Energy vs Responsiveness Tradeoffs in EASY Backfilling

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Context: Computing Platforms

HPC Platforms

- Exascale around 2023
- Energy: locking point

Smaller-Scale Platforms

- ↑ in *small* companies
- Energy: $$

How To Reduce Energy Consumption?

- Energy-efficient machines/cooling system
- DVFS
- **Shutting machines down**
- ...

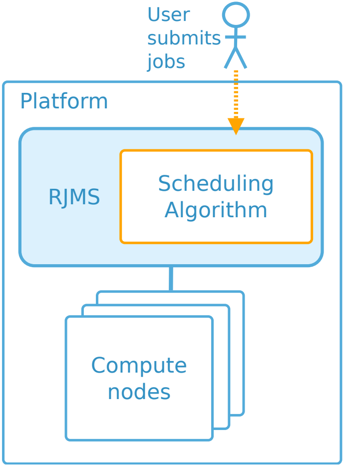
Why focus on the shutdown?

- Can be used on most platforms
- Significant potential gains
- Compatible with DVFS

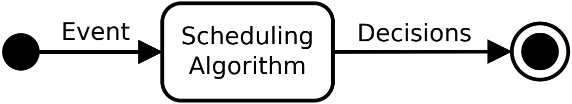
Platform Management

Resources and Jobs Management Systems (RJMS)

- AKA batch scheduler
- Orchestrates resources
  - Implements scheduling policies
  - Manages parallel jobs
  - Enforces energy policy
- Examples: SLURM, OAR, TORQUE, PBS...



Online Scheduling Algorithm



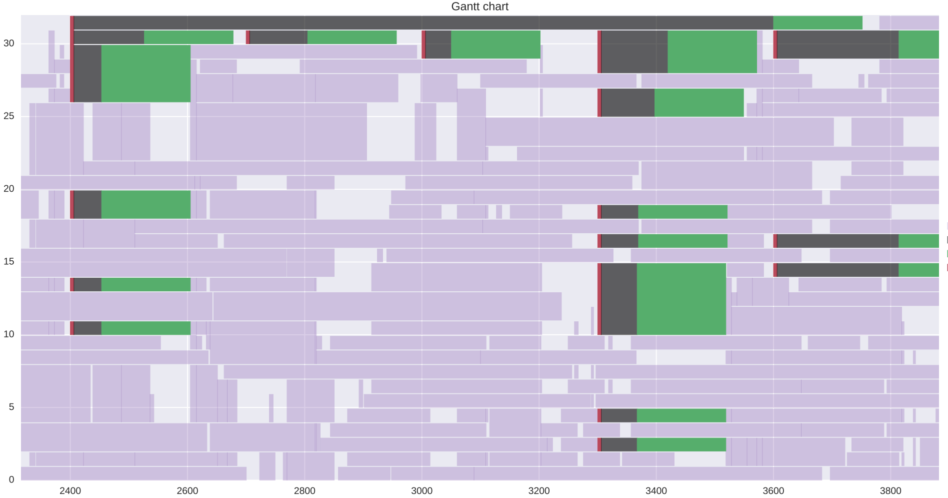
Events

- Job submission/termination
- Resource state alteration (switched ON/OFF, DVFS...)
- (Periodically)

Decisions

- Execute jobs (where?)
- Change resource state (ON, OFF, DVFS...)

Schedule (Gantt Chart)



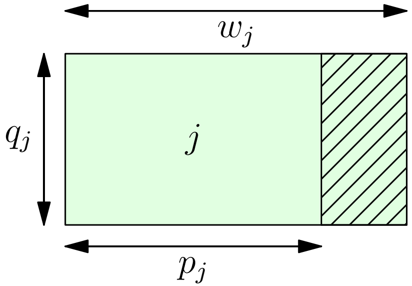
Outline

Workload Definition

$W = \{j_1, j_2, j_3, \ldots\}$. **Unknown** $|W|$

Job j definition:

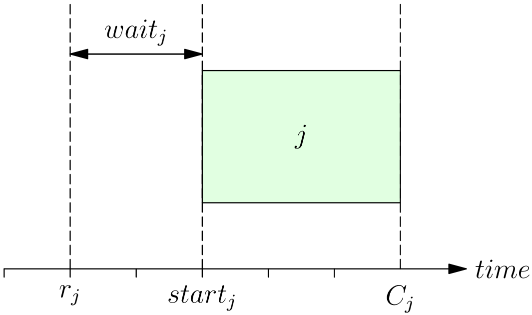
- Submission time r_j (release date). **Unknown** in advance
- Processing time p_j. **Unknown** in advance
- Requested time $w_j \geq p_j$. **Known** at submission time
- Number of requested resources q_j. **Known** at submission time
- ...



More Job-Related Notations

Once the job has been computed:

- Starting time $start_j$
- Completion time C_j
- Waiting time $wait_j = start_j - r_j$



Platform Definition

Platform: ordered set M of identical machines

- $t_{on \to off}$, switching OFF time (s)
- $t_{off \to on}$, switching ON time (s)
- $p_m(t)$, electrical consumption at time t (W)

$$p_M(t) = \sum_m \int_{min(s_j)}^{max(C_j)} p_m(t)\ dt$$

State	Power (W)
computing	p_{comp}
idle	p_{idle}
off	p_{off}
$on \to off$	$p_{on \to off}$
$off \to on$	$p_{off \to on}$

Hypotheses:

- $p_{off} \ll p_{idle} < p_{comp}$
- $p_{off} < p_{* \to *} \leq p_{comp}$

Problem Definition

Input:

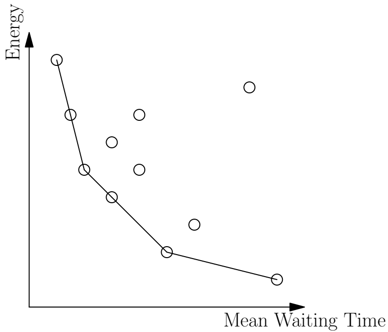
- Workload W of $|W|$ jobs
- Platform M of $|M|$ machines

Compute W on M,
minimizing:

- Total Consumed Energy
- Mean Waiting Time (QoS)

$$E = \sum_{m} \int_{min(s_j)}^{max(C_j)} p_m(t)\ dt$$

$$MWT = \frac{1}{|W|} \sum_{j} wait_j$$



Desired Properties

Results:

- High energy savings
- Low performance loss
- Robustness, predictability...

