

# Aperiodic Scheduling

Earliest Deadline Due, Latest Deadline First, Earliest Deadline First

Exercise class 4

---

*Presenter:*  
Jürgen Mattheis

*In cooperation with:*  
Pascal Walter

*Based on the lecture of:*  
Marco Zimmerling

*November 29, 2022*

University of Freiburg, Chair for Embedded Systems



# Gliederung

Organisation

Overview Aperiodic Task Scheduling

Task 1

Task 2

Task 3



Task 4

# Organisation






# Organisation I

► feedback for me: <https://forms.gle/f3YN8EFrZ1vsfPoC6>

Feedback for Introduction to ESE Tutor Jürgen  

Questions Responses Settings

0 responses  

Accepting responses 

Waiting for responses

# Overview Aperiodic Task Scheduling



# Overview Aperiodic Task Scheduling

	Equal arrival times non preemptive	Arbitrary arrival times preemptive
Independent tasks	EDD (Jackson)	EDF (Horn)
Dependent tasks	LDF (Lawler)	EDF* (Chetto)

# Task 1

# Task 1

## Earliest Deadline Due

### Task 1.1:

	$J_1$	$J_2$	$J_3$	$J_4$
$C_i$	3	6	2	4
$D_i$	8	15	3	11

$(\forall J_i : r_i = 0)$

### Requirements 1.1:

- ▶ *non-preemptive*
- ▶ tasks have *same arrival times* (synchronous arrivals)
- ▶ tasks are *independent*
- ▶  $\min(D_i)$  for all remaining  $J_i$
- ▶ *minimizing the maximum lateness*



# Task 1

## Earliest Deadline Due

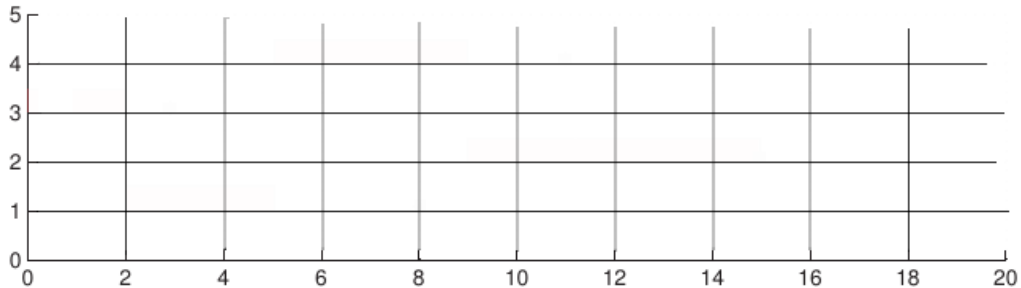


Figure 1: EDD schedule.

# Task 1

## Earliest Deadline Due

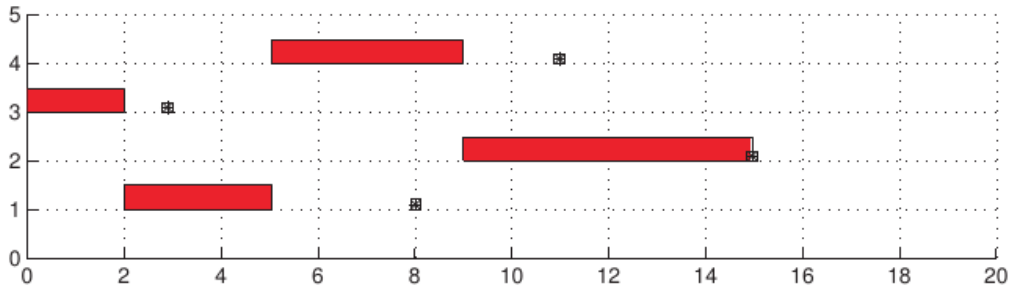


Figure 1: EDD schedule.

# Task 2



# Task 2

## Latest Deadline First

### Task 2.1:

	$J_1$	$J_2$	$J_3$	$J_4$	$J_5$	$J_6$	$J_7$	$J_8$
$C_i$	3	4	2	3	3	2	2	1
$D_i$	5	8	11	15	12	18	19	20

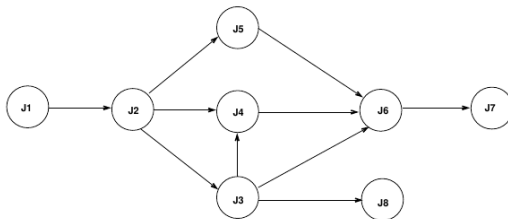


Figure 2: Precedence graph.

