Reservation-Based Federated Scheduling for Parallel Real-Time Tasks

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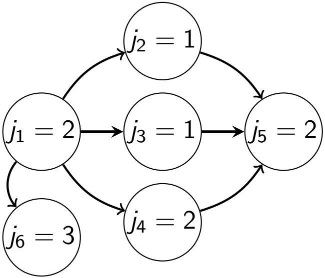
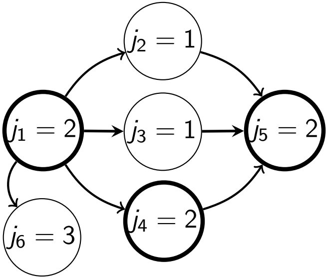
Directed Acyclic Graph (DAG) Task Model



Directed Acyclic Graph (DAG) Task Model

- Critical-path length: $len(G_i)$



Directed Acyclic Graph (DAG) Task Model

- Critical-path length: $len(G_i)$
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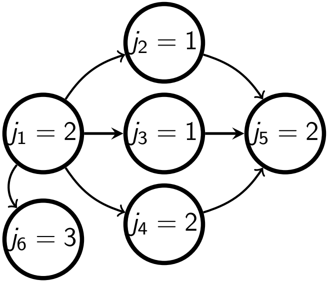
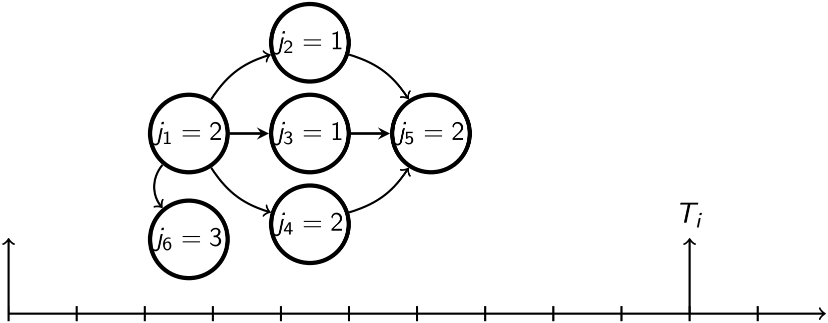


Directed Acyclic Graph (DAG) Task Model

- Critical-path length: $len(G_i)$
- Cumulative worst-case execution time $vol(G_i)$
- Period T_i



Directed Acyclic Graph (DAG) Task Model

- Critical-path length: $len(G_i)$
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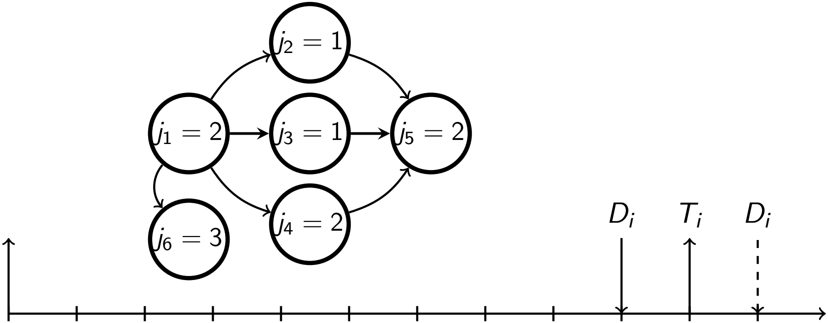
- Period T_i
- Deadline D_i



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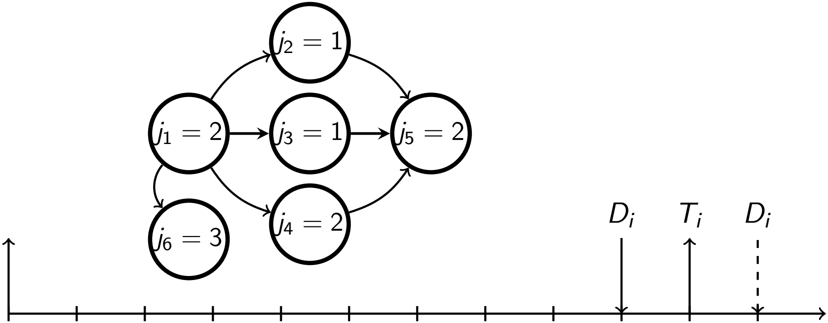