Constraints:

- Scalability
- No further job knowledge required
- Low #switch
- Ease of implementation

Some Related Work

Theoretical:

- DVFS/shutdown models&algo [Albers, 2010]
- Markov Chains [Herlich and Karl, 2012]

Practical:

- DVFS/shutdown in SLURM [Georgiou et al., 2015]
- Energy budget in EASY [Dutot et al., 2016a]
- Applications [Etinski et al., 2012]

Overprovisioning:

- Max throughput, power budget [Sarood et al., 2014]

Algorithms Overview

- Based on EASY backfilling
- Called on *classical* events **and** every T seconds
- Study interactions of two main mechanisms

Opportunistic Shutdown

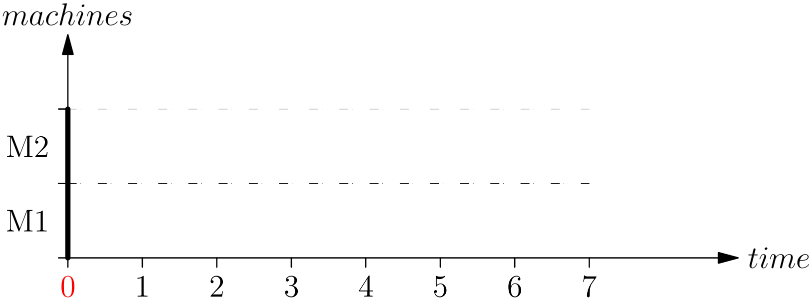
- Machine idle for $t \geq t_{idle}$ seconds $\rightarrow$ switched off

Adjusting the number of usable machines

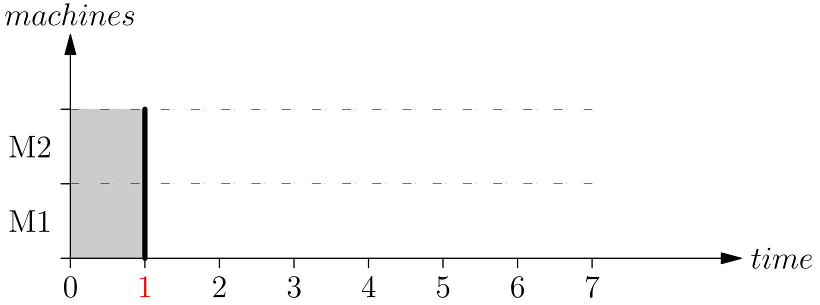
- Statically, avoid using more than $f \cdot |M|$ machines
- Dynamically, depending on system *unresponsiveness*

If the priority job **do requires** more machines, they will be switched-on.

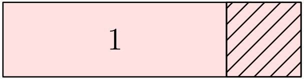
Easy Backfilling Example



Easy Backfilling Example



New job!



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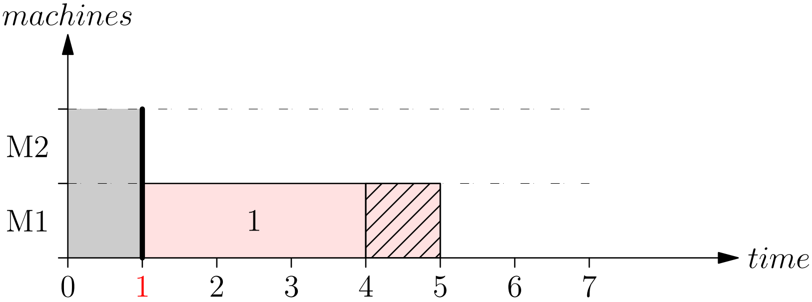

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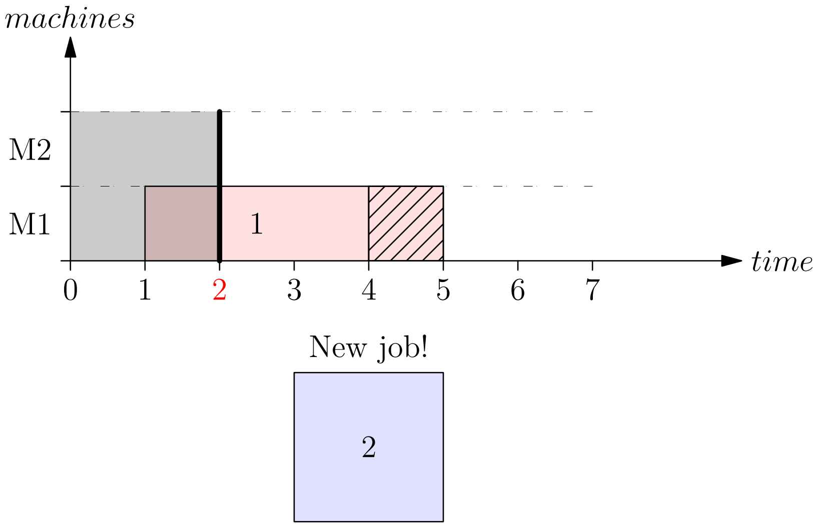

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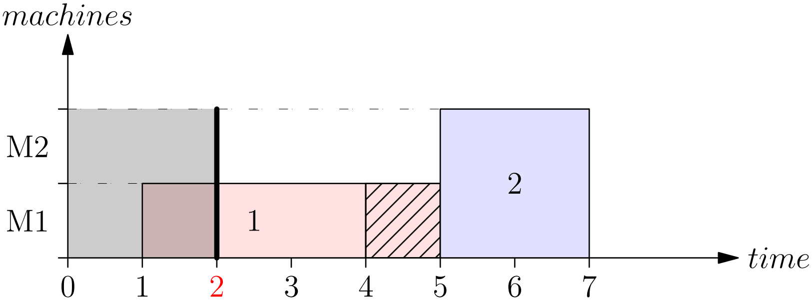

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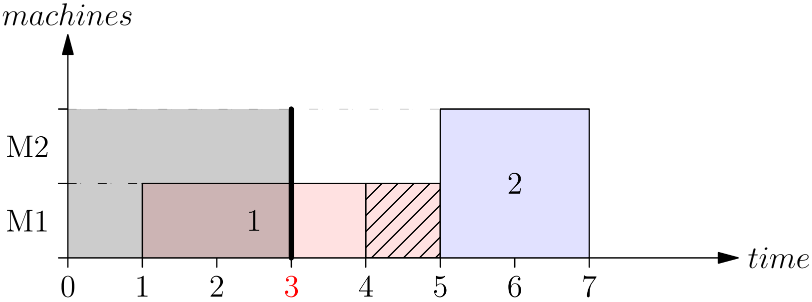
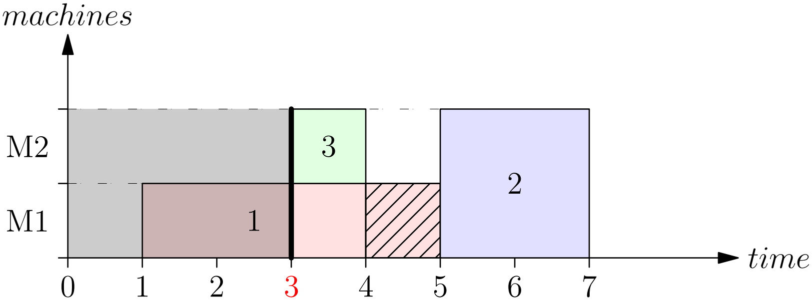


New job!

