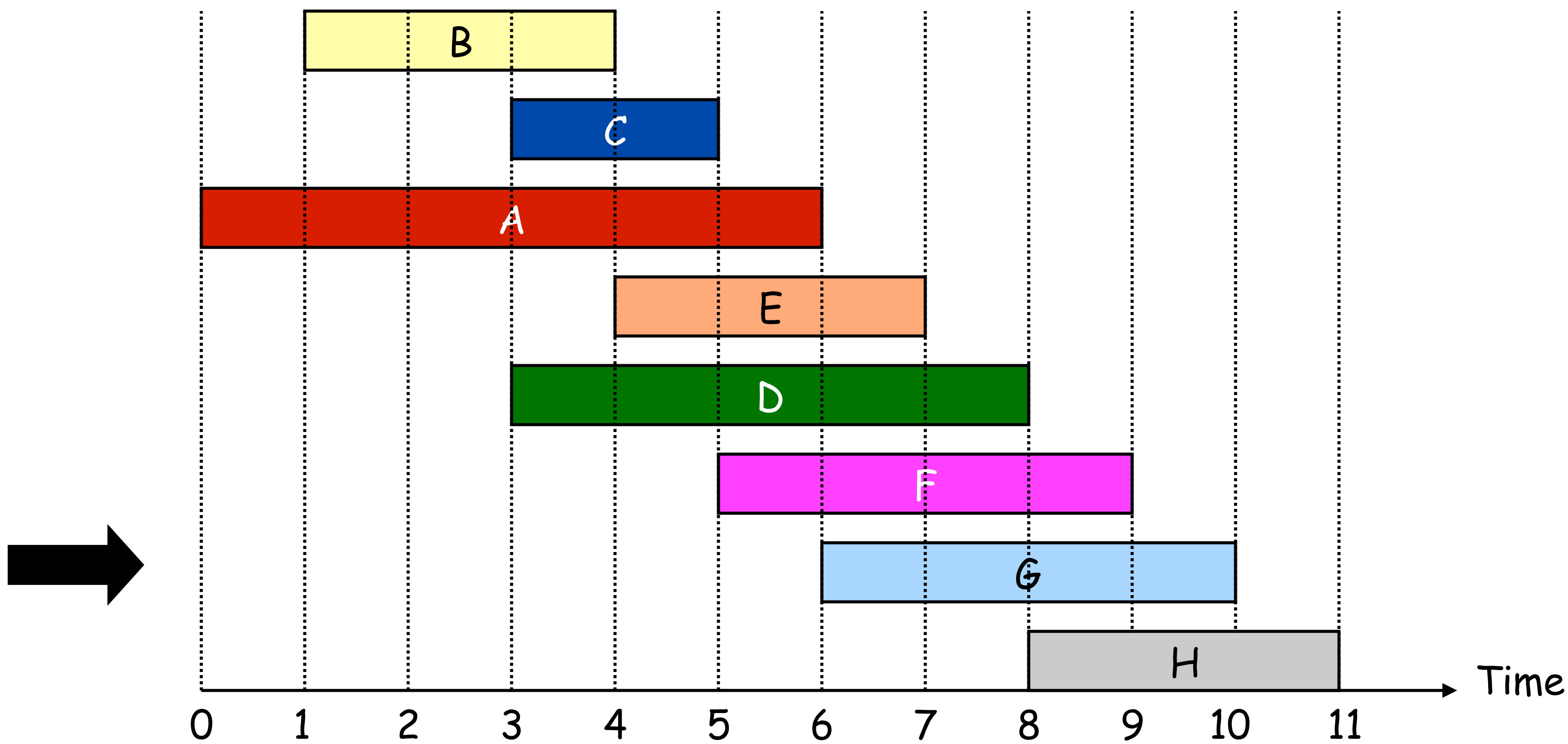

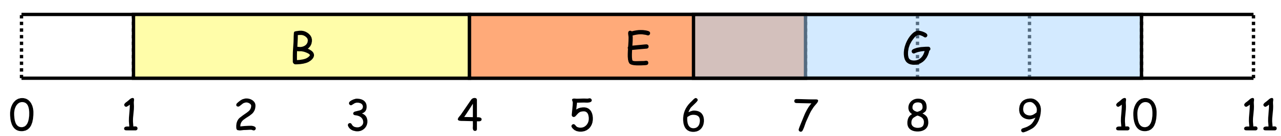

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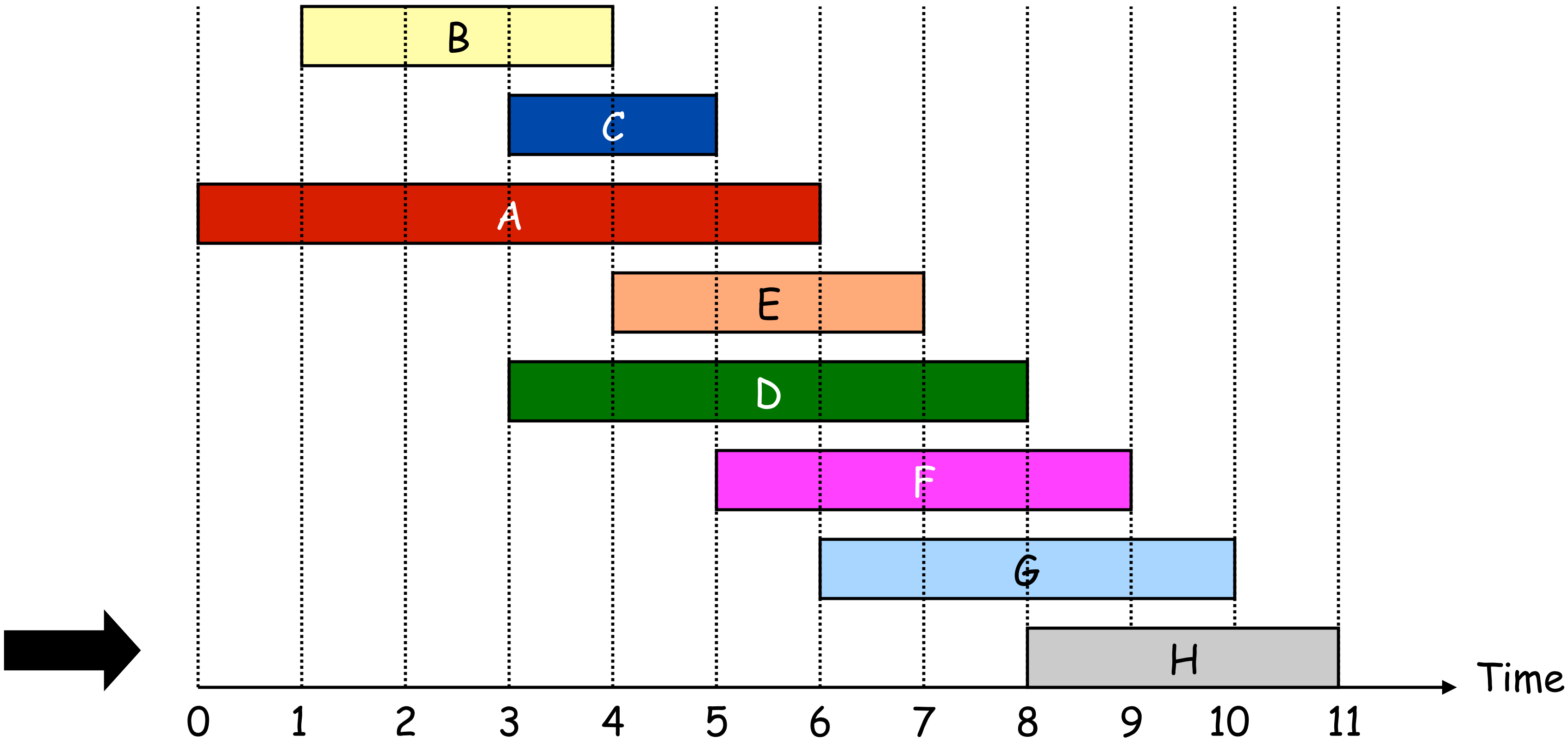
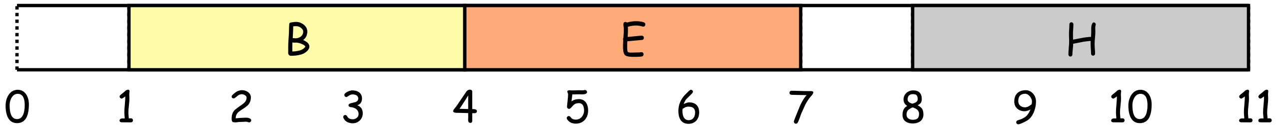




Interval Scheduling: Correctness

Theorem. Greedy algorithm is optimal.

