EDF-schedulability of synchronous periodic task systems is coNP-hard

Friedrich Eisenbrand & Thomas Rothvoß

Institute of Mathematics
EPFL, Lausanne

SODA'10

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

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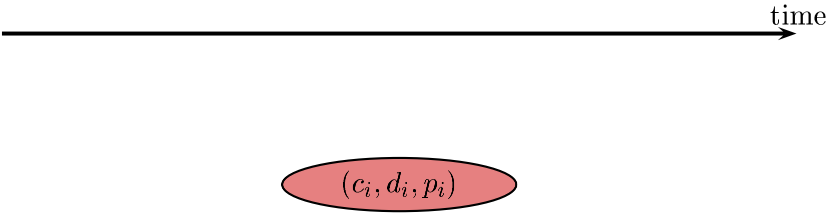

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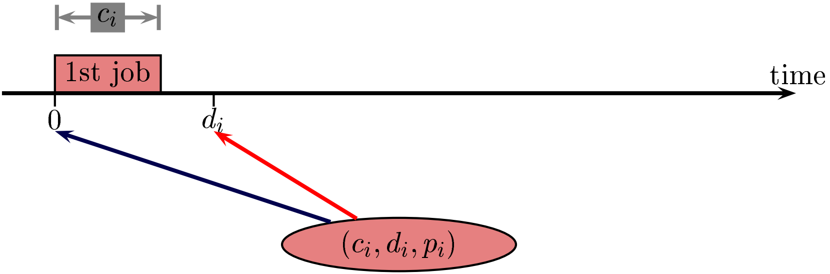

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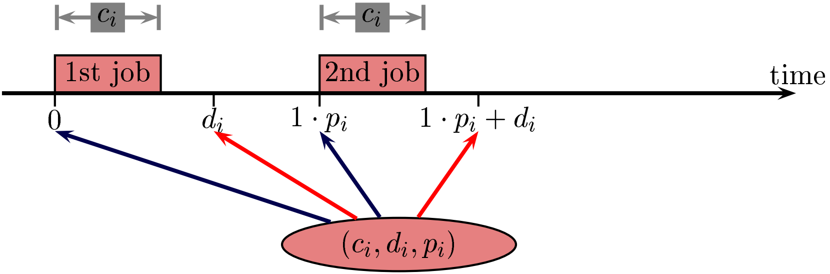

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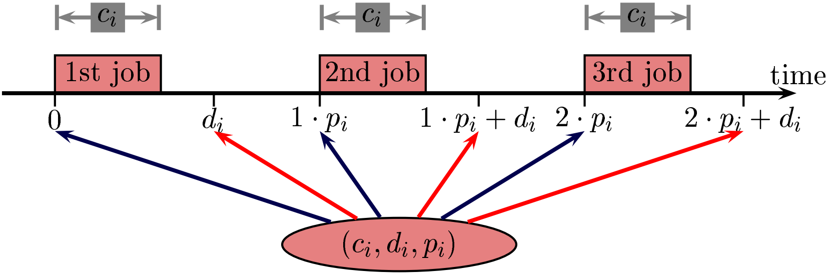

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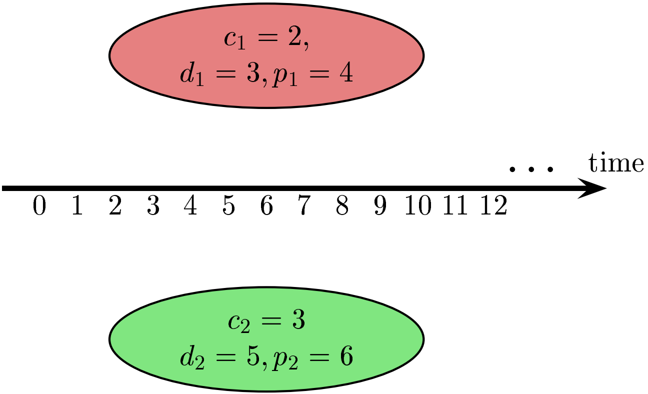
Consider:

- Earliest-Deadline-First schedule (EDF)
- uni-processor
- pre-emptive

Question: Will all jobs meet the deadline?

