Variable Capacity Scheduling

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Joint work with Y. Robert, L. Perotin, J. Cendrier, F. Vivien (ENS Lyon)
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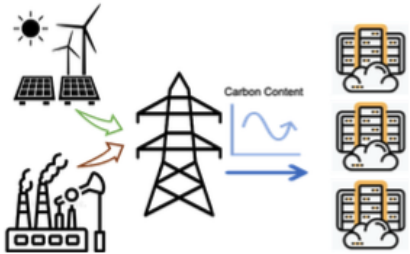
September 4, 2024 – CCDSC – La Maison des Contes

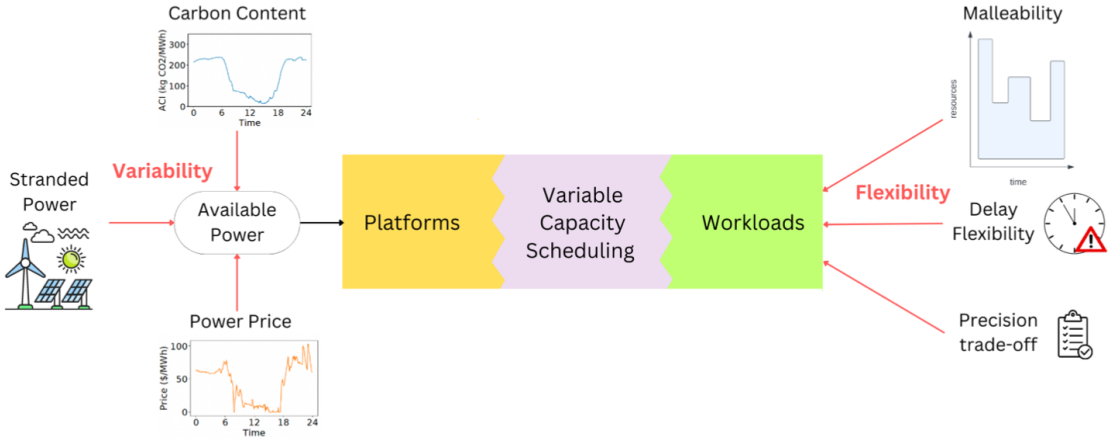
Variable power



- Today's data centers assume resource capacity as a fixed quantity
- Emerging approaches:
  - Exploit grid renewable energy
  - Reduce carbon emissions

$\Rightarrow$ Variable power

Big picture


Carbon Content
ACI (kg CO2/MWh)
300
200
100
0
0 6 12 18 24
Time
Malleability
resources
time
Stranded Power
Variability
Available Power
Platforms
Variable Capacity Scheduling
Workloads
Flexibility
Delay Flexibility
Precision trade-off
Power Price
Price ($/MWh)
100
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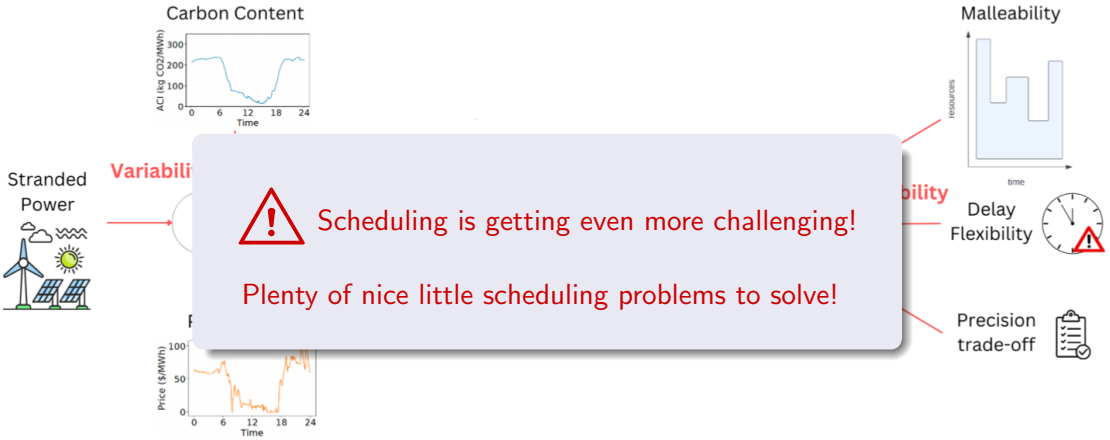
Time