Easy Backfilling Example



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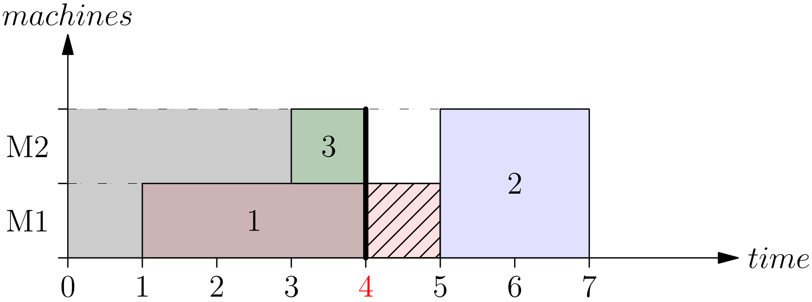
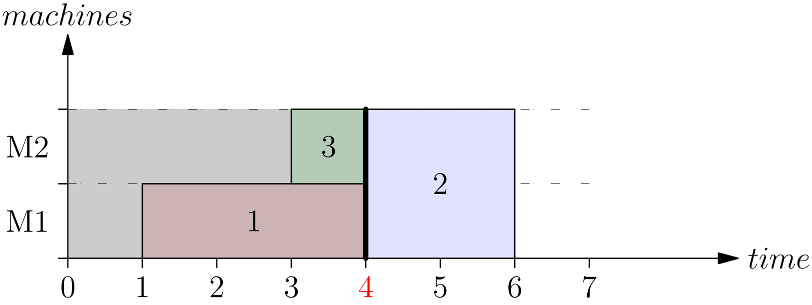


Jobs 1 and 3 finished

Easy Backfilling Example



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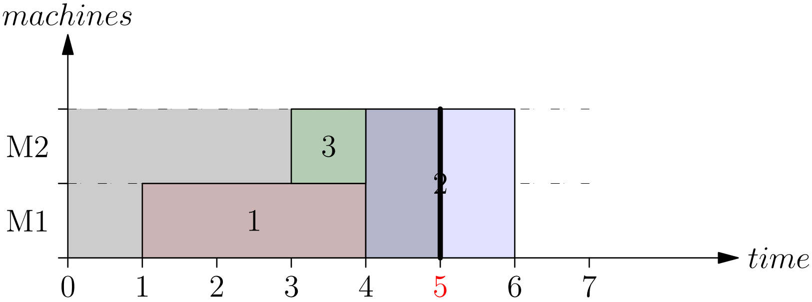

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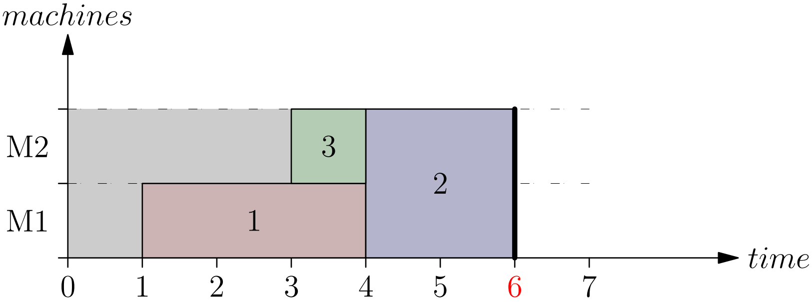
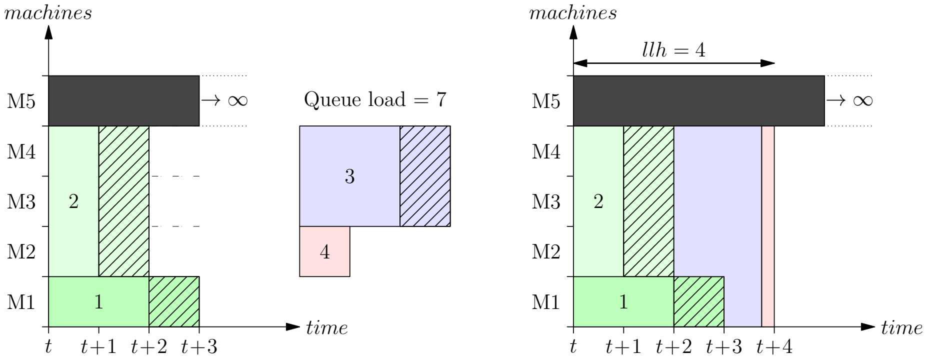


How to Estimate Unresponsiveness? Liquid Load Horizon

Required time to dump current load in the provisional schedule.

$$\text{Load} = \sum_j q_j \times w_j$$

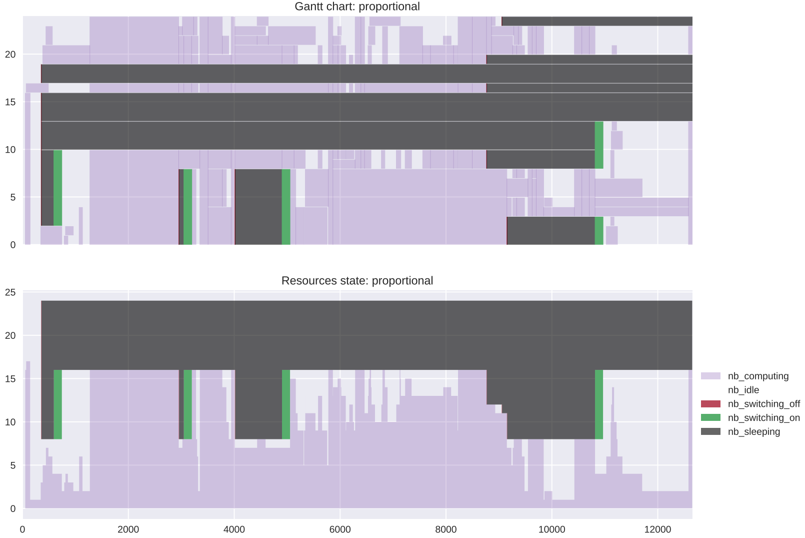


Opportunistic Shutdown

$T = 300$. $t_{idle} = 0$.