Example



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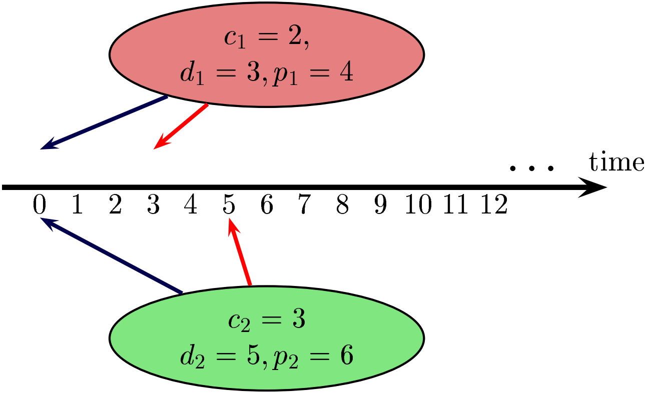

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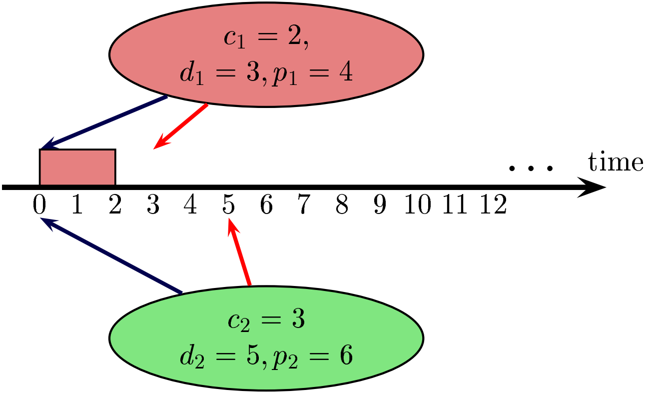

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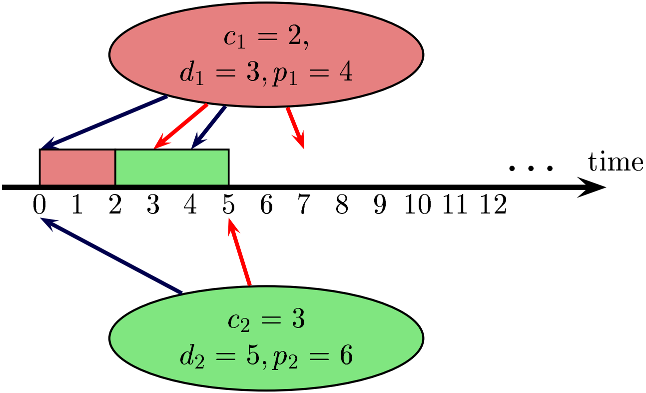

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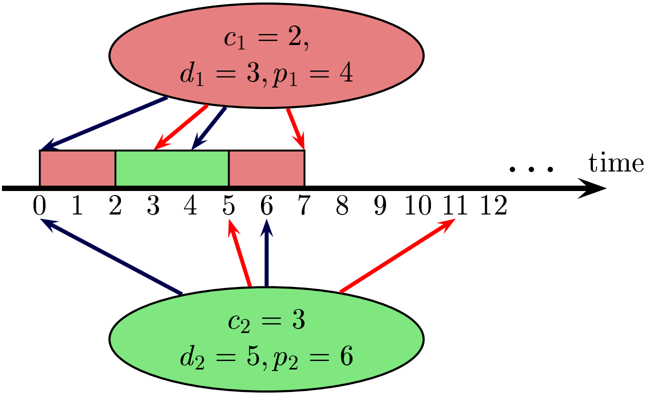