Big picture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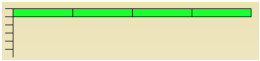
Time
Scheduling is getting even more challenging!
Plenty of nice little scheduling problems to solve!

Parallel jobs



- **Rigid jobs**: Processor allocation is fixed
- **Moldable jobs**: Processor allocation is decided by the user or the system but cannot be changed during execution
- **Malleable jobs**: Processor allocation can be dynamically changed

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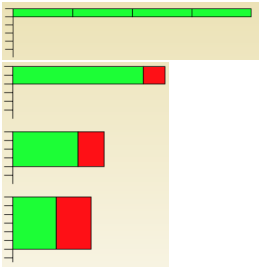

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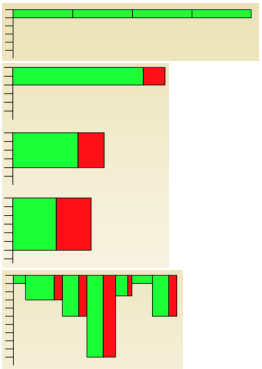

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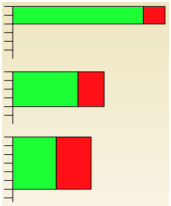

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The case for moldable jobs:

- Easily adapt to the amount of available resources (contrarily to rigid jobs)
- Easy to design/implement (contrarily to malleable jobs)
- Computational kernels in scientific libraries are provided as moldable jobs

Checkpoints

- Some jobs cannot be interrupted
- Some jobs can be checkpointed

Half the projected load for US Exascale systems include checkpointing capabilities
(from APEX worklows, Sandia/LosAlamos/NERSC report, April 2016)

Checkpoints

Scheduling opportunity

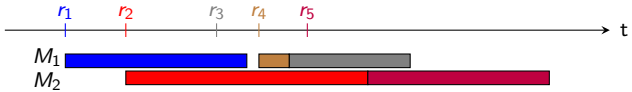
- Many checkpointable jobs are moldable
- These jobs are able to restart with a different allocation (size and shape)

Resizing impacts performance

(from APEX workflows, Sandia/LosAlamos/NERSC report, April 2016)

Risk aware?

1. **Which machine to shutdown?**



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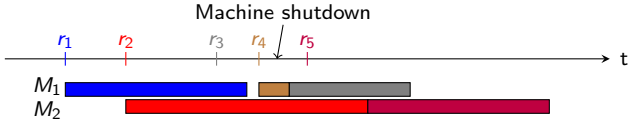

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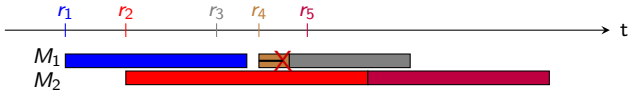

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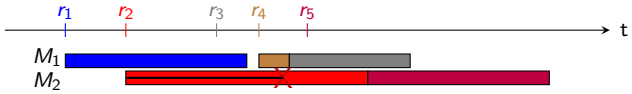