Pf. ("greedy stays ahead")

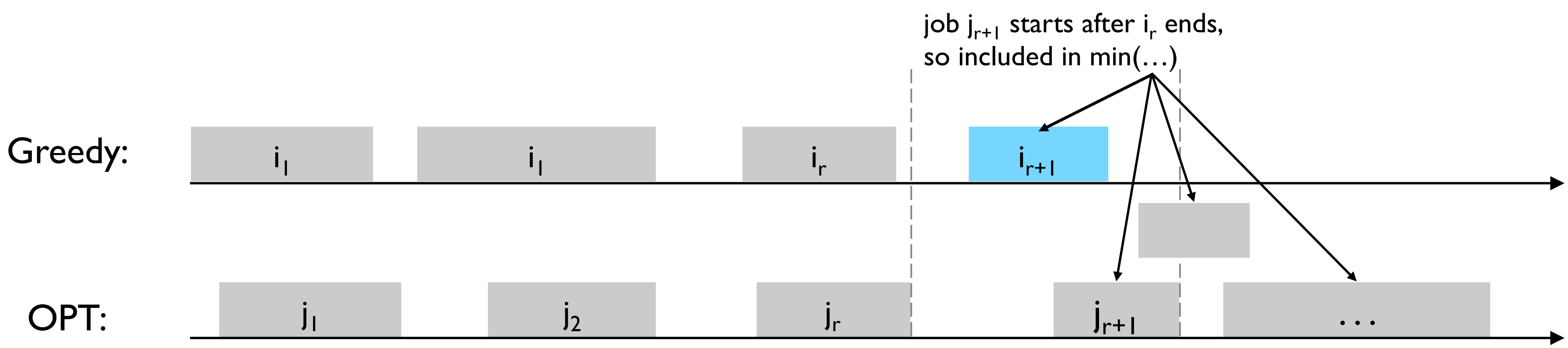
Let $i_1, i_2, \ldots i_k$ be jobs picked by greedy, $j_1, j_2, \ldots j_m$ those in some optimal solution

Show $f(i_r) \leq f(j_r)$ by induction on r.

Basis: i_1 chosen to have min finish time, so $f(i_1) \leq f(j_1)$

Ind: $f(i_r) \leq f(j_r) \leq s(j_{r+1})$, so j_{r+1} is among the candidates considered by greedy when it picked i_{r+1}, & it picks min finish, so $f(i_{r+1}) \leq f(j_{r+1})$

Similarly, $k \geq m$, else j_{k+1} is among (nonempty) set of candidates for i_{k+1}



4.1 Interval Partitioning

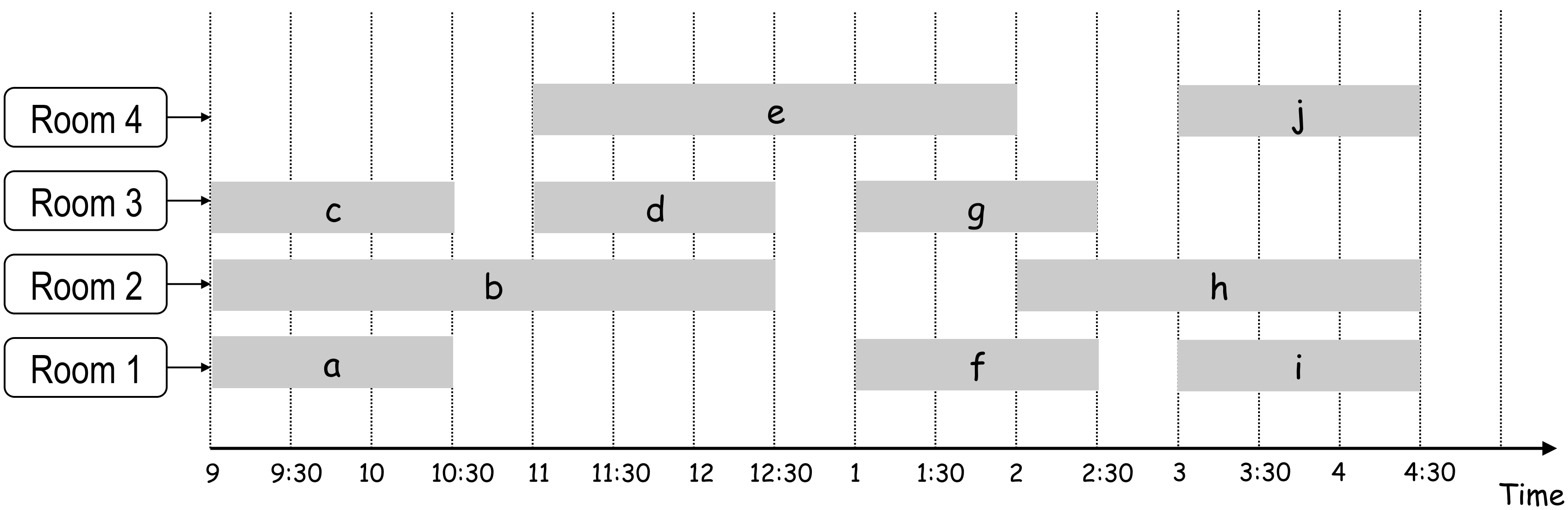
Proof Technique 2: "Structural"

Interval Partitioning

Interval partitioning.

- Lecture j starts at s_j and finishes at f_j.
- Goal: find minimum number of classrooms to schedule all lectures so that no two occur at the same time in the same room.

Ex: This schedule uses 4 classrooms to schedule 10 lectures.



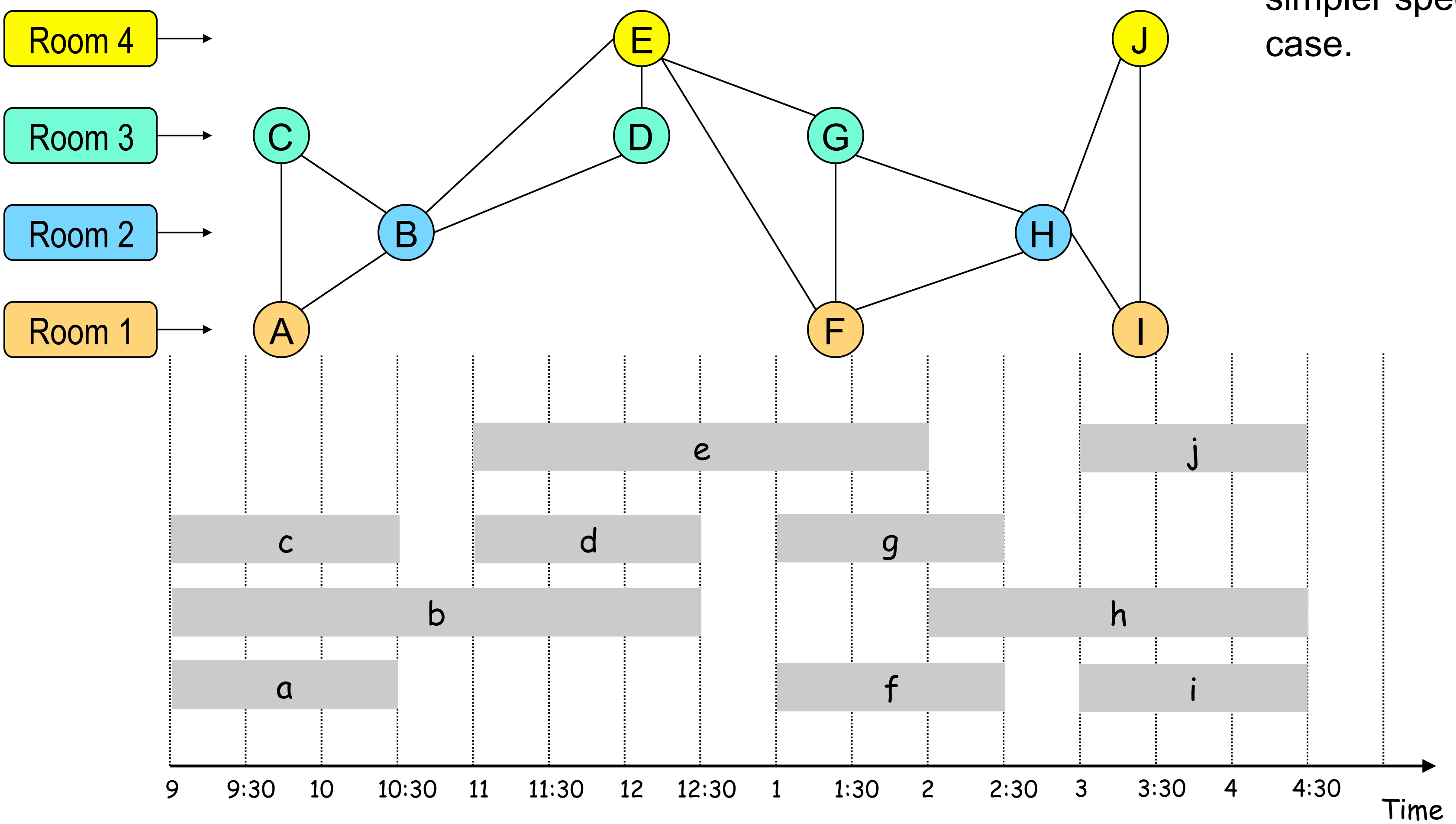
Interval Partitioning as Interval Graph Coloring