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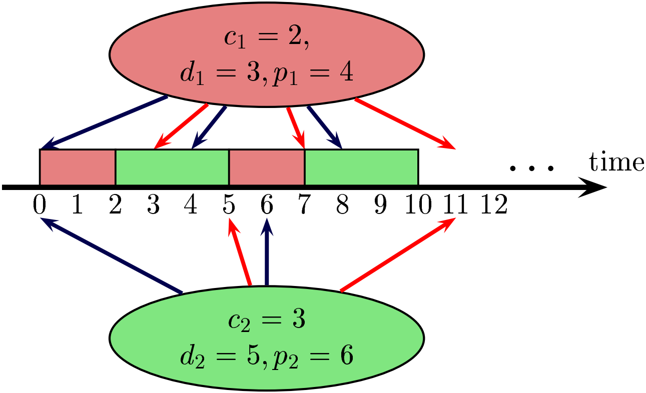

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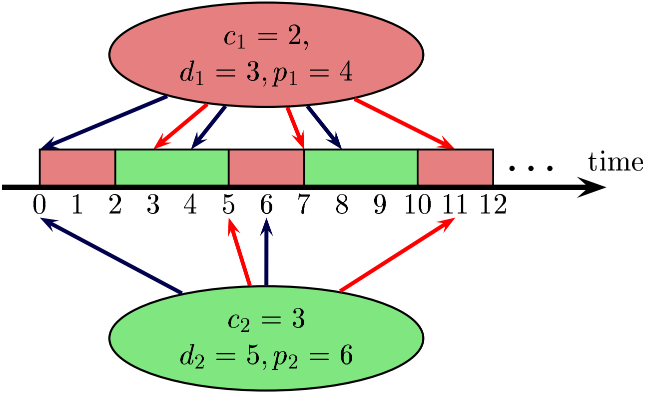

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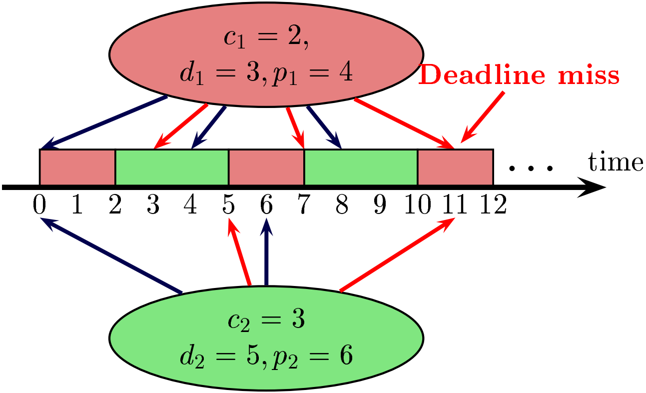

$c_1 = 2,$
$d_1 = 3, p_1 = 4$
Deadline miss
. . . time
0 1 2 3 4 5 6 7 8 9 10 11 12
$c_2 = 3$
$d_2 = 5, p_2 = 6$

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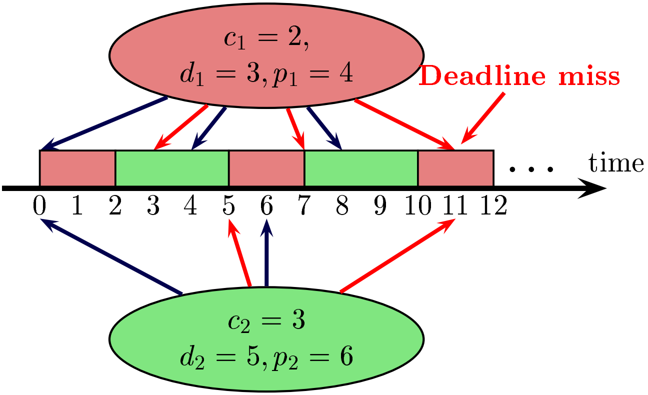

Theorem (Dertouzos '74)

EDF is an optimum pre-emptive uni-processor scheduling policy.