Directed Acyclic Graph (DAG) Task Model

- Critical-path length: $len(G_i)$
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- Period T_i
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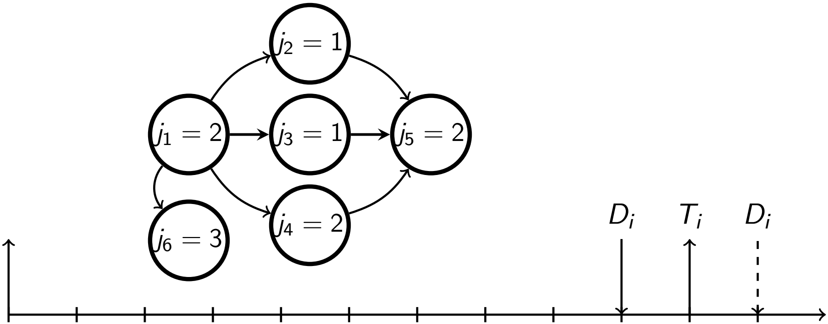
- Utilization $U_i = \frac{vol(G_i)}{T_i}$



Directed Acyclic Graph (DAG) Task Model

- Critical-path length: $len(G_i)$
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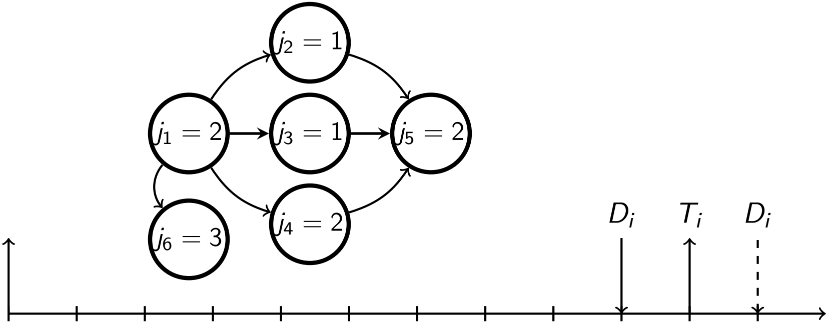
- Density $\delta_i = \frac{vol(G_i)}{\min\{D_i, T_i\}}$



System Model and Problem Definition

- Set $\mathbf{T}$ of sporadic arbitrary-deadline DAG tasks

System Model and Problem Definition

- Set **T** of sporadic arbitrary-deadline DAG tasks
- Set of **M** identical processors

System Model and Problem Definition

- Set **T** of sporadic arbitrary-deadline DAG tasks
- Set of **M** identical processors
- Schedule all tasks such that no task misses it's deadline

Federated Scheduling

- DAG task set is partitioned into **light** and **heavy** tasks

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- Each **heavy** task is allocated to processors exclusively

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Federated Scheduling

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We only focus on heavy tasks

Problem with Federated Scheduling?

$$m = \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)}$$

Problem with Federated Scheduling?

$$m = \left\lceil \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)} \right\rceil$$

Problem with Federated Scheduling?

$$\left\lceil \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)} \right\rceil - \left\lfloor \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)} \right\rfloor$$

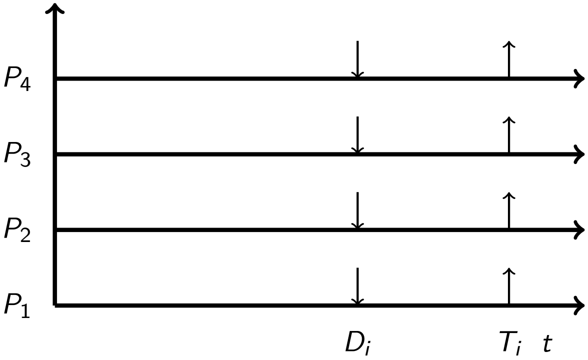
Problem with Federated Scheduling?

$$\underbrace{\left\lceil \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)} \right\rceil - \left\lfloor \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)} \right\rfloor}_{\epsilon}$$

Semi-Federated Scheduling [Jiang - RTSS 2017]