Vertices = classes;

edges = conflicting class pairs;

different colors = different assigned rooms

Note: graph coloring is very hard in general, but graphs corresponding to interval intersections are a much simpler special case.

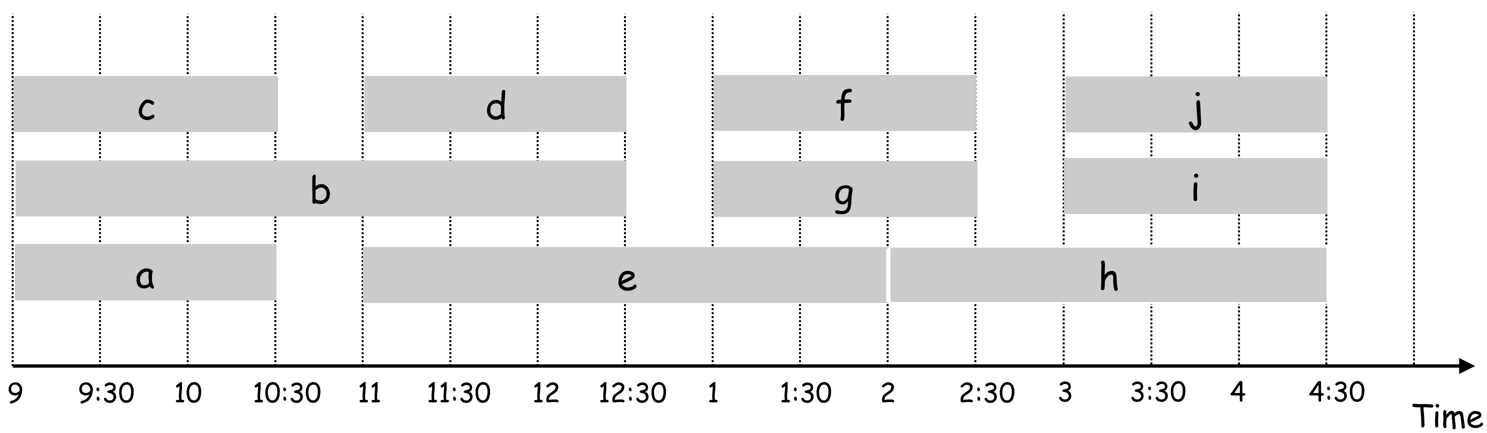


Interval Partitioning

Interval partitioning.

- Lecture j starts at s_j and finishes at f_j.
- Goal: find minimum number of classrooms to schedule all lectures so that no two occur at the same time in the same room.

Ex: This schedule uses only 3.



Interval Partitioning: A "Structural" Lower Bound on Optimal Solution

Def. The depth of a set of open intervals is the maximum number that contain any given time.

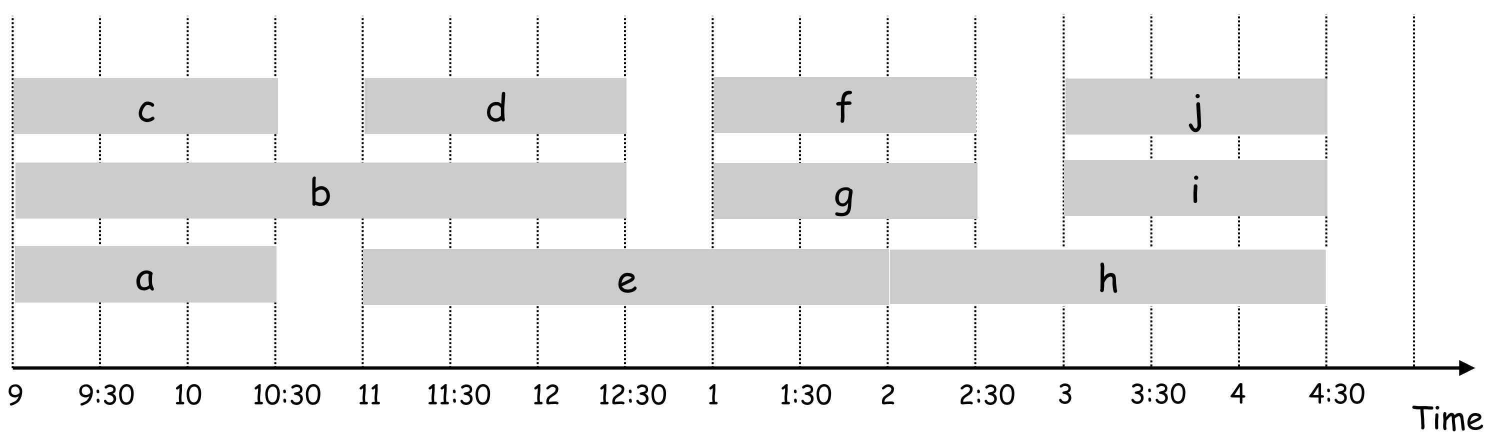
no collisions at ends

Key observation. Number of classrooms needed $\geq$ depth.

Ex: Depth of schedule below = 3 $\Rightarrow$ schedule below is optimal.