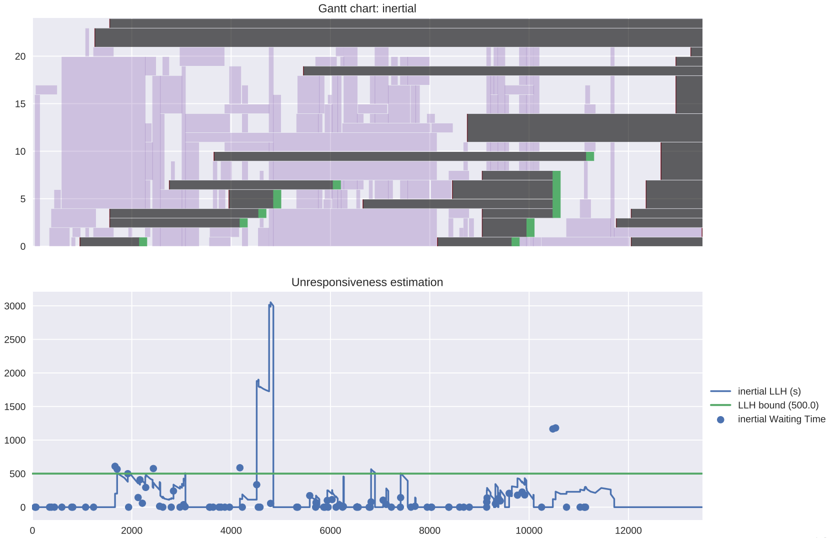
Static Adjustement

$T = 300$. 8 usable machines instead of 24.



Dynamic (Inertial) Adjustement

$T = 300.\ \bar{\upsilon}_{ub} = 500$ s. $f(x) = 2x$.



Inertial + Opportunistic

$T = 300.\ \bar{\upsilon}_{ub} = 500 \text{ s}.\ f(x) = 2x.\ t_{idle} = 0.$

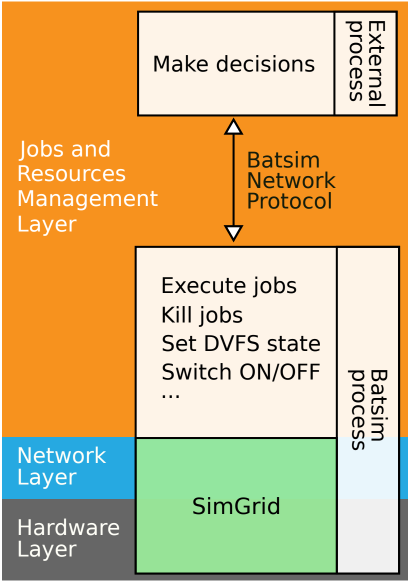
Experimental Setup

Simulation:

- Batsim (SimGrid)
- Batsched (C++)

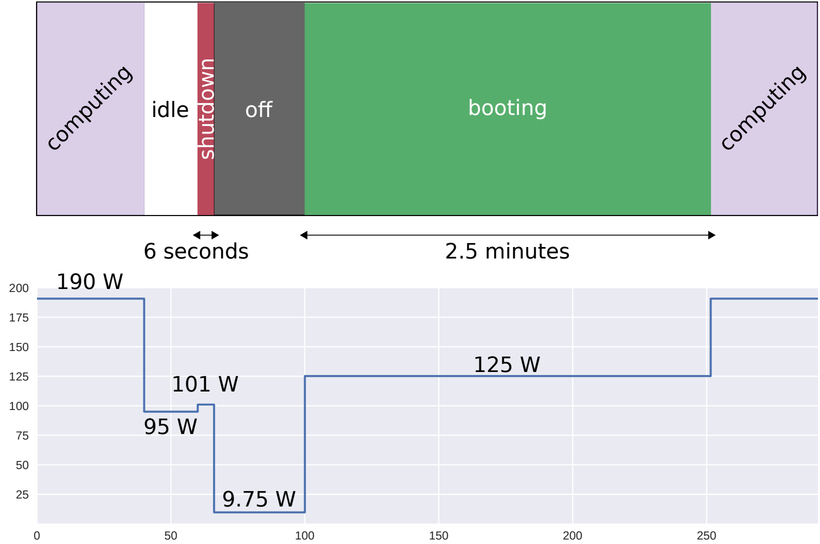
Workloads:

- KTH SP2, SDSC SP2
- Kept valid jobs ($w_j > r_j$)
- 11, 24 months → assess robustness
- Periodic utilization → room to save energy



Experimental Setup (platform)

Homogeneous. $|M| \in \{100, 128\}$. G5K Taurus [Dutot et al., 2016a].



Experimental Setup (exploration space)

Shared by all algorithms	
Workloads	KTH_SP2, SDSC_SP2
Platform	homogeneous240
Shared by Proportional and Inertial	
T (s)	60, 120, 300, 600
t_{idle} (s)	0, 30, 60, 600, 6000, $+\infty$
Make run decisions on period	true, false
Proportional-specific	
ρ	1.00, 0.95, 0.90, 0.85
Inertial-specific	
$f(n)$	$n+1$, $n \times 2$
$\bar{\upsilon}_{ub}$ (s)	$1 \cdot 10^4$, $1 \cdot 10^5$, $2 \cdot 10^5$
Allow future switches	true, false

All these parameters combinations have been tested

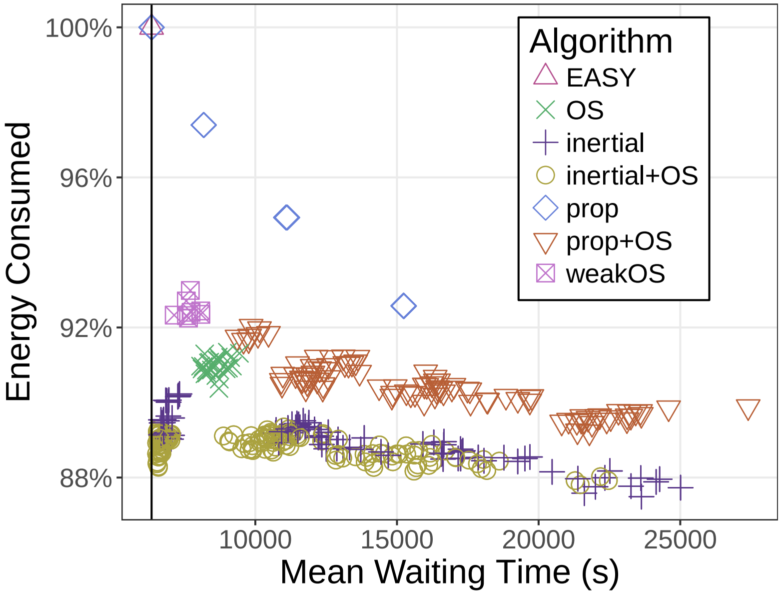
Algorithm Nomenclature

Opportunistic shutdown aggressiveness:

- strong: $t_{idle} \in \{ 0, 30, 60, 600 \}$
- weak: $t_{idle} \in \{ 6000, +\infty \}$

Name	Opp.?	Proportional?	Inertial?
EASY			
weakOS	weak		
prop	weak	✓	
inertial	weak		✓
OS	strong		
prop+OS	strong	✓	
inertial+OS	strong		✓

Energy / Mean Waiting Time (KTH_SP2)



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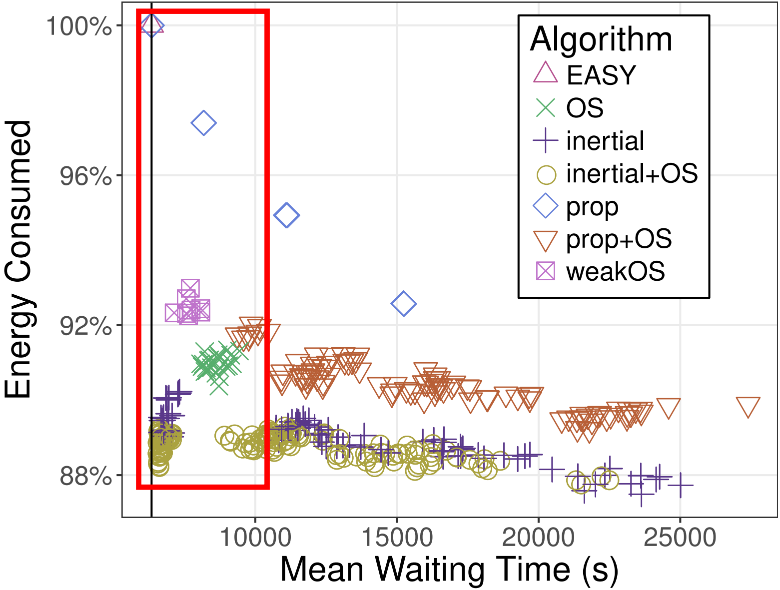

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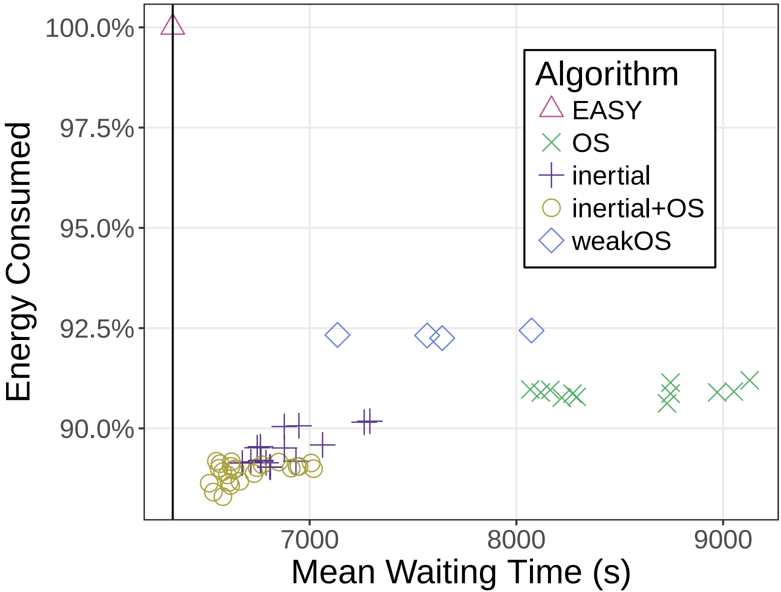
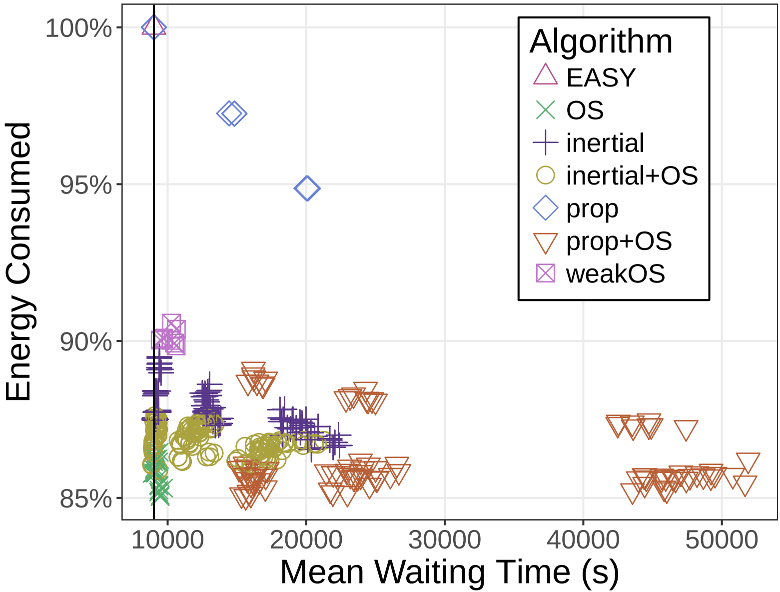
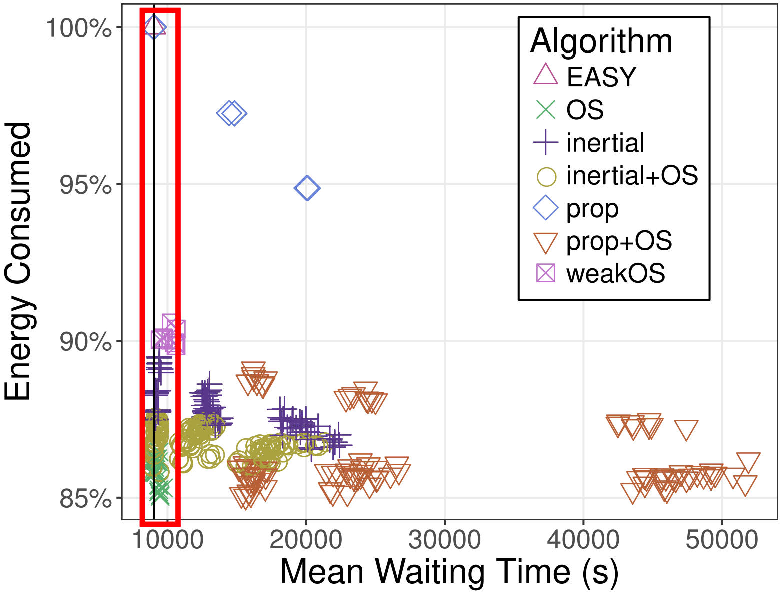