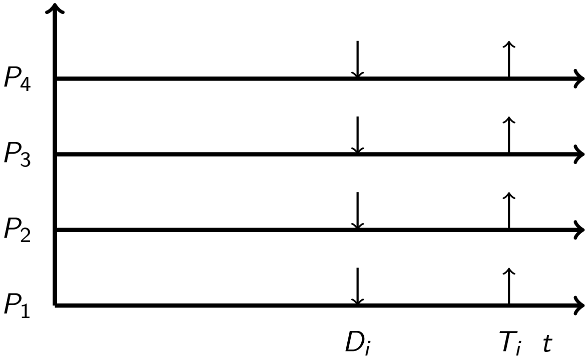
$$\left\lfloor \frac{vol(G_i) - len(G_i)}{\min\{D_i, T_i\} - len(G_i)} \right\rfloor + \epsilon$$

Problems with Federated & Semi-Federated Scheduling



Problems with Federated & Semi-Federated Scheduling

$\max\left\{0, \frac{T_i - D_i}{T_i}\right\}$ of processor capacity is at least wasted



Reservation-Based Federated Scheduling

Reserve **sufficient resources** for heavy tasks

but **not** necessarily **entire processors**

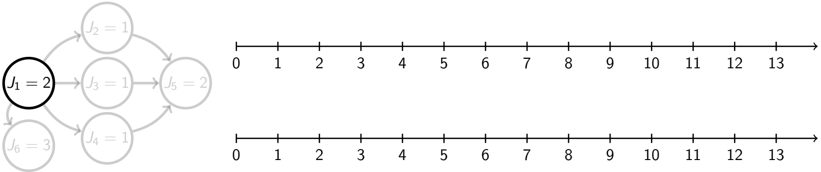
Reservation-Based Federated Scheduling

1. Specify a set of reservation servers for each heavy DAG task
2. Schedule the set of reservation servers

Reservation-Based Federated Scheduling

1. Specify a set of reservation servers for each heavy DAG task
2. Schedule the set of reservation servers
3. Schedule each DAG task within it's reservation servers

Reservation Servers



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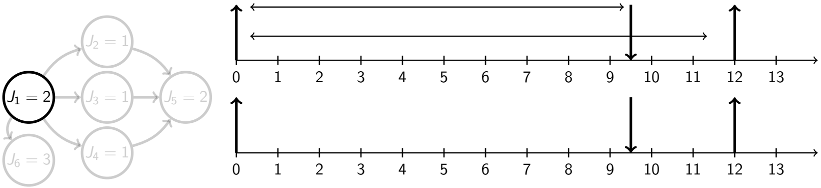
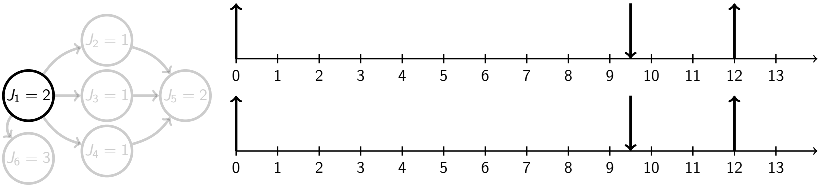


1. Sporadic arbitrary-deadline DAG task is released

Reservation Servers



1. Sporadic arbitrary-deadline DAG task is released
2. Reservations are *released* with the DAG task and scheduled according to some policy

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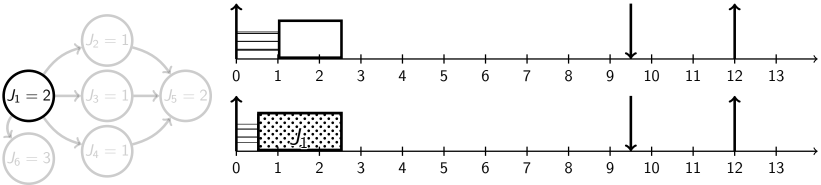

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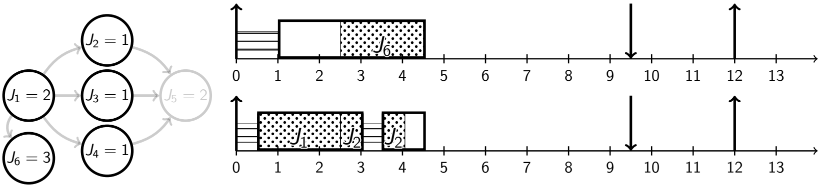