Demand bound function

Observation: In $[0, Q]$ exactly $\left\lfloor \frac{Q-d_i}{p_i} \right\rfloor + 1$ jobs of task τ_i have release time <u>and</u> deadline

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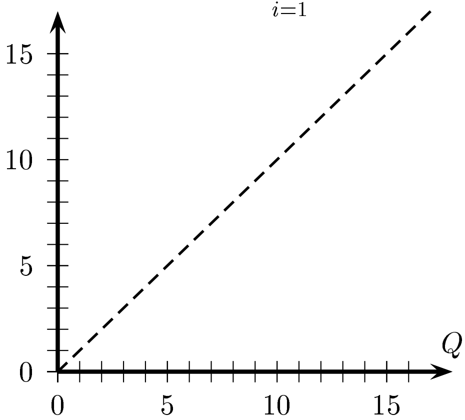

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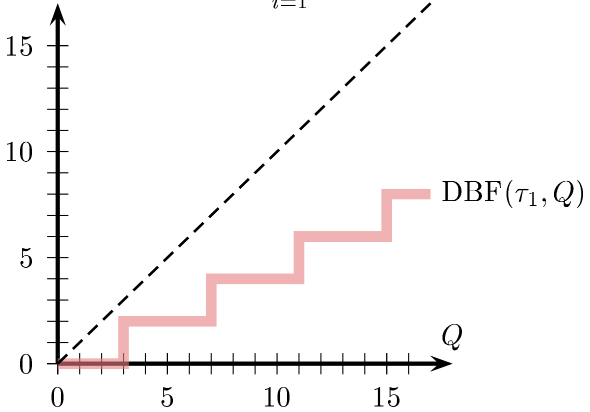

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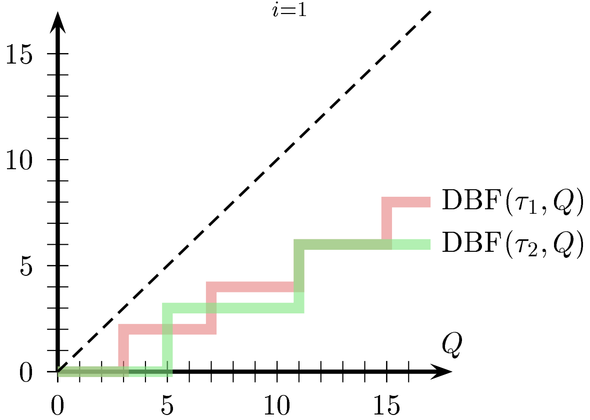

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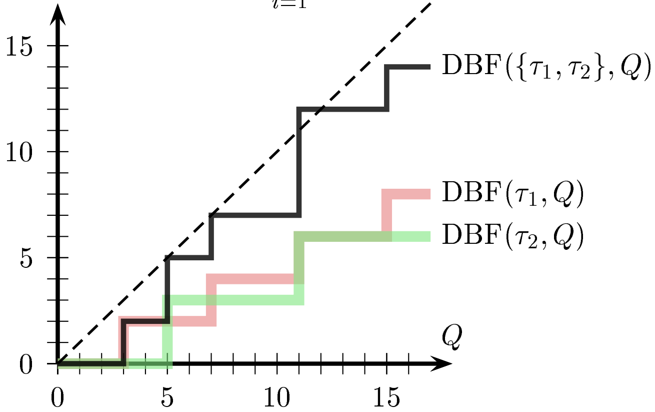

EDF-schedulability condition

Theorem (Baruah, Mok & Rosier '90)

Earliest-Deadline-First schedule is feasible $\Leftrightarrow$

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Theorem (Albers & Slomka '04)

In time $poly(n, 1/\varepsilon)$ *one can distinguish*

- *Feasible:* $\forall Q \geq 0 : DBF(\mathcal{S}, Q) \leq Q$
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Theorem

Testing EDF-schedulability, i.e. deciding whether

$$\forall Q \geq 0 : \sum_{i=1}^{n} \left(\left\lfloor \frac{Q - d_i}{p_i} \right\rfloor + 1 \right) \cdot c_i \leq Q$$

is weakly **coNP**-hard.