a, b, c all contain 9:30

Q. Does there always exist a schedule equal to depth of intervals?



Interval Partitioning: Greedy Algorithm

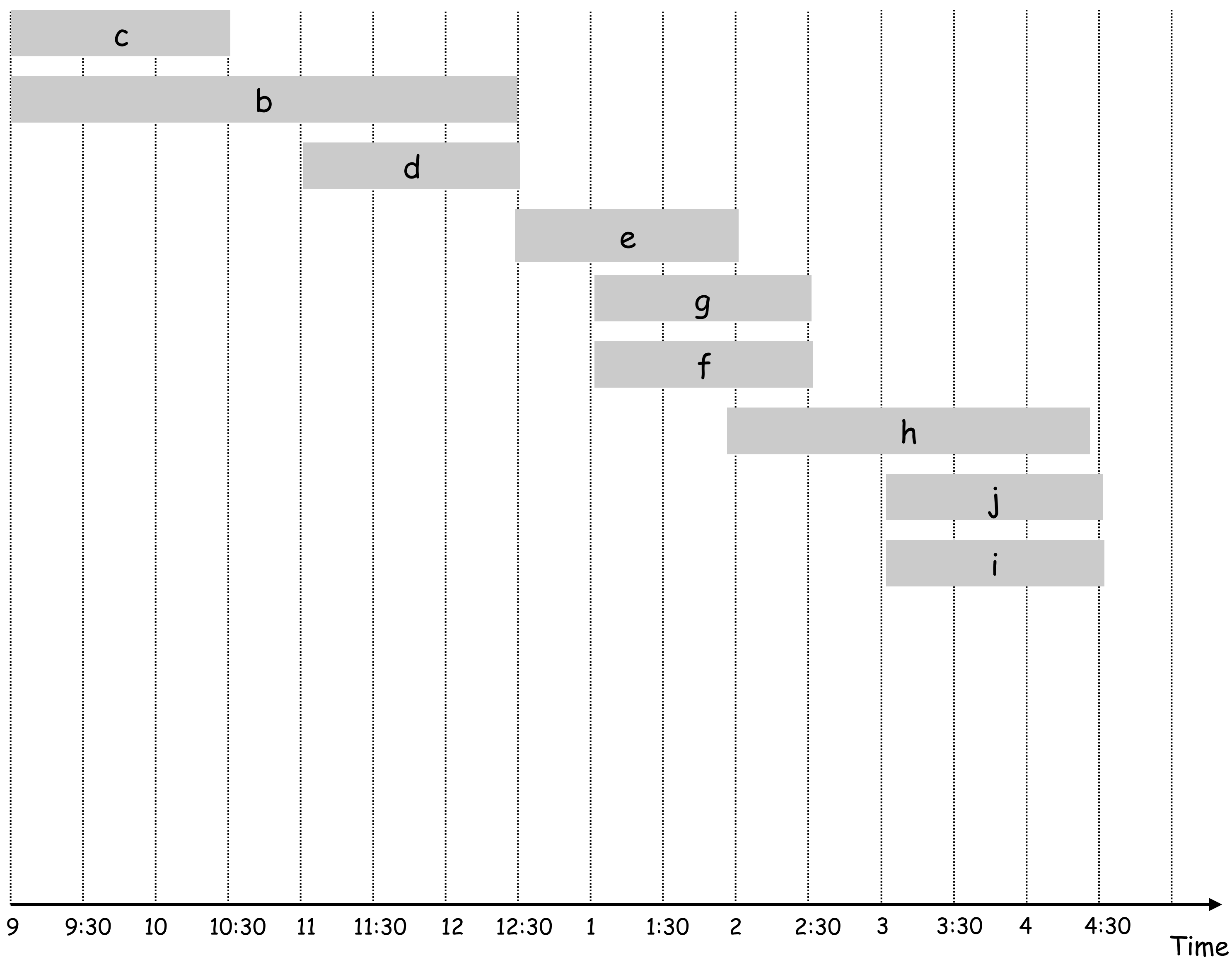
Greedy algorithm. Consider lectures in increasing order of start time: assign lecture to any compatible classroom.

```
Sort intervals by starting time so that s1 ≤ s2 ≤ ... ≤ sn.
d= 0       ← number of allocated classrooms

for j = 1 to n {
   if (lect j is compatible with some classroom k, 1≤k≤d)
      schedule lecture j in classroom k
   else
      allocate a new classroom d + 1
      schedule lecture j in classroom d + 1
      d = d + 1
}
```

Implementation? Run-time?
Exercises

Interval Partitioning



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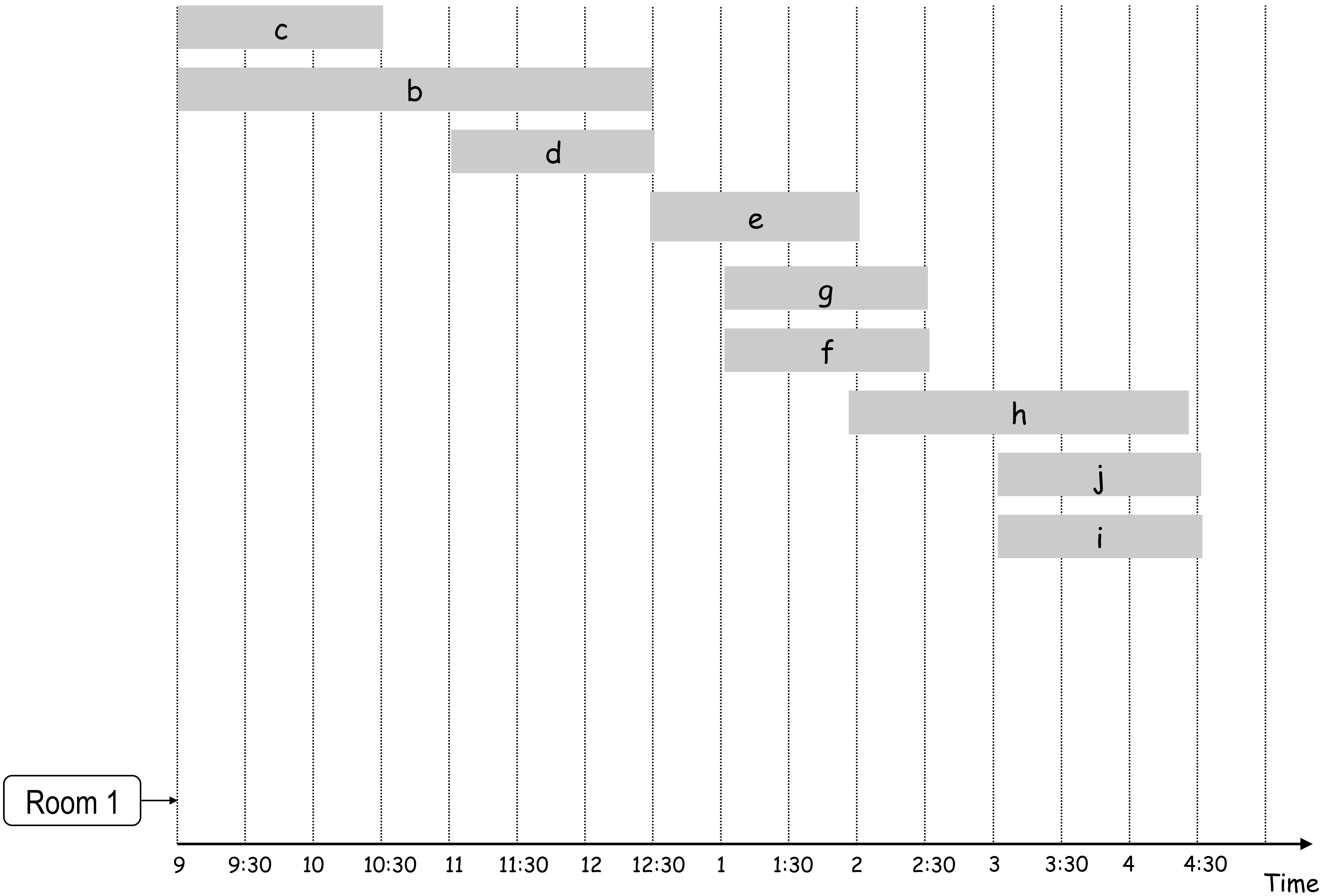