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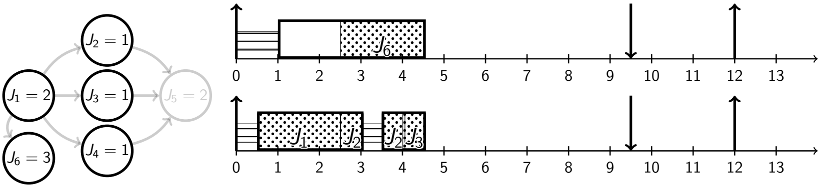

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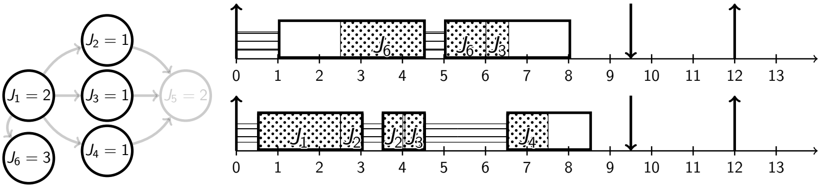

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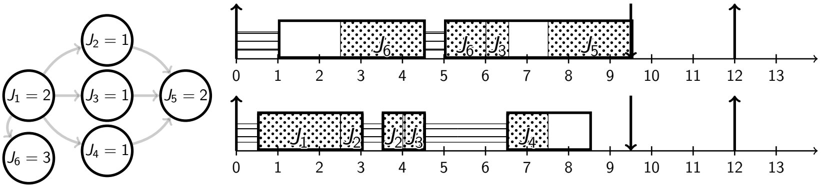

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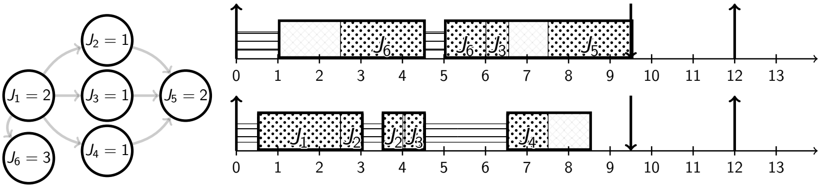

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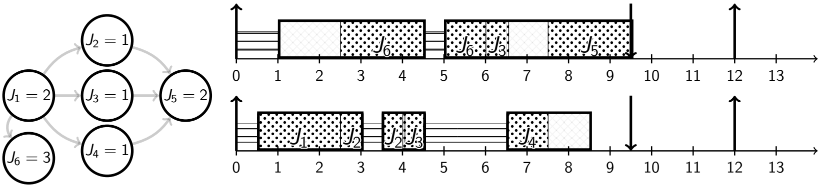

1. Sporadic arbitrary-deadline DAG task is released
2. Reservations are *released* with the DAG task and scheduled according to some policy
3. DAG task is serviced whenever a reservation is scheduled
4. How much reservation is required?

How to calculate the reservations?

$$vol(G_i) + len(G_i) \cdot (m_i - 1) \leq \sum_{j=1}^{m_i} E_j = \sum_{j=1}^{m_i} \gamma_j \cdot len(G_i)$$

How to calculate the reservations?