# Task 2

## Latest Deadline First

### Requirements 2.1:



- ▶ is *non-preemptive*
- ▶ *synchronous task activations*
- ▶ tasks are *dependent*, use *precedence graph*, going from *tail* to *head*
- ▶  $\max(D_i)$  for all tasks  $J_i$  *without successors* or whose *successors* have been all selected in the *precedence graph* inserted into the queue to be *executed last*
- ▶ at runtime, tasks are extracted from the *head of the queue*: the *first task* inserted in the queue will be *executed last*
- ▶ *minimizes the maximum lateness*

# Task 2

## Latest Deadline First

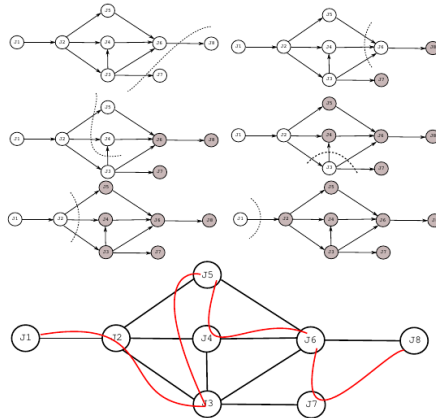


Figure 4: The LDF algorithm proceeds as depicted (figures left to right)

# Task 2

## Latest Deadline First

► queue of tasks: ( , , , , , , , )

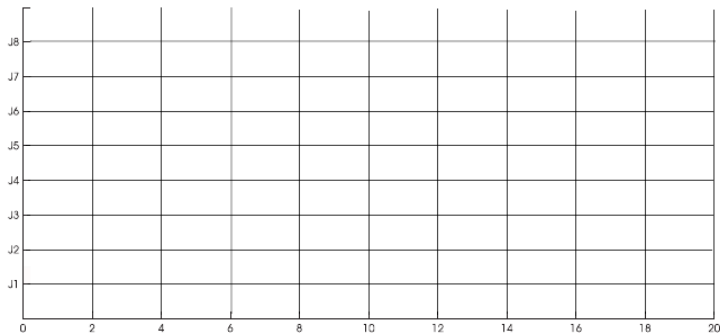


Figure 3: LDF schedule.

# Task 2

## Latest Deadline First

- queue of tasks:  $(J_1, J_2, J_3, J_5, J_4, J_6, J_7, J_8)$

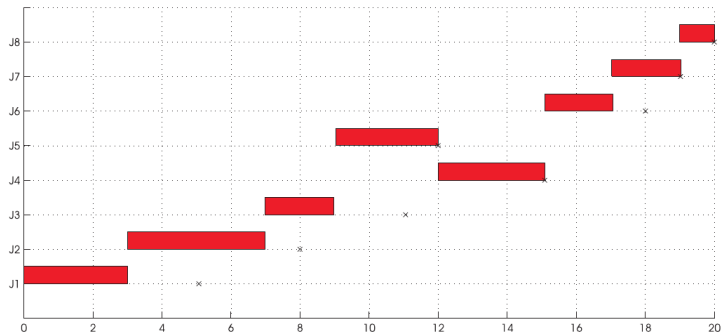


Figure 3: LDF schedule.



# Task 3



# Task 3

## Earliest Deadline First

### Task 3.1:

	$J_1$	$J_2$	$J_3$	$J_4$	$J_5$
$a_i$	0	2	0	8	13
$C_i$	3	1	6	2	3
$d_i$	16	7	8	11	18

### Requirements 3.1:

- ▶ *is preemptive*
- ▶ *arbitrary arrival times*
- ▶ *the tasks are independent*
- ▶ *minimizes the maximum lateness*
- ▶  *$\min(D_i)$  for all remaining tasks  $J_i$  that have already arrived (are ready) and not finished every time the arrival time of a task is reached*