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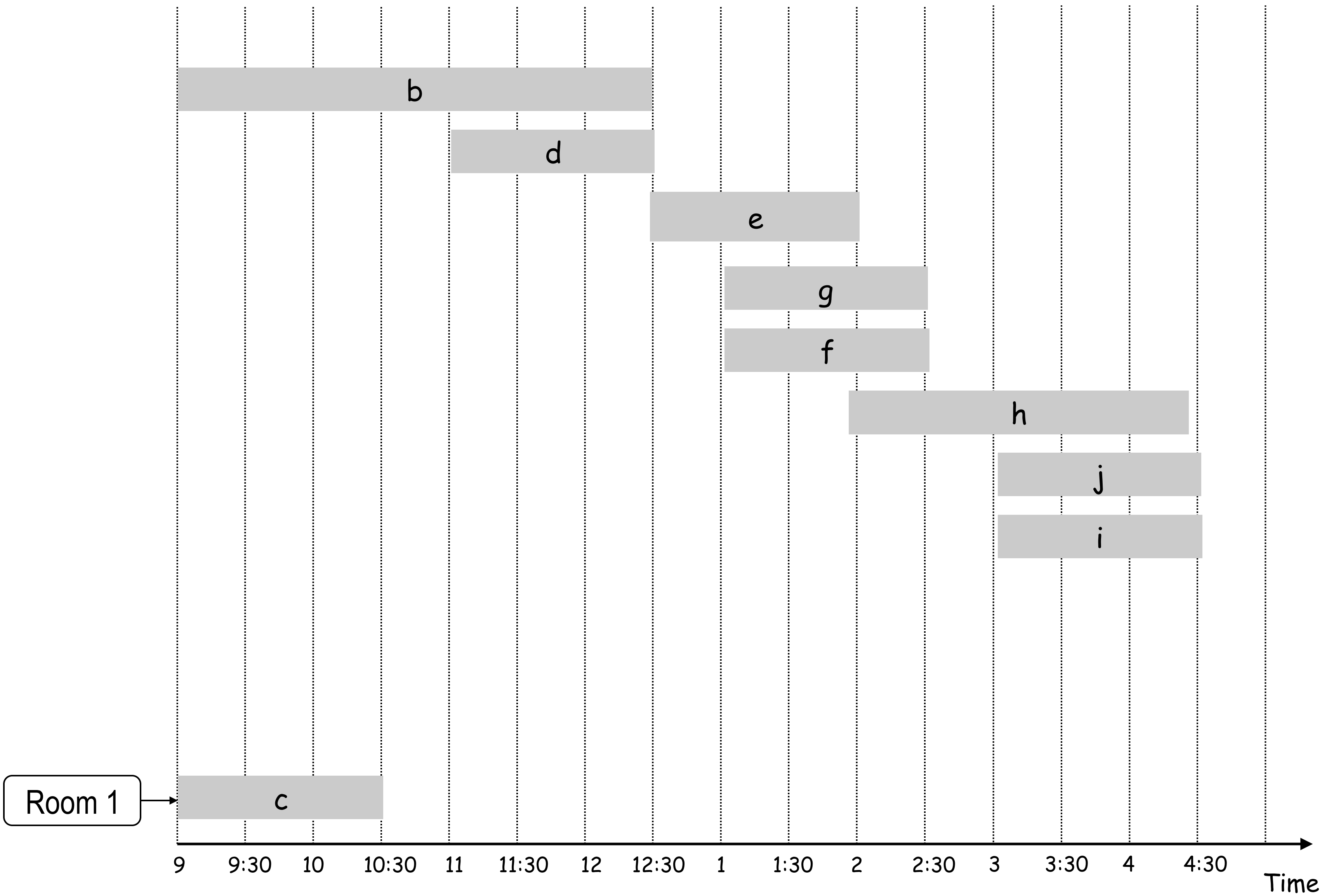

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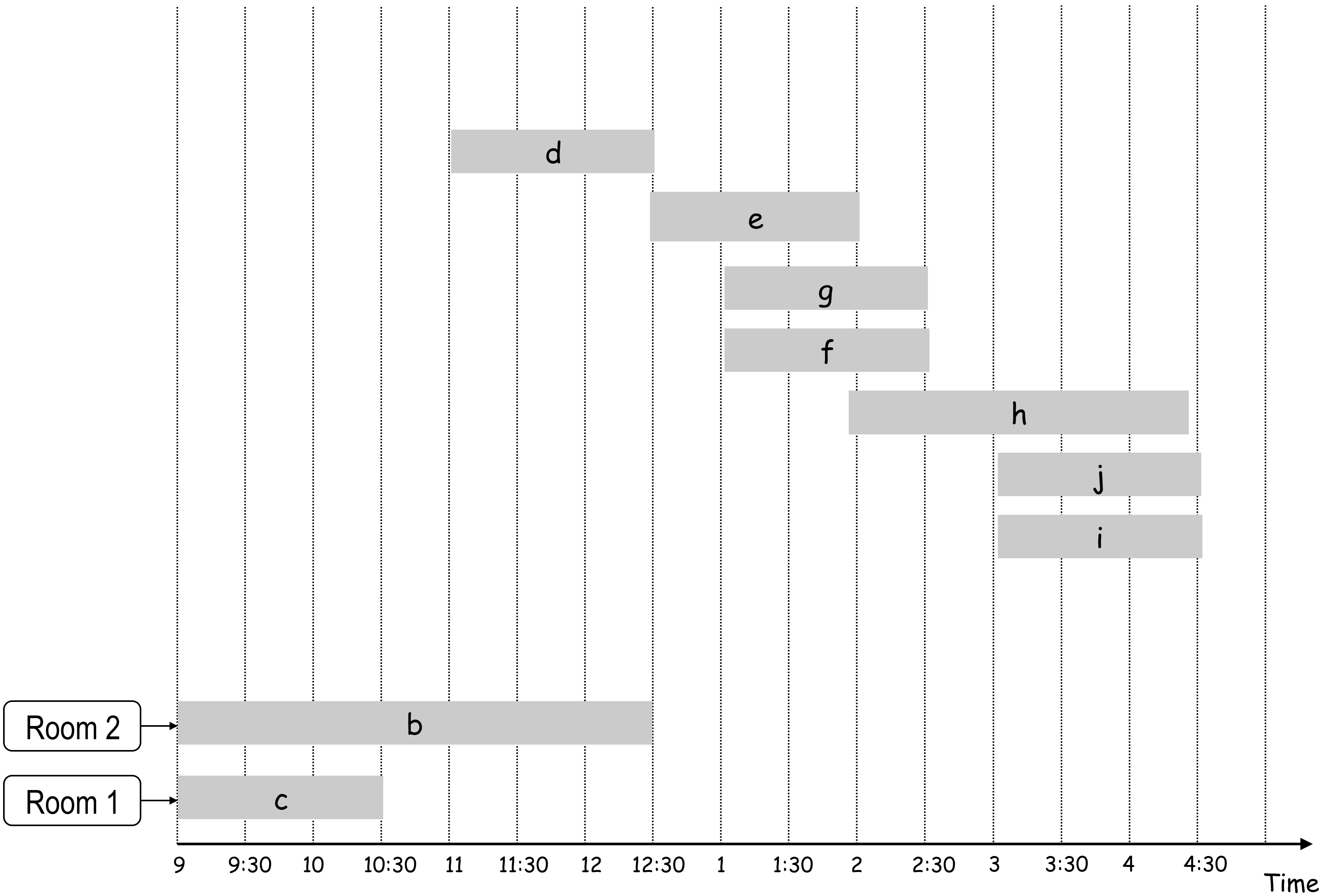

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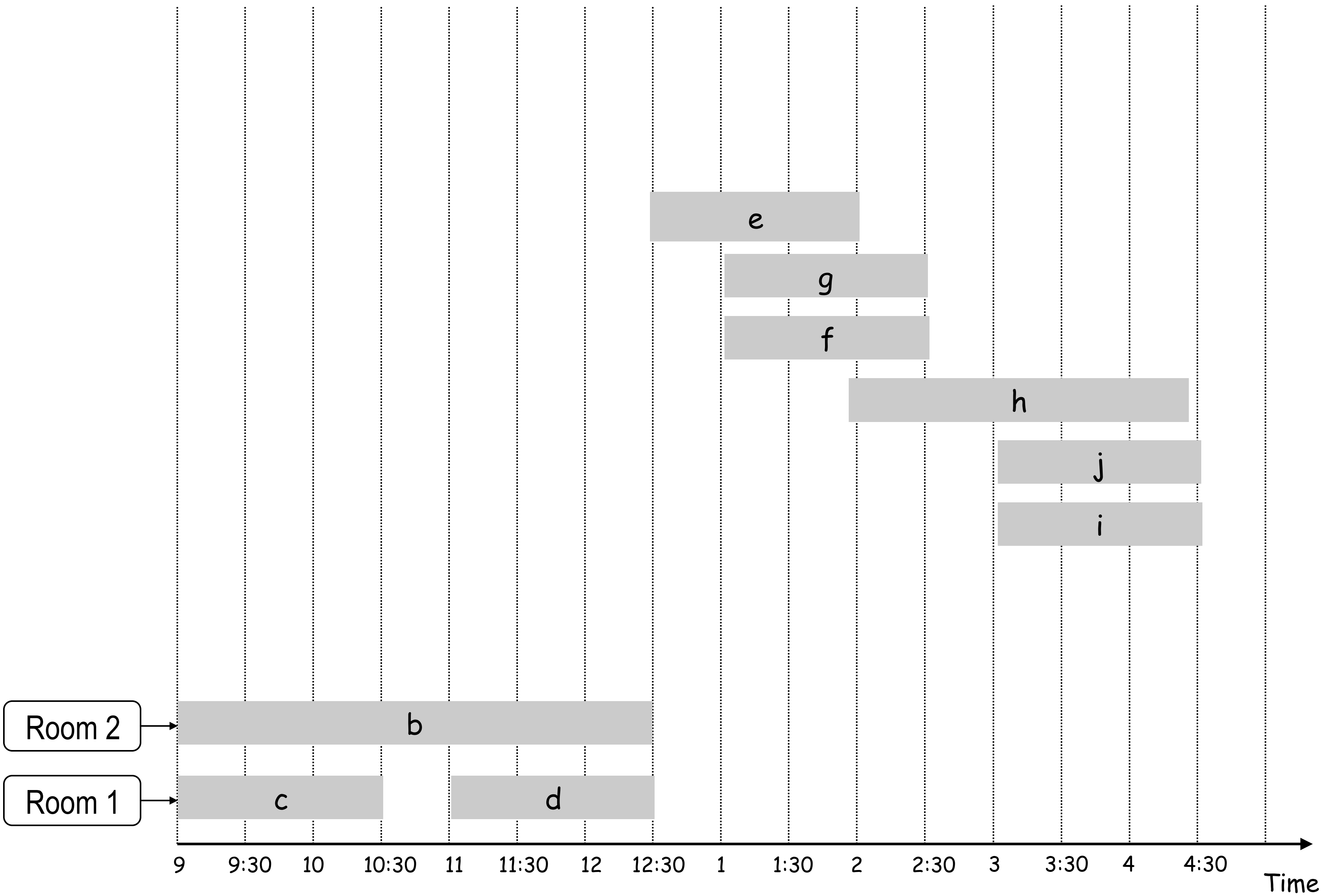