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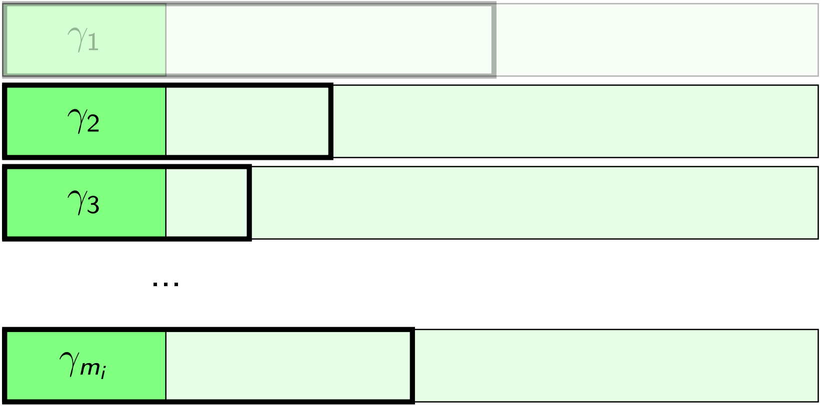
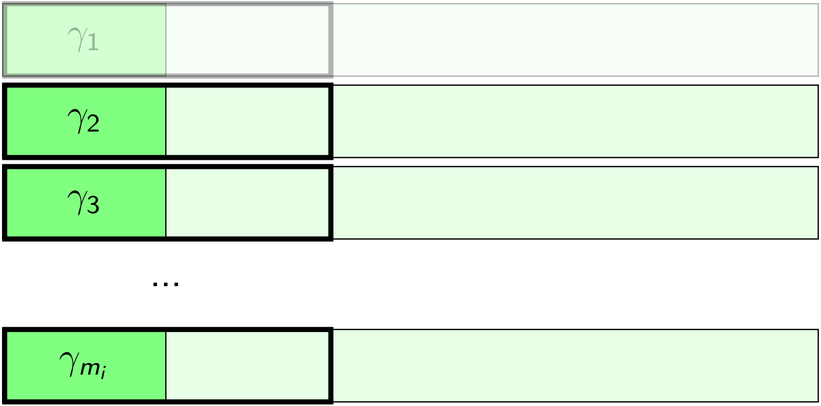


How to calculate the reservations?



What does equal inflation give?

$$\underbrace{m_i \cdot \gamma_i \cdot len(G_i)}_{cumulative\ \ reservation} \leq \left(1 + \frac{1}{\gamma_i - 1}\right) \cdot vol(G_i)$$

How to calculate systems of reservation servers?

- **Decoupled** Calculate the reservation servers based on insights

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Example (Decoupled: Maximal Inflation Reservations)

Set γ_j of each task to the maximal value.

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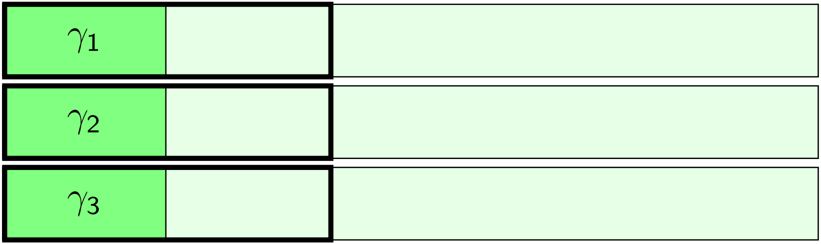
- Constant speedup factor of $3 + 2 \cdot \sqrt{2}$ (Global & Partitioned)

Coupled Algorithm: Split-On-Fail

1. M Processors and reservation servers for each task in $\mathbf{T}$

$$vol(G_i) + len(G_i) \cdot (\mathbf{3} - 1) \leq len(G_i) \cdot (\gamma_\mathbf{1} + \gamma_\mathbf{2} + \gamma_\mathbf{3})$$



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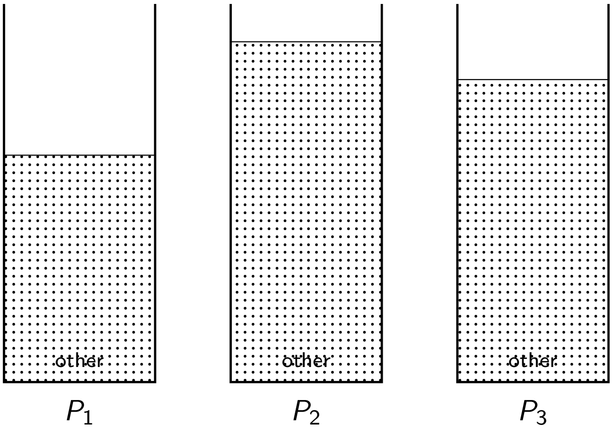
1. M Processors and reservation servers for each task in $\mathbf{T}$
2. Try to partition reservation servers

Coupled Algorithm: Split-On-Fail

1. M Processors and reservation servers for each task in $\mathbf{T}$
2. Try to partition reservation servers
3. Not schedulable? Increment number of reservations and decrease reservation budget