Energy / Mean Waiting Time (SDSC_SP2)



Energy / Mean Waiting Time (SDSC_SP2)



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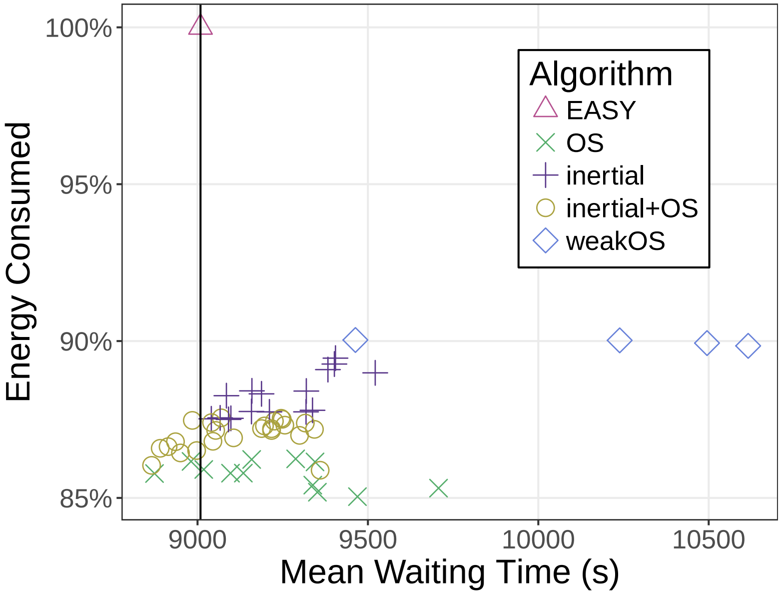
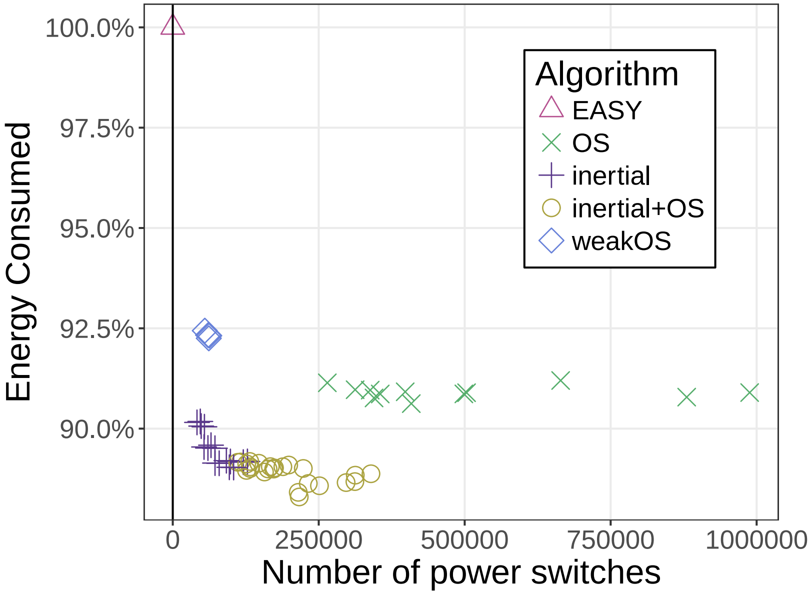
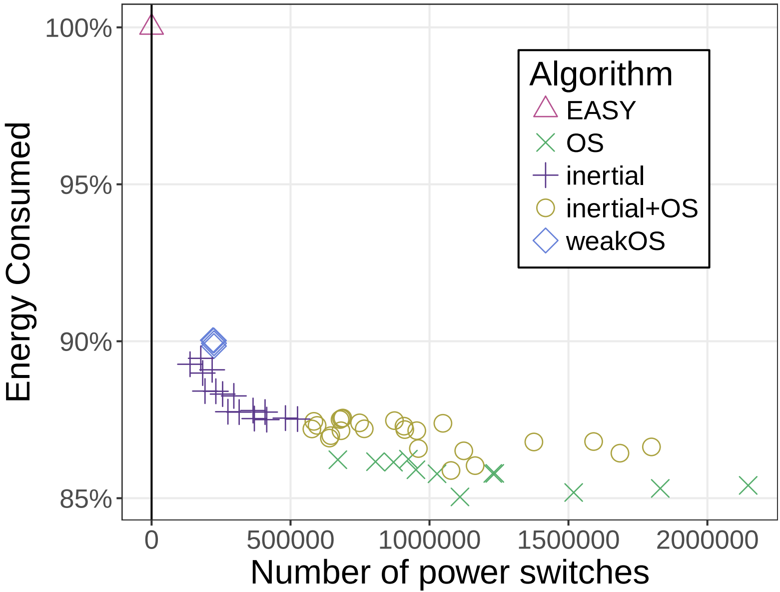


Number of Switches (KTH_SP2)



Number of Switches (SDSC_SP2)



Conclusion

Inertial shutdown:

- Energy/Performance tradeoffs
- Same order of energy savings as OS
- Low mean performance loss
- No max performance loss (not the case of OS)
- Low #switch
- Stable, predictable

Future work:

- Communication
- EASY constraints?

Thanks!

Batsim: https://github.com/oar-team/batsim
Experiment: https://gitlab.inria.fr/batsim/article-cluster17

Contact

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Inertial Shutdown

Parameters:

- $f : \mathbb{N} \to \mathbb{N}$, the inertia function
- $\bar{\upsilon}_{ub}$, the unresponsiveness mean threshold

Idea:

- Based on Easy Backfilling
- Estimates the system unresponsiveness at each event
- Do switches periodically, computing MU: the *mean* unresponsiveness since last periodic call
  - +MU → switch some machines ON
  - -MU → switch some machines OFF

Inertial Shutdown: Idertia state

$state \in \{sedating, awakening\}$ is stored
Initially, $state = awakening$

At each periodic call i:

- $(\tilde{\upsilon}_i \geq \overline{\upsilon}_{ub}) \implies$ state set to awakening. Decision made immediately.
- Otherwise,
  - $(state = awakening) \wedge (\tilde{\upsilon}_i \leq \tilde{\upsilon}_{i-1}) \implies$ state set to $sedating$. No decision made now.
  - $(state = sedating) \wedge (\tilde{\upsilon}_i > \tilde{\upsilon}_{i-1}) \implies$ state set to $awakening$. No decision made now.
  - Otherwise, decision made immediately.