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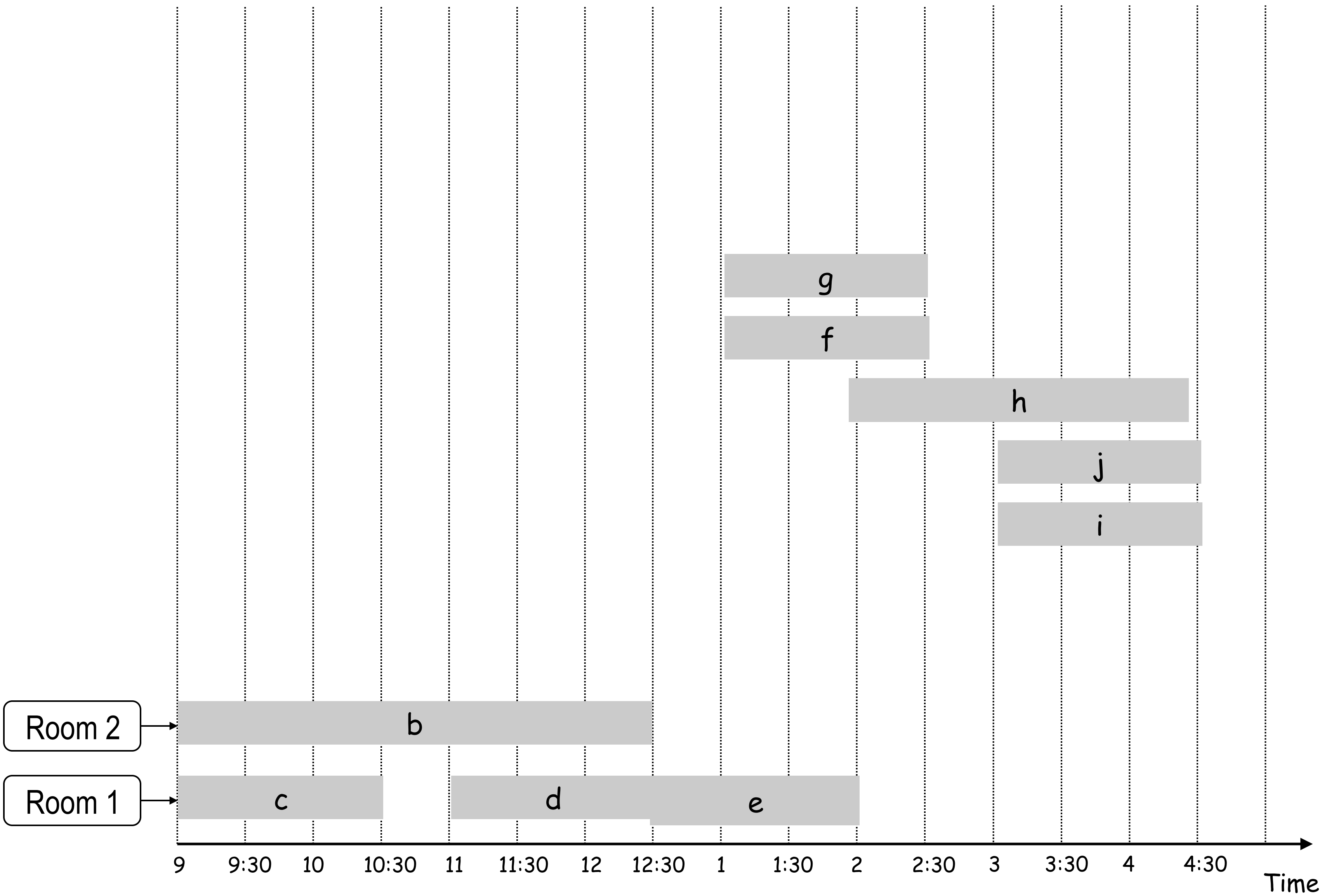

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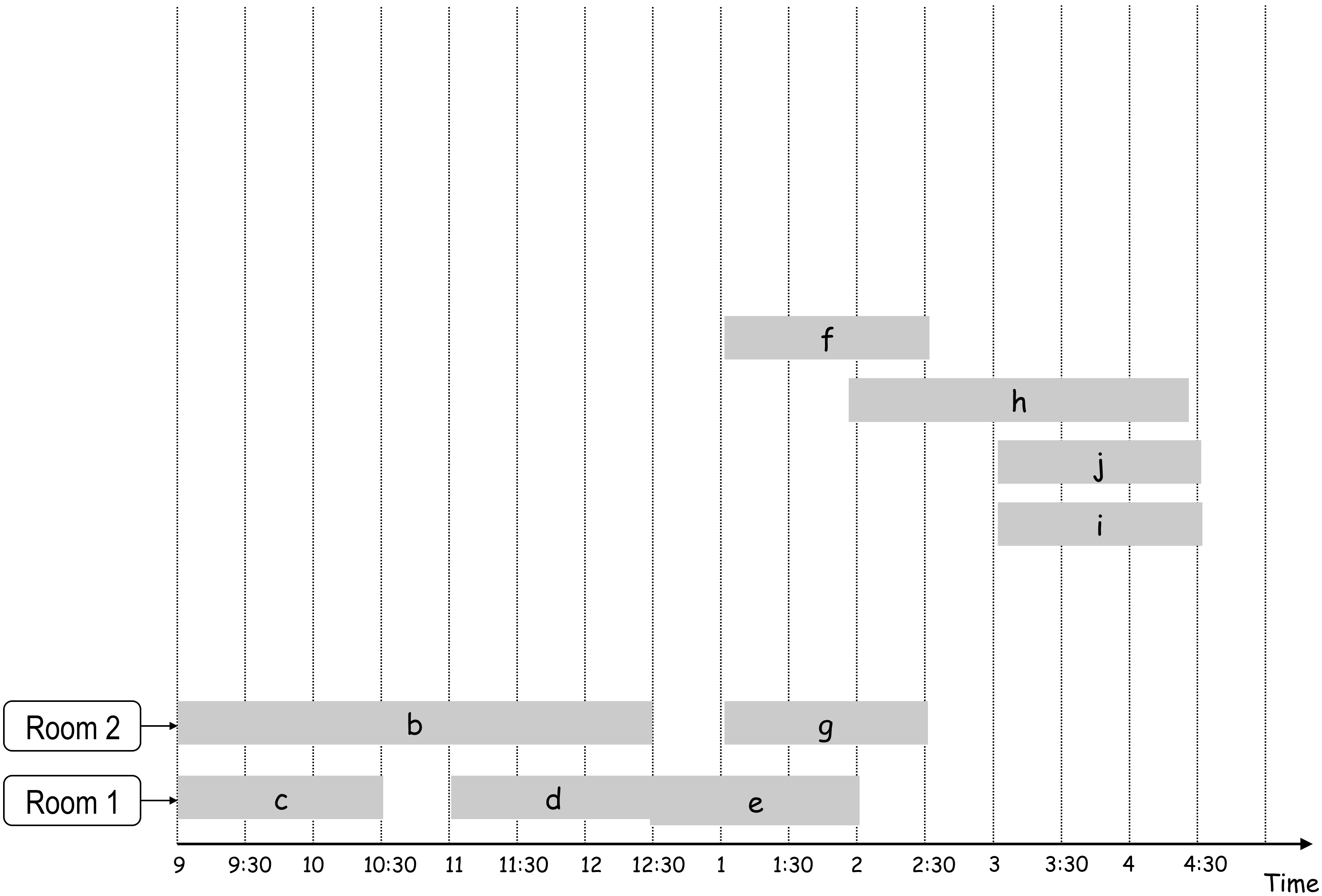