Coupled Algortithm: Split-On-Fail



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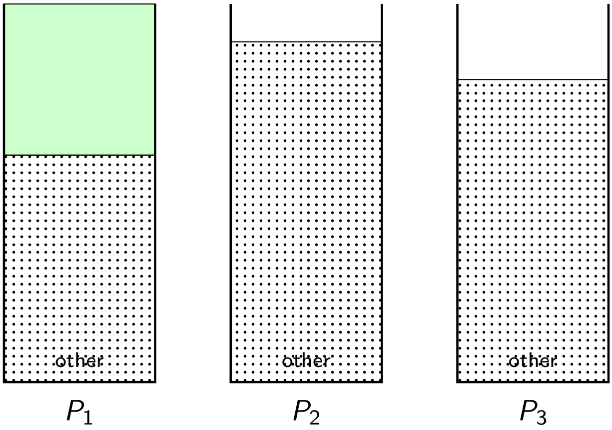

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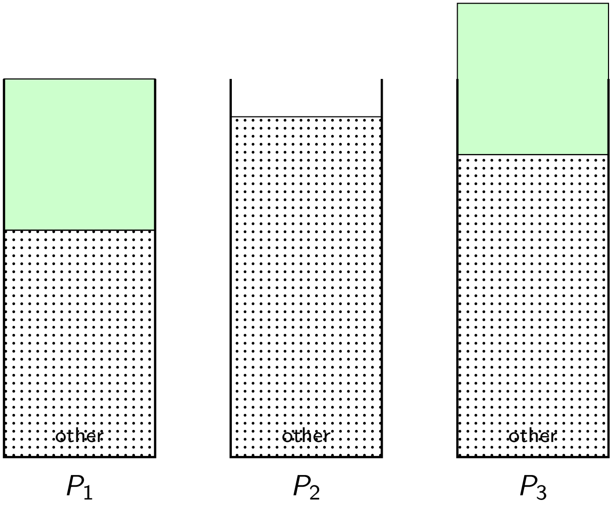
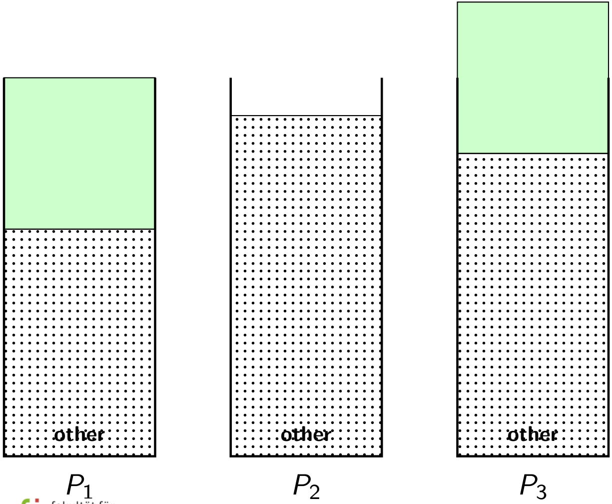


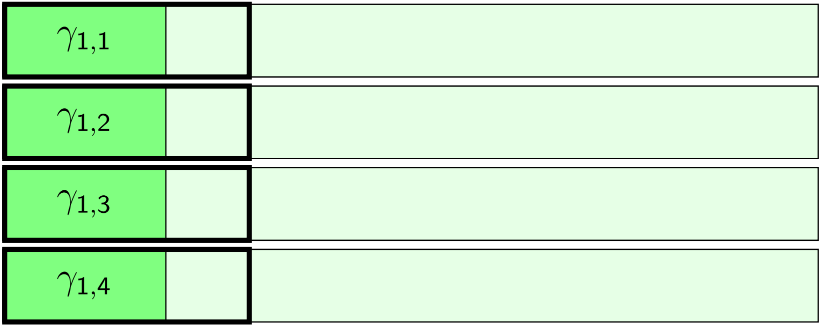
Coupled Algortithm: Split-On-Fail

Increment number of reservation servers and decrease budget



Coupled Algortithm: Split-On-Fail

$$vol(G_i) + len(G_i) \cdot (\mathbf{4} - 1) \leq len(G_i) \cdot (\gamma_{\mathbf{1}} + \gamma_{\mathbf{2}} + \gamma_{\mathbf{3}} + \gamma_{\mathbf{4}})$$