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- **NP**-hard [Lagarias '85]
- Gap version **NP**-hard [Rössner & Seifert '96, Chen & Meng '07]
- $2^{O(n)}$-apx (2-sided) via LLL-algo [Lagarias '85]

Directed Diophantine Approximation (DDA)

Theorem (Eisenbrand & R. - APPROX'09)

Given $\alpha_1, \dots, \alpha_n$, N, $\varepsilon > 0$ *it is* **NP**-*hard to distinguish*

- $\exists Q \in \{N/2, \dots, N\} : \max_{i=1,\dots,n} |\lceil Q\alpha_i \rceil - Q\alpha_i| \leq \varepsilon$
- $\nexists Q \in \{1, \dots, n^{\frac{O(1)}{\log\log n}} \cdot N\} : \max_{i=1,\dots,n} |\lceil Q\alpha_i \rceil - Q\alpha_i| \leq 2^n \cdot \varepsilon$

Some technicalities

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- $Q \in \mathbb{Z} \to Q \in \mathbb{Q}_+$: Admit weights w_i. Add $\alpha_0 := 1$ with a huge weight w_0.

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Given: DDA instance $\alpha_1, \ldots, \alpha_n > 0,\ w_1, \ldots, w_n,\ N,\ \varepsilon > 0$

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Define: Task set $\mathcal{S} = \{\tau_0, \dots, \tau_n\}$ s.t.

- **Yes:** $\exists Q \in [N/2, N] : \sum_{i=1}^{n} w_i(Q\alpha_i - \lfloor Q\alpha_i \rfloor) \leq \varepsilon$
  $\Rightarrow \mathcal{S}$ not EDF-schedulable ($\exists Q \geq 0 : \mathrm{DBF}(\mathcal{S}, Q) > \beta \cdot Q$)
- **No:** $\nexists Q \in [N/2, 3N] : \sum_{i=1}^{n} w_i(Q\alpha_i - \lfloor Q\alpha_i \rfloor) \leq 3\varepsilon$
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Task system:

$$\tau_i = (c_i, d_i, p_i) := \left(w_i, \frac{1}{\alpha_i}, \frac{1}{\alpha_i}\right) \quad \forall i = 1, \ldots, n$$

$$\tau_0 = (c_0, d_0, p_0) := (3\varepsilon, N/2, \infty)$$

$$\beta := \underbrace{\sum_{i=1}^{n} \frac{c_i}{p_i}}_{=: U = \text{utilization}} + \frac{\varepsilon}{N}$$

Reduction (2)

$$Q \cdot U - \sum_{i=1}^{n} \left(\left\lfloor \frac{Q - d_i}{p_i} \right\rfloor + 1 \right) c_i$$