# Task 3

## Earliest Deadline First

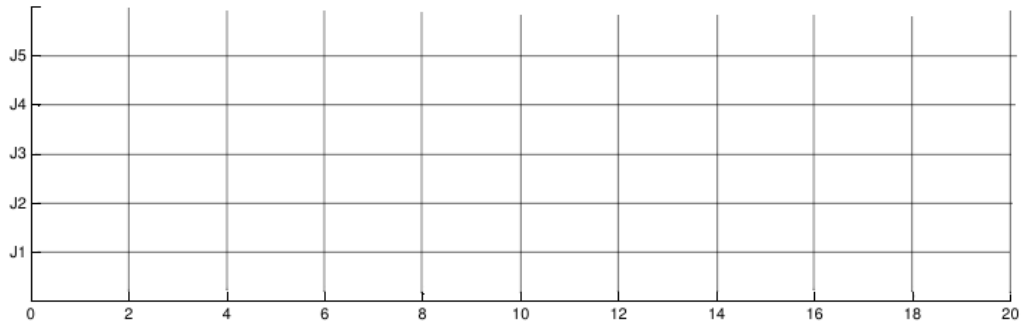


Figure 5: EDF schedule

# Task 3

## Earliest Deadline First

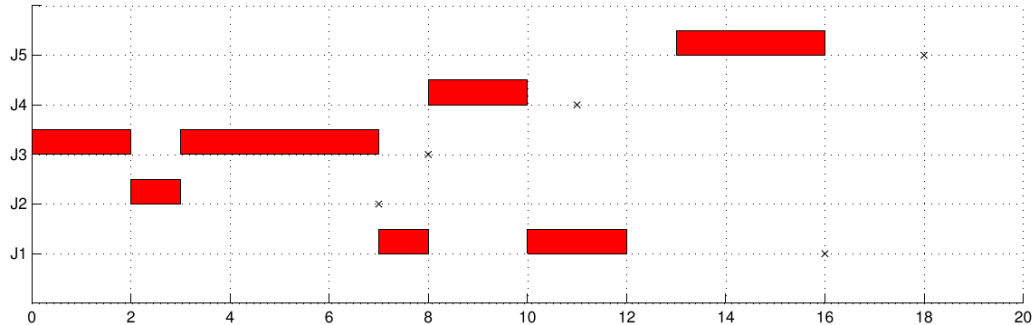


Figure 5: EDF schedule

# Task 3

## Earliest Deadline First

### Task 3.2:

- ▶ at time  $t = 3$ , a new task  $J_x$  arrives with execution time  $C_x = 2$  and deadline  $d_x = 10$ .
- ▶ still **guarantee the schedulability** of task set?

### Requirements 3.2:

- ▶  $\forall i = 1, \dots, n \quad t + \sum_{k=1}^i c_k(t) \leq d_i$

# Task 4

# Task 4 I

## EDF\* - Example

### Task 4.1:

Given tasks  $A, B, C, D, E, F, G$  with precedences  $A \rightarrow C, B \rightarrow C, C \rightarrow E, D \rightarrow F, B \rightarrow D, C \rightarrow F, D \rightarrow G$ .

All tasks arrive at time  $t_0 = 0$ , have a common deadline  $d = 20$  and the following execution times:

	A	B	C	D	E	F	G
$C_i$	3	2	4	3	2	5	1

We will now prepare the tasks for EDF\*

# Task 4

## EDF\*

### Requirements 4.1:

- ▶ *non-preemptive*
- ▶ *arbitrary arrival times*
- ▶ *tasks are dependent*
- ▶ *release time and deadline* of individual tasks are modified such that all the *precedence constraints* are satisfied
- ▶ *scheduling problem is transformed* into a problem *without precedence constraints*, which can then be handled by a "normal" EDF scheduler



# Task 4 I

## EDF\* - Transformation

- ▶ EDF\* transforms the arrival time and deadline of every task in the following way:

### Deadline:

1. Task must finish the execution time within its deadline:  $f_i \leq d_i$
2. Task must not finish the execution time later than the maximum start time of its successor(s):  $f_i \leq d_j - C_j$

$$\rightarrow d_i^* = \min(d_i, \min(d_j^* - C_j : J_i \rightarrow J_j))$$

# Task 4 II

## EDF\* - Transformation

### Arrival time

1. Task must start the execution not earlier than its release time:  $s_j \geq r_j$
2. Task must not start execution earlier than the minimum finishing time of its predecessor(s):  $s_j \geq r_i + C_i$

$$\rightarrow r_j^* = \max(r_j, \max(r_i^* + C_i : J_i \rightarrow J_j))$$

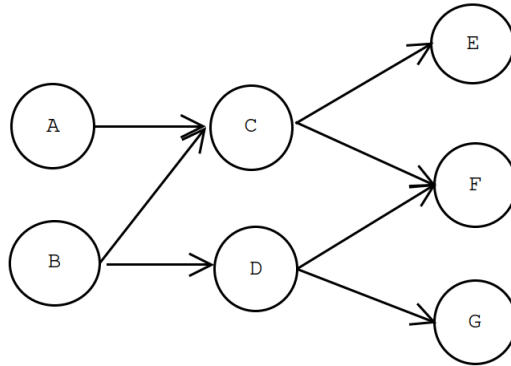
# Task 4

## EDF\* - Precedence graph example

Given the precedences  $A \rightarrow C$ ,  $B \rightarrow C$ ,  $C \rightarrow E$ ,  $D \rightarrow F$ ,  $B \rightarrow D$ ,  $C \rightarrow F$ ,  $D \rightarrow G$  we first draw the precedence graph:

# Task 4

## EDF\* - Precedence graph example



*Figure 1: Task 4: precedence graph*

# Task 4 I

## EDF\* - Transformation example

- ▶  $r_A^* = r_A, r_B^* = r_B$
- ▶  $r_C^* = \max\{r_C, \max\{r_A^* + C_A, r_B^* + C_B\}\} = \max\{0, \max\{3, 2\}\} = 3$
- ▶  $r_D^* = \max\{r_D, r_B^* + C_B\} = \max\{0, 2\} = 2$
- ▶  $r_F^* = \max\{r_F, \max\{r_C^* + C_C, r_D^* + C_D\}\} = \max\{0, \max\{7, 5\}\} = 7$
- ▶  $r_E^* = \max\{r_E, r_C^* + C_C\} = \max\{0, 7\} = 7$
- ▶  $r_G^* = \max\{r_G, r_D^* + C_D\} = \max\{0, 5\} = 5$

# Task 4 II

## EDF\* - Transformation example

- ▶  $d_E^* = d_F^* = d_G^* = 20$
- ▶  $d_C^* = \min\{d_C, \min\{d_E^* - C_E, d_F^* - C_F\}\} = \min\{20, \min\{18, 15\}\} = 15$
- ▶  $d_D^* = 15$
- ▶  $d_A^* = 11$
- ▶  $d_B^* = 11$

We now successfully have transformed the problem into one without precedence and can simply use EDF!

# Task 4

## EDF\* - Transformation example

- The modified **release times** and **deadlines** are:

	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>	<i>G</i>
$r_i^*$	0	0	3	2	7	7	5
$d_i^*$	11	11	15	15	20	20	20

# Task 4

## EDF\* - Schedule

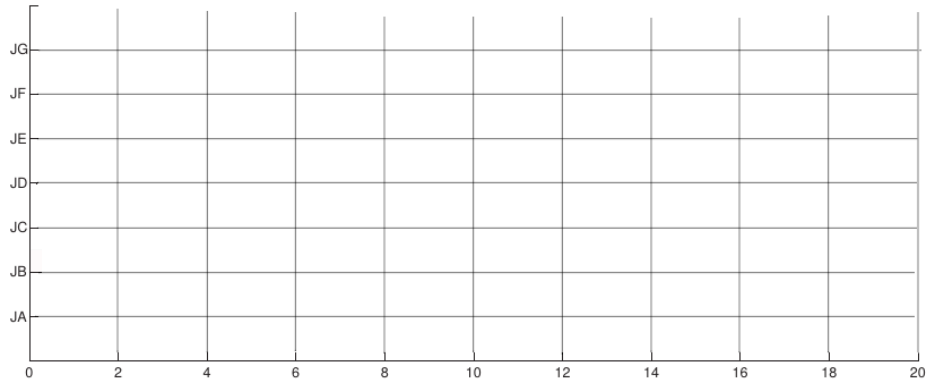


Figure 7: EDF\* schedule



# Task 4

## EDF\* - Schedule

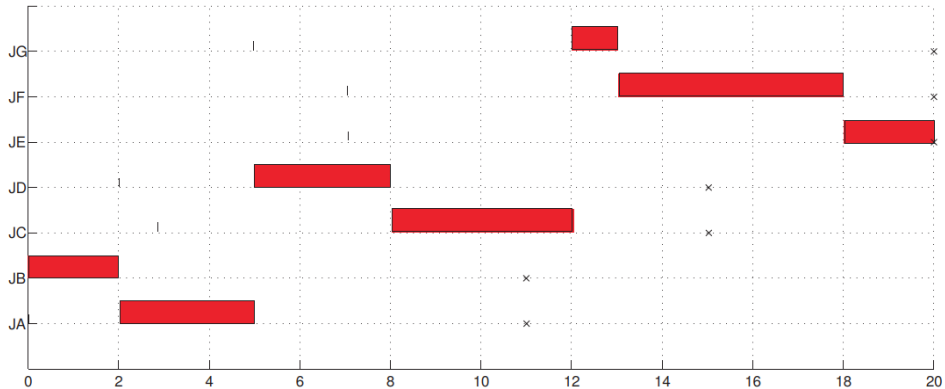


Figure 7: EDF\* schedule