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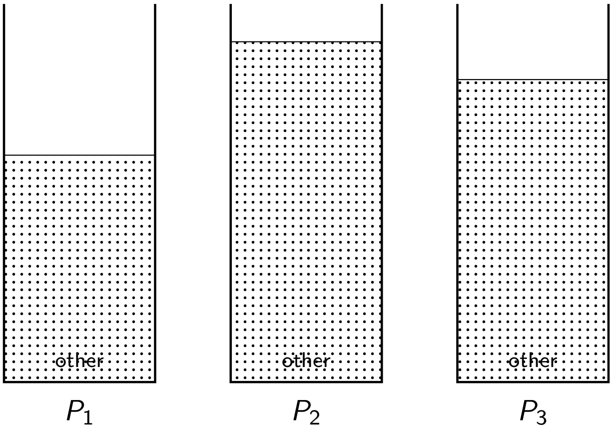

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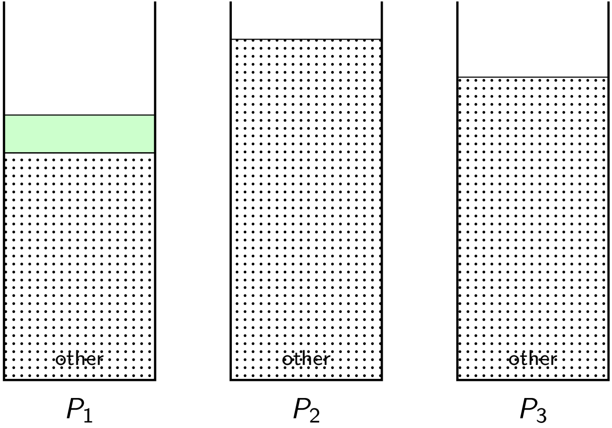

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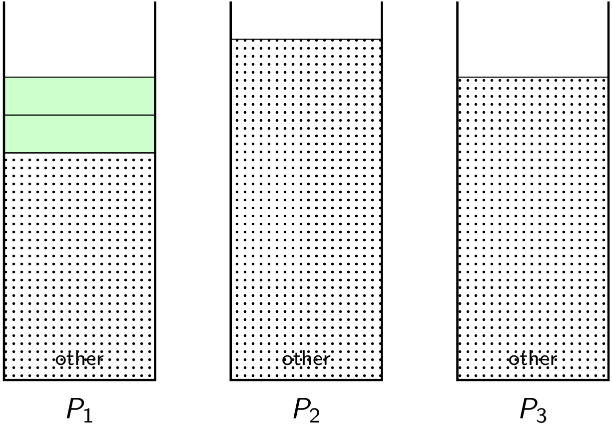

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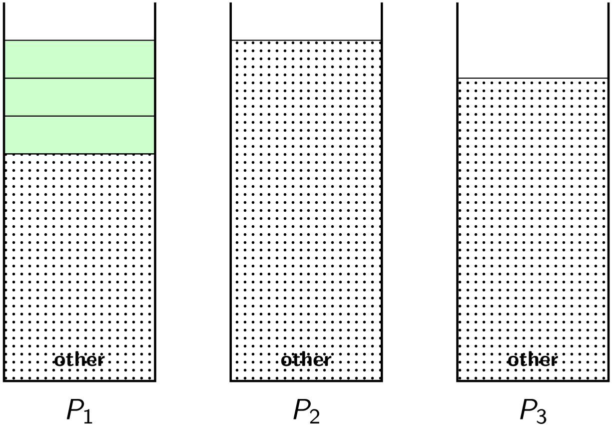
Increment number of reservation servers and decrease budget



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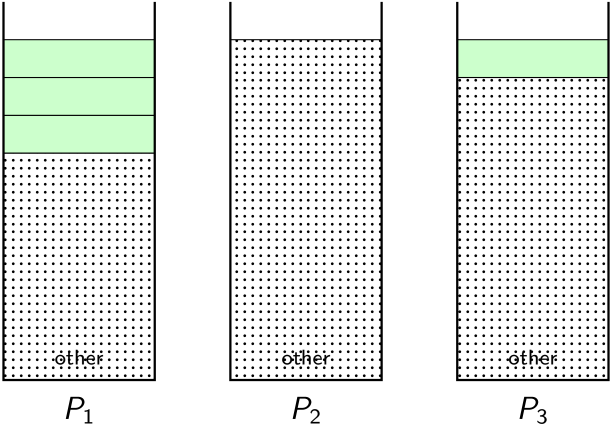