Inertial Shutdown: Decision

Decision: Switch *nb* machines (ON/OFF depending on *state*)

S_a, switchable machines at i
S_e, switched machines since $i-1$ (for inertia reasons)

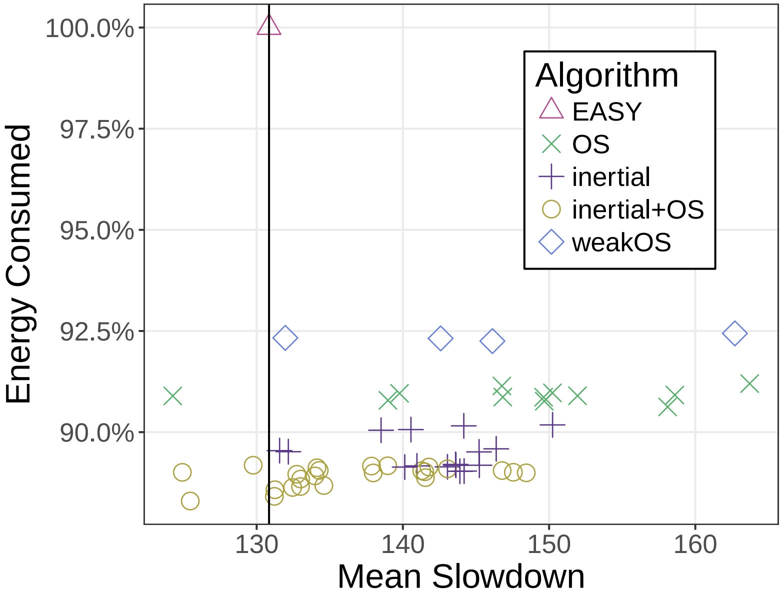
Switch at least 1 machine, without doing the impossible:

$$nb = min\left(max\left(f(|S_e|), 1 \right), |S_a| \right)$$

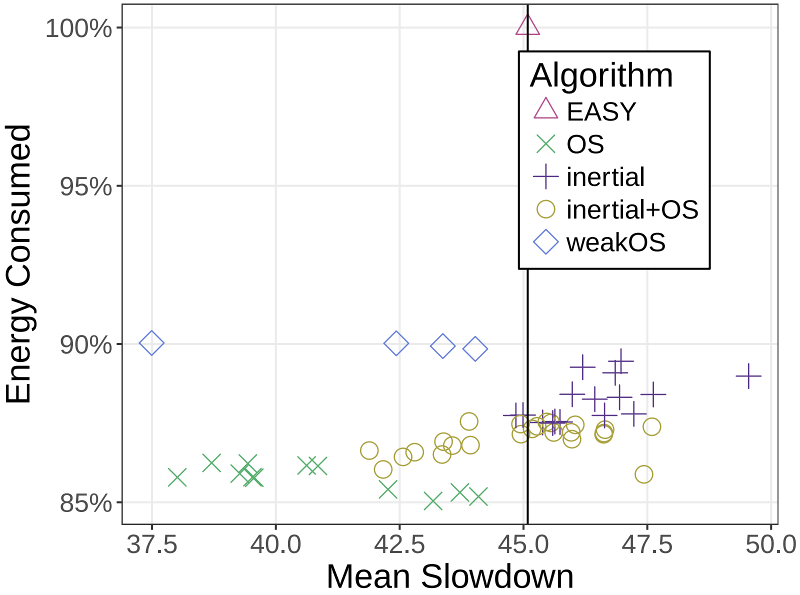
Energy information

Variable	Simulator	Scheduler
$t_{on \rightarrow off}$	151.52	$152 + 5$
$t_{off \rightarrow on}$	6.1	$6.1 + 5$
p_{off}	9.75	9.75
p_{idle}	95	95
p_{comp}	190.738	190.738
$p_{on \rightarrow off}$	100.997	101.640
$p_{off \rightarrow on}$	125.174	125.197

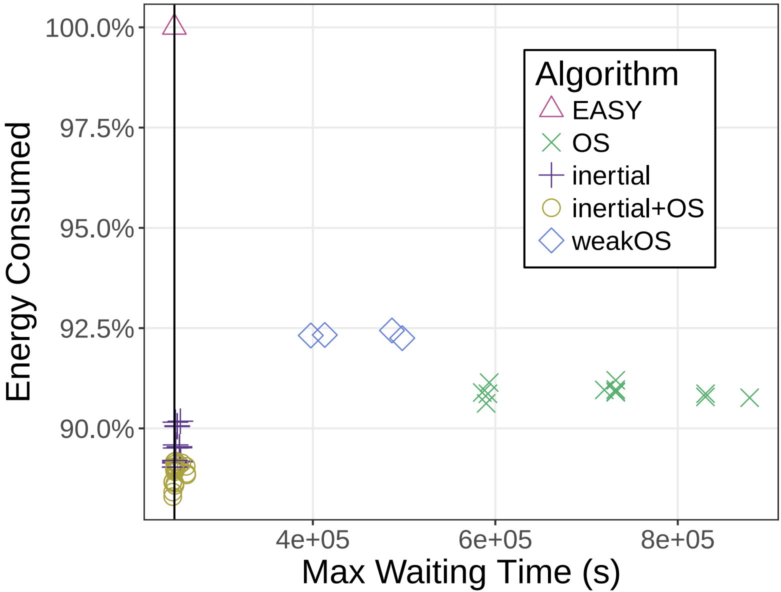
Energy / Mean Slowdown (KTH_SP2)



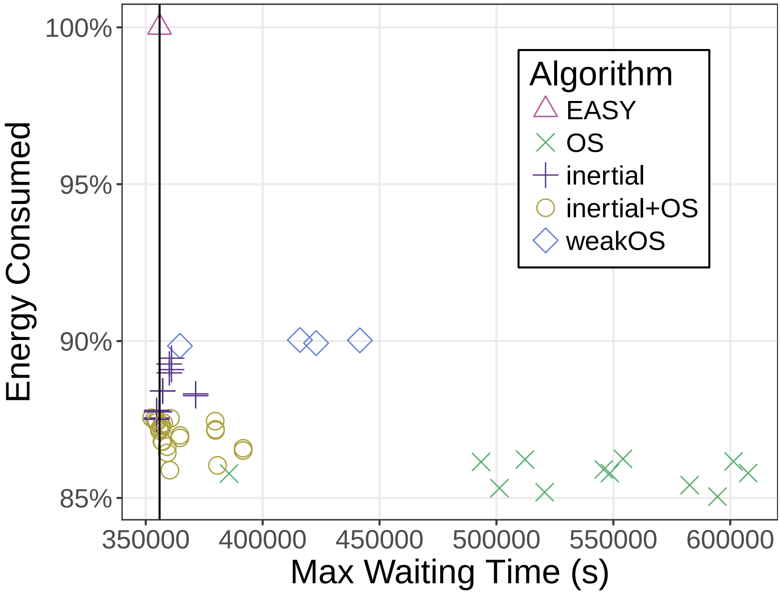
Energy / Mean Slowdown (SDSC_SP2)