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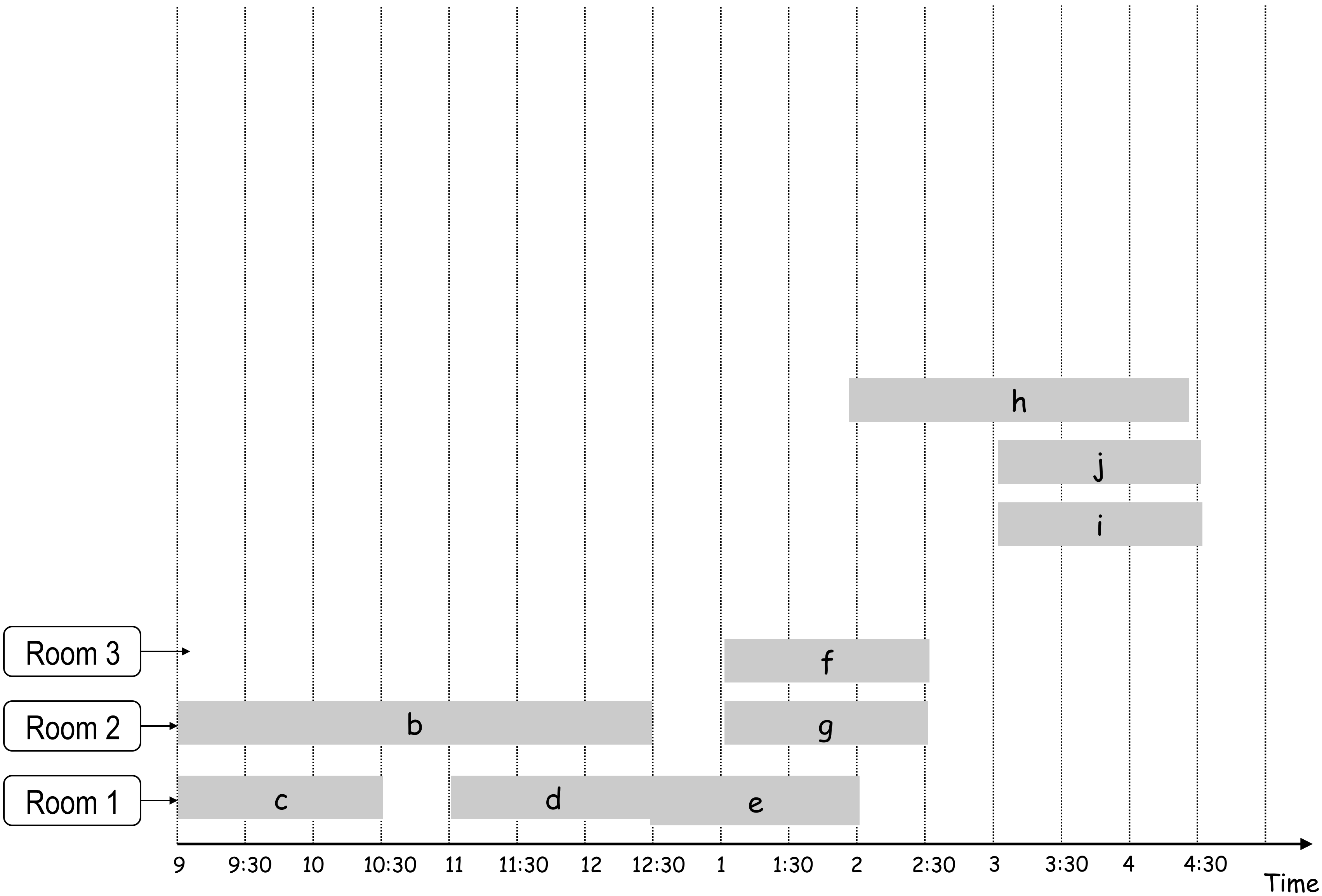

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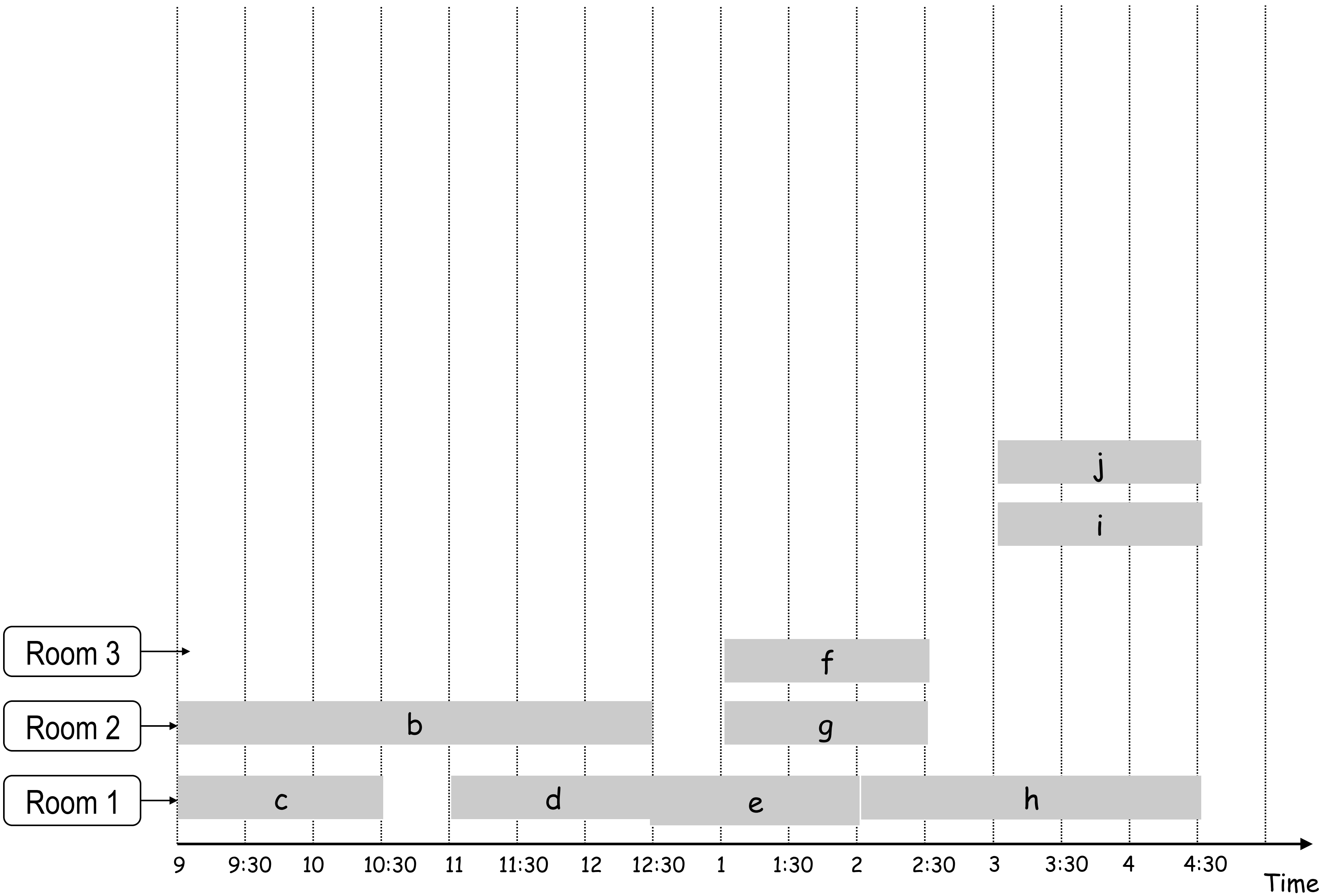