Experimental Results

Evaluations: DAG Task Set Generation

Parametric DAG Task Generation

- Task $\tau_i = (vol(G_i),\ len(G_i),\ D_i,\ T_i)$

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Evaluations: DAG Task Set Generation

Parametric DAG Task Generation

- Task $\tau_i = (vol(G_i),\ len(G_i),\ D_i,\ T_i)$
- Randfixedsum for utilizations
- Uniformly distributed random variables: α, β, U_i, T_i:
  1. $0 < U_i \leq M$ (M is number of homogeneous processors)
  2. $0 < T_i \leq 100$
  3. $vol(G_i) = U_i \cdot T_i$
  4. $D_i = \alpha \cdot T_i$, and $len(G_i) = \beta \cdot D_i$

Evaluations: Experimental Setup

- 8, 16, and 32 identical processors systems

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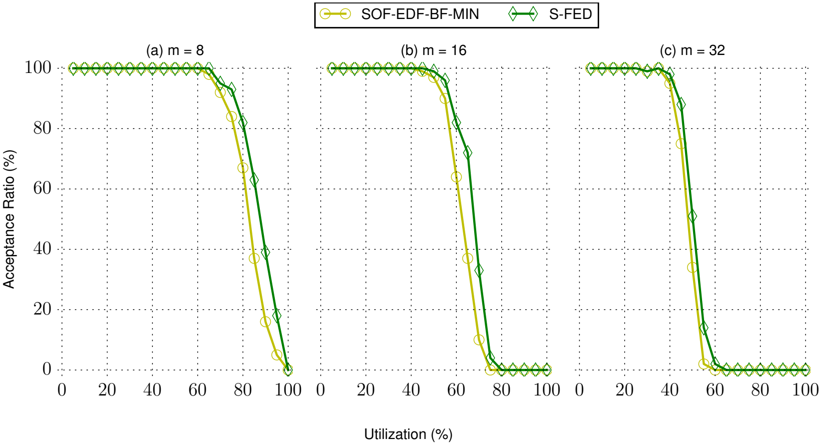
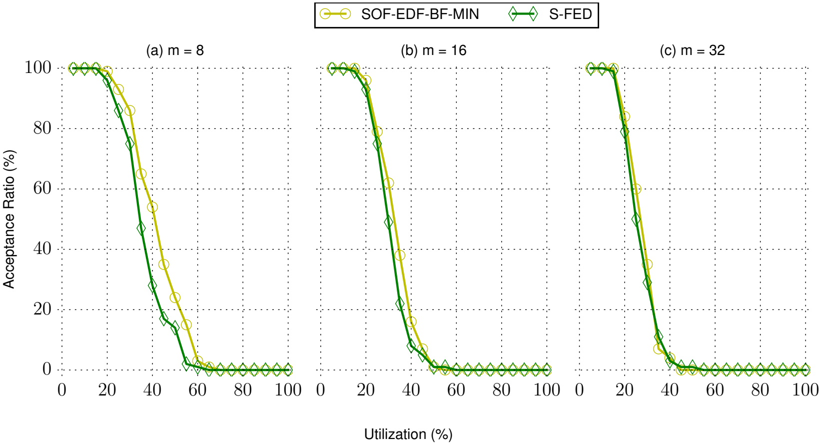
Evaluations: Experimental Setup

- 8, 16, and 32 identical processors systems
- 100 task sets with 20 DAG tasks each
- Set size: **large enough** to allow smaller individual utilizations
  $\Longrightarrow$ more options for the partitioning
- But small enough to be **difficult enough** to partition

Implicit-deadline DAG task sets



Constrained-deadline DAG task sets



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- Constant speedup factor of $3 + 2 \cdot \sqrt{2}$ (Global & Partitioned) for arbitrary-deadline DAG task systems

Thank You! Questions?

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- Constant speedup factor of $3 + 2 \cdot \sqrt{2}$ (Global & Partitioned) for arbitrary-deadline DAG task systems
- Implementation exist

Thank You! Questions?