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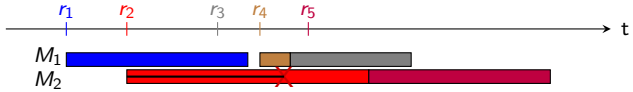
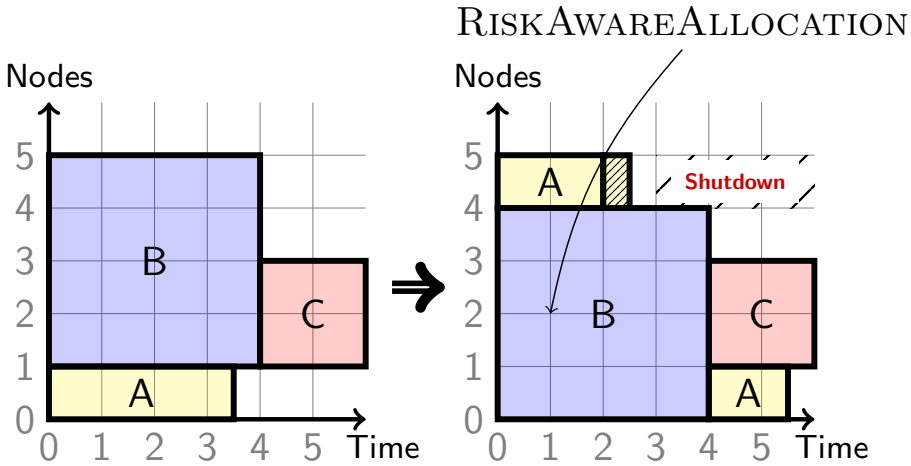


2. **How to schedule jobs to minimize impact?**

Small example



Main questions

- When power decreases, which machines to power off? Which jobs to interrupt? And to re-schedule?
- Are we notified ahead of a power change?
  - Resource variation in power obeys specific parameters whose evolution is dictated by a mix of technical availability and economic conditions
  - Accurate external predictor (precision, recall)? Maybe too optimistic ☹
- Re-scheduling interrupted jobs
  - Can we take a proactive checkpoint before the interruption?
  - Which priority should be given to each interrupted job?
  - Which geometry and which nodes for re-execution?

Main questions

- When power decreases, which machines to power off? Which jobs to interrupt? And to re-schedule?
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Scheduling opportunity & challenge

- Nodes ordered according to non-decreasing risk, say from left to right
- Shutdown nodes starting from the right
- Assign priority jobs, such as large jobs, to nodes on the left
- Global load of the platform must remain balanced

Sophisticated algorithms that go well beyond first-fit decisions

Outline

Framework

- Set of rigid **jobs**, each using a given number of cores (work w_i on c_i cores)
- Identical multicore **machines**, number of machines alive evolves with time
- Number of alive machines not known until it changes
- No possibility to checkpoint jobs or to anticipate a resource variation
- **Objective function:** Goodput $\Rightarrow$ fraction of useful work up to time T
  - $\mathcal{J}_{comp,T}$: set of jobs that are complete at time T ($e_i \leq T$)
  - $\mathcal{J}_{started,T}$: set of jobs running and not finished at time T ($s_i \leq T < e_i$)
  - Total number of units of work that can be executed in $[0, T]$: $n_c \sum_{t \in [0,T-1]} M_{alive}(t)$

$$\textsc{Goodput}(T) = \frac{\sum_{\tau_i \in \mathcal{J}_{comp,T}} w_i c_i + \sum_{\tau_i \in \mathcal{J}_{started,T}} (T - s_i) c_i}{n_c \sum_{t \in [0,T-1]} M_{alive}(t)}$$

Keep an eye on maximum stretch

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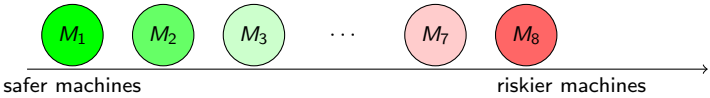
Risk-aware



Risk-aware job allocation strategies

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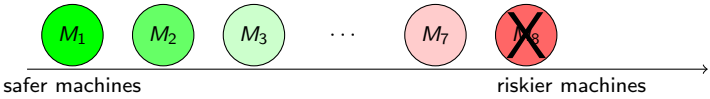