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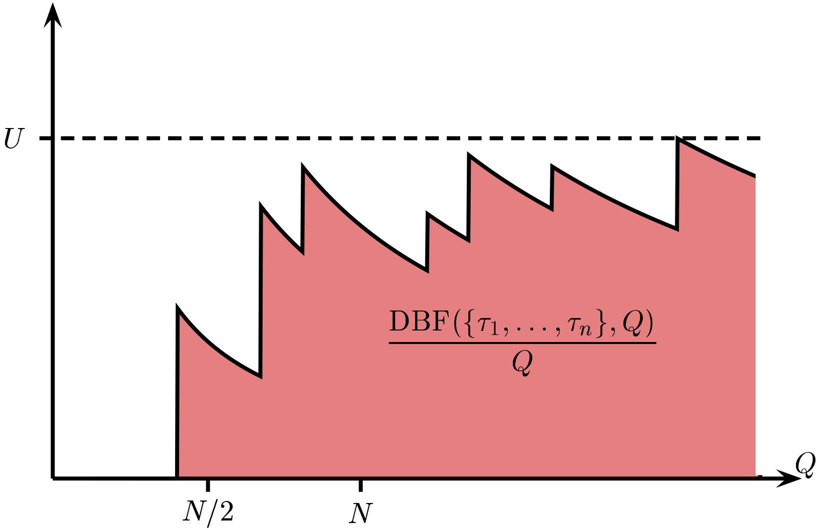
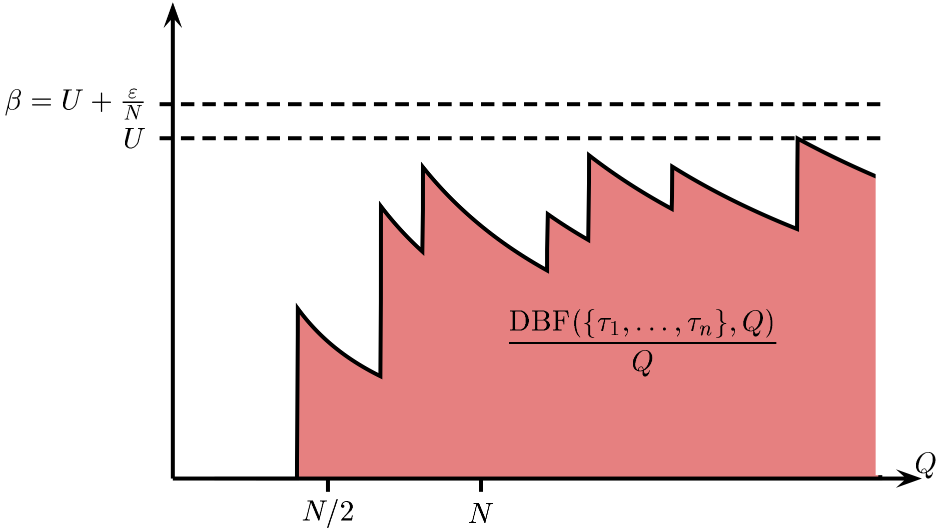
Hence

$$
\frac{\mathrm{DBF}(\{\tau_1, \ldots, \tau_n\}, Q)}{Q} \approx U \quad \Leftrightarrow \quad \text{approx. error small}
$$

Reduction (3)

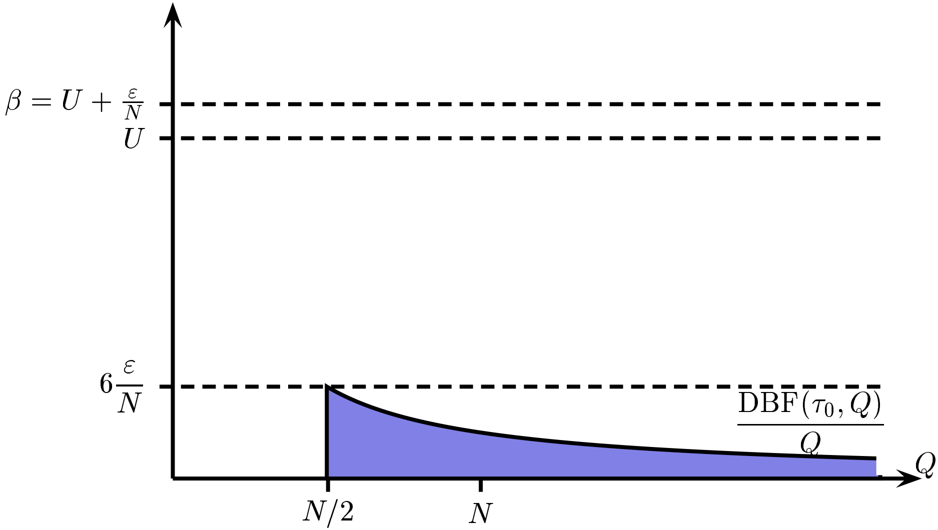


Reduction (3)



