## CS 218 Design and Analysis of Algorithms

#### Nutan Limaye

Module 3: NP hardness and reductions

In Module 1 and 2 we saw many problems that are efficiently solvable.

In Module 1 and 2 we saw many problems that are efficiently solvable.

One might feel that indeed all problems ARE efficiently solvable.

In Module 1 and 2 we saw many problems that are efficiently solvable.

One might feel that indeed all problems ARE efficiently solvable.

Is this true?

In Module 1 and 2 we saw many problems that are efficiently solvable.

One might feel that indeed all problems ARE efficiently solvable.

Is this true?

The answer is

In Module 1 and 2 we saw many problems that are efficiently solvable.

One might feel that indeed all problems ARE efficiently solvable.

Is this true?

The answer is we do not know.

In Module 1 and 2 we saw many problems that are efficiently solvable.

One might feel that indeed all problems ARE efficiently solvable.

Is this true?

The answer is we do not know.

There are problems believed to be impossible to solve efficiently.

There are problems believed to be impossible to solve efficiently.

Unfortunately, many of them are extremely important problems.

There are problems believed to be impossible to solve efficiently.

Unfortunately, many of them are extremely important problems.

Which we would like to solve efficiently.

There are problems believed to be impossible to solve efficiently.

Unfortunately, many of them are extremely important problems.

Which we would like to solve efficiently.

In this module we will see some examples of such problems.

There are problems believed to be impossible to solve efficiently.

Unfortunately, many of them are extremely important problems.

Which we would like to solve efficiently.

In this module we will see some examples of such problems.

We will also build a theory around such problems.

There are problems believed to be impossible to solve efficiently.

Unfortunately, many of them are extremely important problems.

Which we would like to solve efficiently.

In this module we will see some examples of such problems.

We will also build a theory around such problems.

Jobs and processors.

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively.

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

A schedule  ${\cal S}$  is an ordering of these jobs on the two processors.

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

A schedule  ${\cal S}$  is an ordering of these jobs on the two processors.

E.g. If we have jobs  $J_1, J_2, J_3, J_4$ . A schedule  $S = (\sigma_1, \sigma_2)$  could be  $(\langle 1, 4 \rangle, \langle 3, 2 \rangle)$ .

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

A schedule  ${\cal S}$  is an ordering of these jobs on the two processors.

E.g. If we have jobs  $J_1, J_2, J_3, J_4$ . A schedule  $S = (\sigma_1, \sigma_2)$  could be  $(\langle 1, 4 \rangle, \langle 3, 2 \rangle)$ .

This says that schedule job 1 followed by job 4 on  $P_1$  and schedule job 3 on followed by 2 on  $P_2$ .

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

A schedule  ${\cal S}$  is an ordering of these jobs on the two processors.

E.g. If we have jobs  $J_1, J_2, J_3, J_4$ . A schedule  $S = (\sigma_1, \sigma_2)$  could be  $(\langle 1, 4 \rangle, \langle 3, 2 \rangle)$ .

This says that schedule job 1 followed by job 4 on  $P_1$  and schedule job 3 on followed by 2 on  $P_2$ .

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

A schedule  $S = (\sigma_1, \sigma_2)$  is an ordering of these jobs on the two processors.

Let  $S_1$  be the set of jobs scheduled on  $P_1$ .

Jobs and processors.

We have 2 processors.  $P_1$ ,  $P_2$ .

We have jobs  $J_1, \ldots, J_n$  with durations  $d_1, \ldots, d_n$ , respectively. We assume that  $d_i$ s are positive integers.

A schedule  $S = (\sigma_1, \sigma_2)$  is an ordering of these jobs on the two processors.

Let  $S_1$  be the set of jobs scheduled on  $P_1$ .

The total completion time of a schedule S is  $\max \{\sum_{i \in S_1} d_i, \sum_{i \in \lceil n \rceil \setminus S_1} d_i \}$ .



Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Some key differences.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Some key differences.

No begin and end times, just durations.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Some key differences.

No begin and end times, just durations.

Multiple processors instead of just one.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Some key differences.

No begin and end times, just durations.

Multiple processors instead of just one.

All jobs must be eventually done.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Some key differences.

No begin and end times, just durations.

Multiple processors instead of just one.

All jobs must be eventually done.

Will this problem be harder or easier to solve?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

Quite similar to the interval scheduling problem from Module 1.

Some key differences.

No begin and end times, just durations.

Multiple processors instead of just one.

All jobs must be eventually done.

Will this problem be harder or easier to solve?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A possible schedule.  $S = (\langle 1, 3, 5, \dots, n-1 \rangle, \langle 2, 4, 6, \dots, n \rangle).$ 

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A possible schedule.  $S = (\langle 1, 3, 5, \dots, n-1 \rangle, \langle 2, 4, 6, \dots, n \rangle)$ . Say n even.

Will this work?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A possible schedule.  $S = (\langle 1, 3, 5, \dots, n-1 \rangle, \langle 2, 4, 6, \dots, n \rangle)$ . Say n even.

Will this work?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A greedy heuristic.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A greedy heuristic.

Schedule a job on the processor which is currently least loaded.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A greedy heuristic.

Schedule a job on the processor which is currently least loaded.

Will this work?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A greedy heuristic.

Schedule a job on the processor which is currently least loaded.

Will this work?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A modified greedy heuristic.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A modified greedy heuristic.

Sort the jobs in ascending order of their duration.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A modified greedy heuristic.

Sort the jobs in ascending order of their duration.

Use this order and do as before, i.e.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A modified greedy heuristic.

Sort the jobs in ascending order of their duration.

Use this order and do as before, i.e.

Schedule a job on the processor which is currently least loaded.

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A modified greedy heuristic.

Sort the jobs in ascending order of their duration.

Use this order and do as before, i.e.

Schedule a job on the processor which is currently least loaded.

Will this work?

Given: jobs  $j_1, \ldots, j_n$  with durations  $d_1, \ldots, d_n$  respectively

Find: a schedule for these jobs on 2 processors that

minimises the total completion time.

A modified greedy heuristic.

Sort the jobs in ascending order of their duration.

Use this order and do as before, i.e.

Schedule a job on the processor which is currently least loaded.

Will this work?