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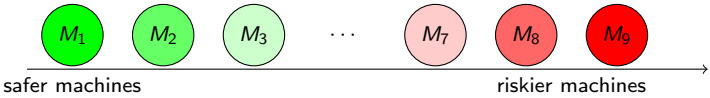

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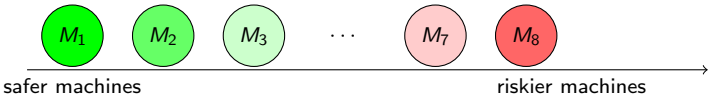

Risk-aware job allocation strategies

Events:

- **Job arrival**: When a job is released, when to schedule it and on which machine?
- **Job completion**: When a job is completed, its cores are released $\Rightarrow$ additional jobs can be scheduled
- **Machine addition**: When a new machine becomes available, how to utilize it?
- **Machine removal**: When a machine is turned off, its jobs are killed and need re-allocation

Heuristics

- FirstFitAware:
  - Ordered list of machines
  - Jobs mapped to leftmost (safer) machines whenever possible
  - Rightmost (riskier) machines are shutdown whenever necessary
- FirstFitUnaware: Shutdown random machines whenever necessary
- Can we do better than first fit?
  - Interrupting a long job is a big performance loss
  - Schedule smaller jobs on machines that are likely to be turned off
  - Schedule longer jobs on risk-free machines

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TargetStretch, TargetASAP, & PackedTargetASAP

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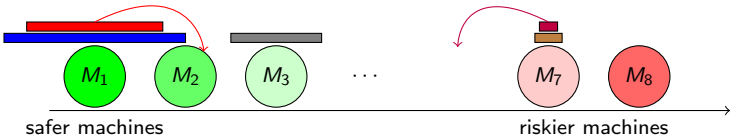
  - Otherwise, assign on machine where it can start ASAP (within acceptable distance)



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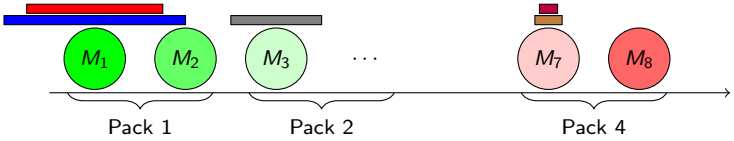
- Variant PackedTargetASAP: group machines into packs, and assign jobs to first machines of the pack, to leave machines empty for future large jobs



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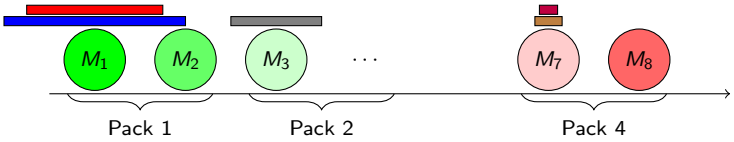
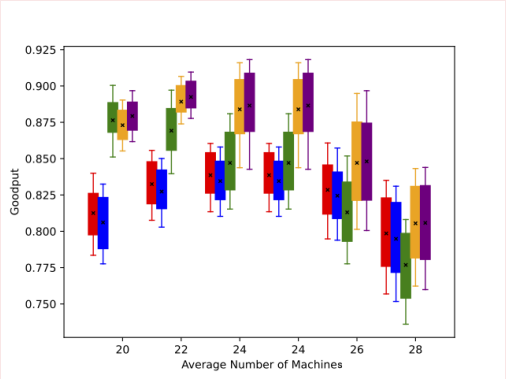
Technical and kind of painful
despite all simplifying hypotheses ☹



TargetStretch, TargetASAP, & PackedTargetASAP

Simulation results using resource variation trace and job traces (Borg)
Significant gains over first-fit algorithms: map the right job to the right machine