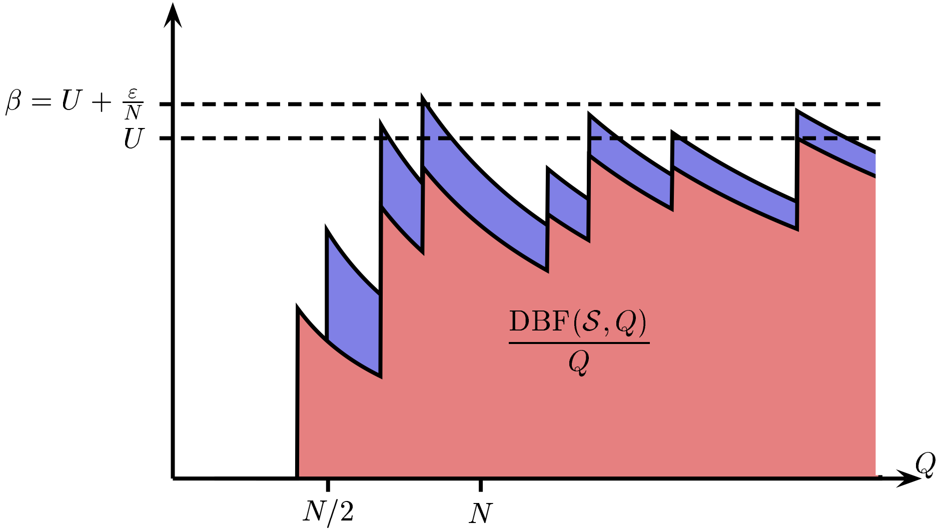
$\beta = U + \frac{\varepsilon}{N}$
U
$\frac{\mathrm{DBF}(\{\tau_1, \ldots, \tau_n\}, Q)}{Q}$
Q
$N/2$
N

Reduction (3)

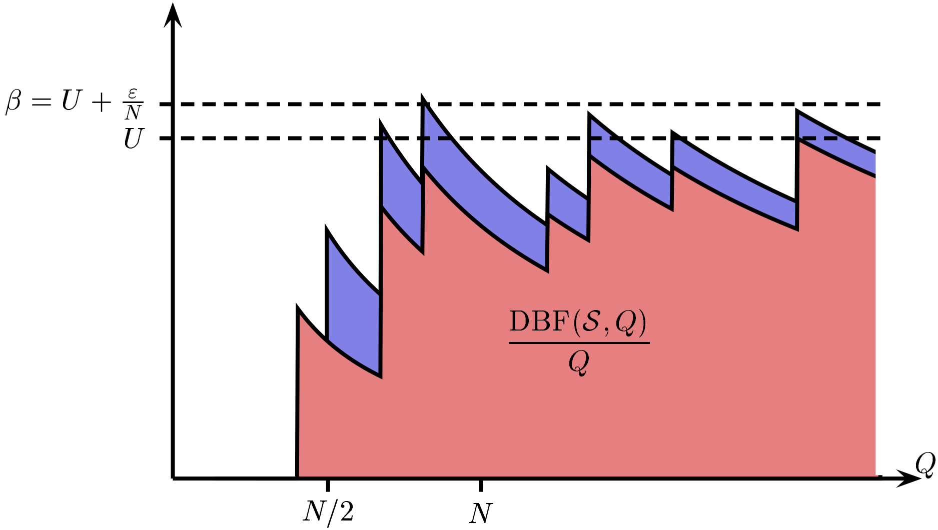


$\beta = U + \frac{\varepsilon}{N}$
U
$6\frac{\varepsilon}{N}$
$\frac{\mathrm{DBF}(\tau_0, Q)}{Q}$
Q
$N/2$
N

Reduction (3)



Reduction (3)



$$\frac{\text{DBF}(\{\tau_0, \ldots, \tau_n\}, Q)}{Q} > \beta \quad \Leftrightarrow \quad Q = \Theta(N) \ \underline{\text{and}} \ \text{apx error} \ = O(\varepsilon)$$

Open problems

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Known:

- first deadline miss $\leq \dfrac{1}{1-U} \cdot \max_{i=1,\ldots,n} p_i$

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Open Problem 1

Is there a pseudopolynomial time algorithm for testing EDF-schedulability (even if $U \approx 1$)

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Is there for every $\delta > 0$ a polynomial time algorithm for testing EDF-schedulability if $U \leq 1 - \delta$.

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Thanks for your attention