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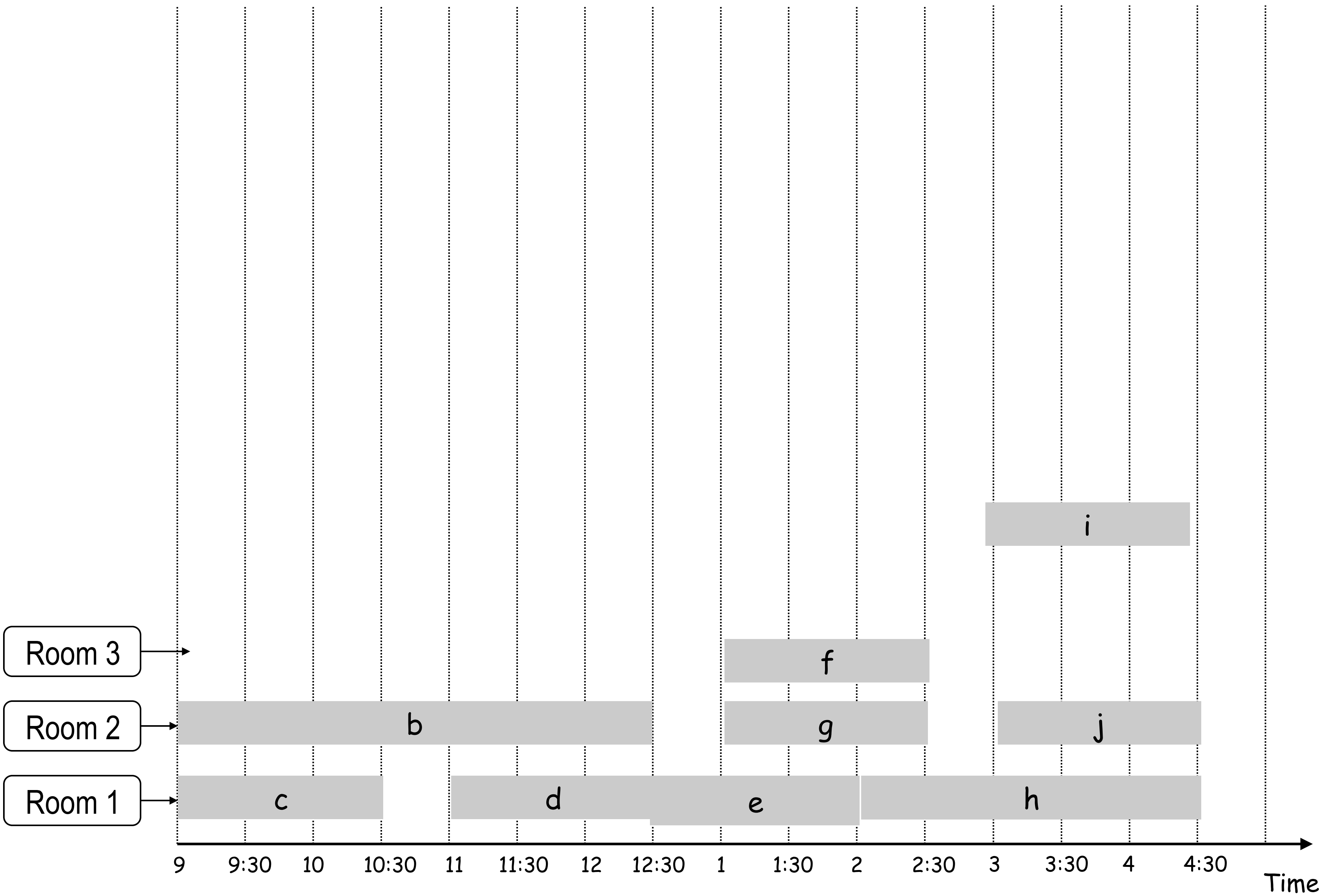

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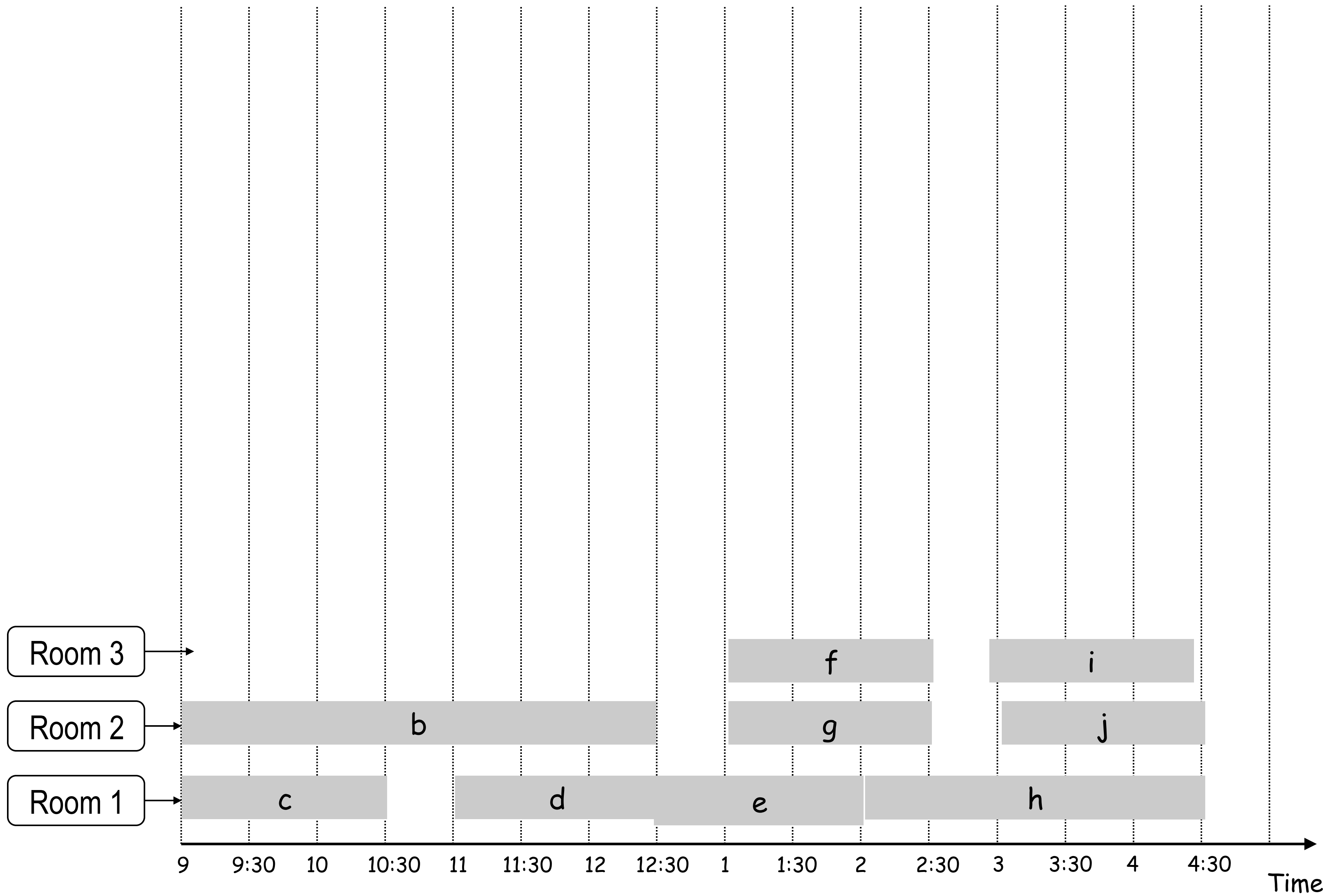

Interval Partitioning: Greedy Analysis

Theorem. Greedy algorithm is optimal.

Pf (exploit structural property).

- Let d = number of classrooms that the greedy algorithm allocates.
- Classroom d is opened because we needed to schedule a job, say j, that is incompatible with all d-1 previously used classrooms.
- Since we sorted by start time, all these incompatibilities are caused by lectures that start no later than s_j.
- Thus, we have d lectures overlapping at time s_j , i.e. depth ≥ d
- "Key observation" all schedules use ≥ depth classrooms, so d = depth and greedy is optimal ▪