Outline

Model

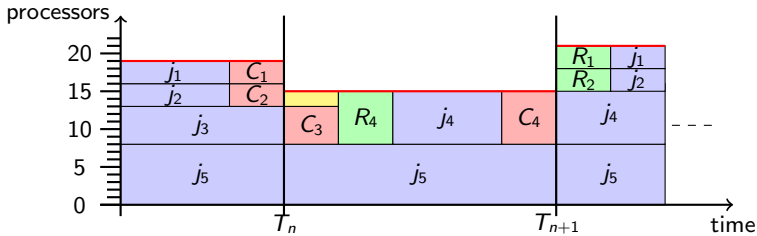
Problem: Scheduling infinite parallel rigid jobs under variable number of processors, during each *section*

Hypotheses:

- A job can be **checkpointed** and recovered
- Knowledge of the duration of each section, and bound on #proc difference

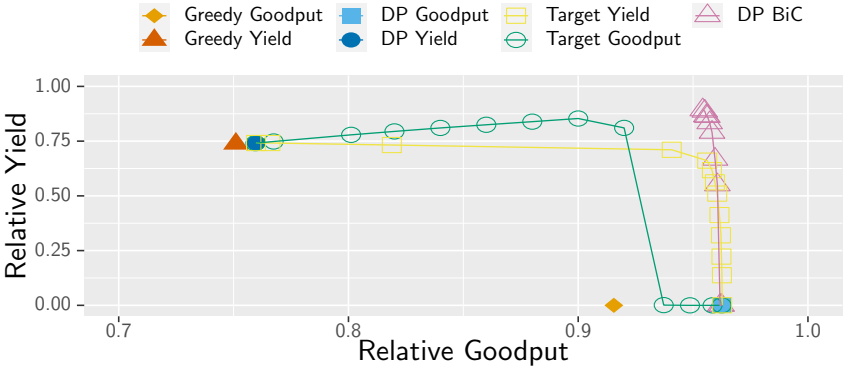
Additional constraint:

- Never lose work (i.e., checkpoint enough before section change, and never shut off a non-checkpointed job)



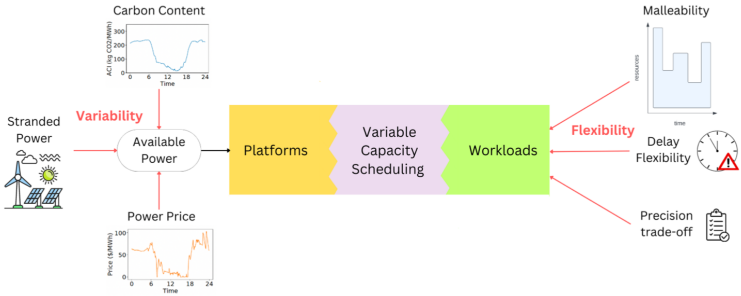
Algorithms

- Sophisticated dynamic programming algorithms to optimize goodput and/or yield at the end of a section
- Evaluation on job traces
- Improvement of novel strategies over greedy approaches



Outline

Back to the big picture



Many challenging scheduling problems when resources subject to variable capacity ☺

Workshop report: *Scheduling Variable Capacity Resources for Sustainability*; March 29-31, 2023, U. Chicago Paris Center

Today's case studies: restricted instances ☹

Risk-Aware Scheduling Algorithms for Variable Capacity Resources; PMBS workshop at SC'23

Research directions

Platforms and resources: New and more complex definitions of capacity; understand and model capacity changes

Flexible workloads: Exploit flexible start dates, allow migration or deferral, support multiple precision levels

Scheduling models and metrics: Consider new multi-criteria metrics for both performance and sustainability (including carbon cost); Account for uncertainty

Policy and societal factors: Mechanisms that help people accept constraints linked to environmental rules; Beware of the superficial feeling of abundance: abuse of computational resources, rebound effect

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Plenty of nice little scheduling problems to solve in the near future!

Happy to discuss around a drink... ☺

Thanks again for the invitation to this great workshop!