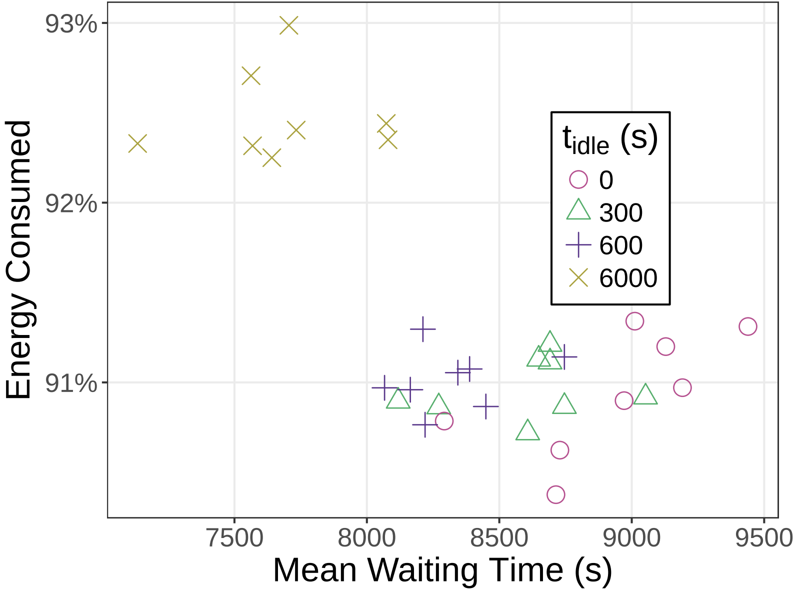
Energy / Max Waiting Time (KTH_SP2)



Energy / Max Waiting Time (SDSC_SP2)



Opportunistic: Impact of t_{idle} (KTH_SP2)



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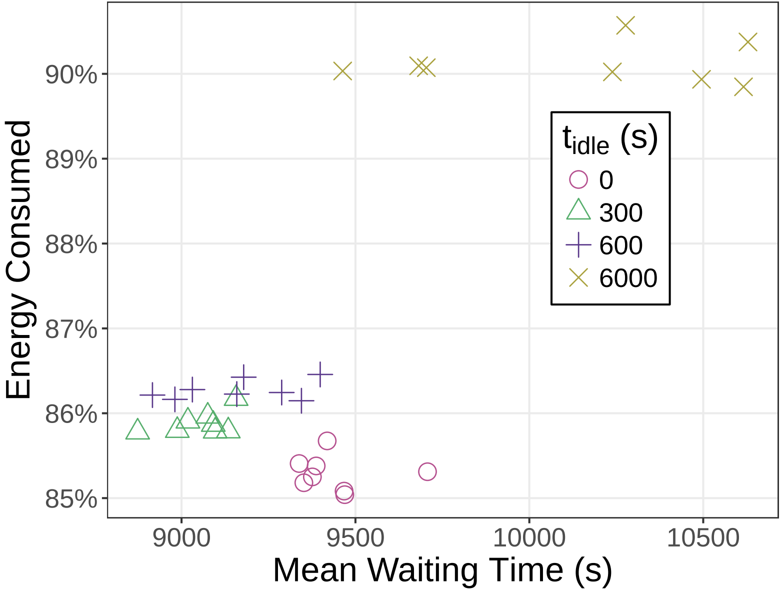
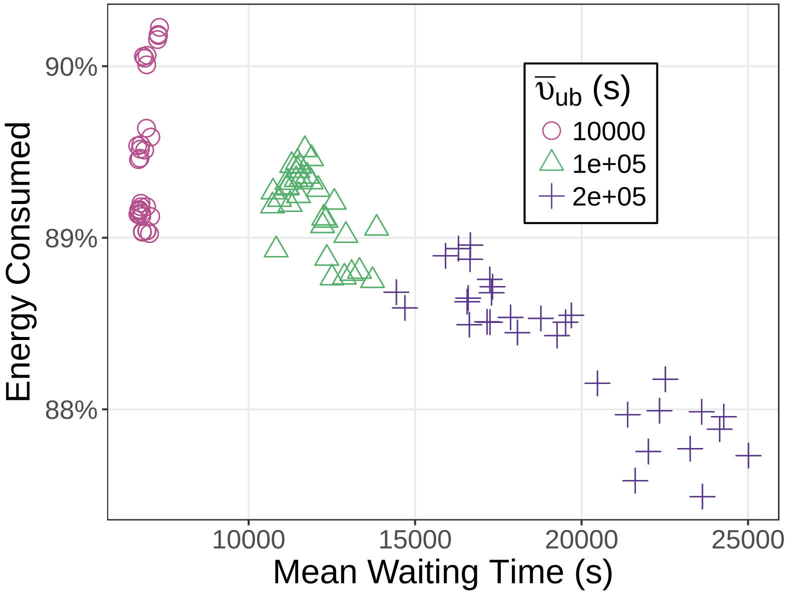
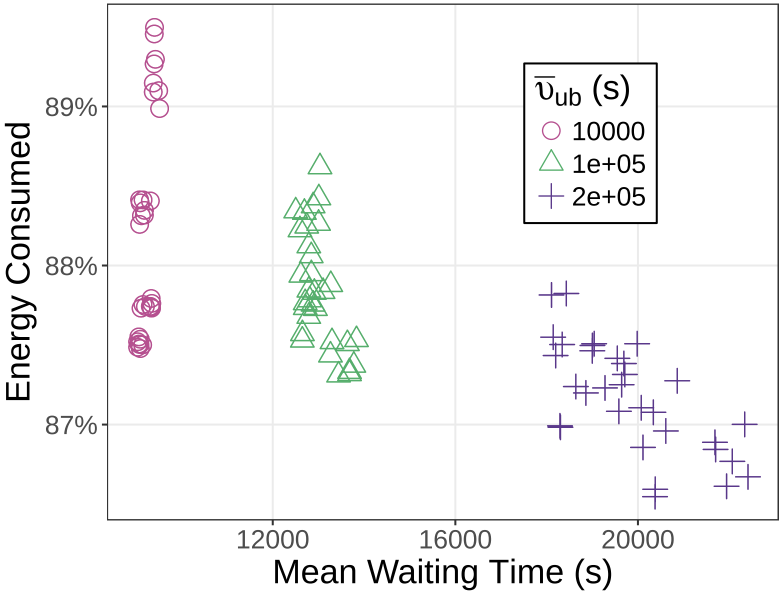


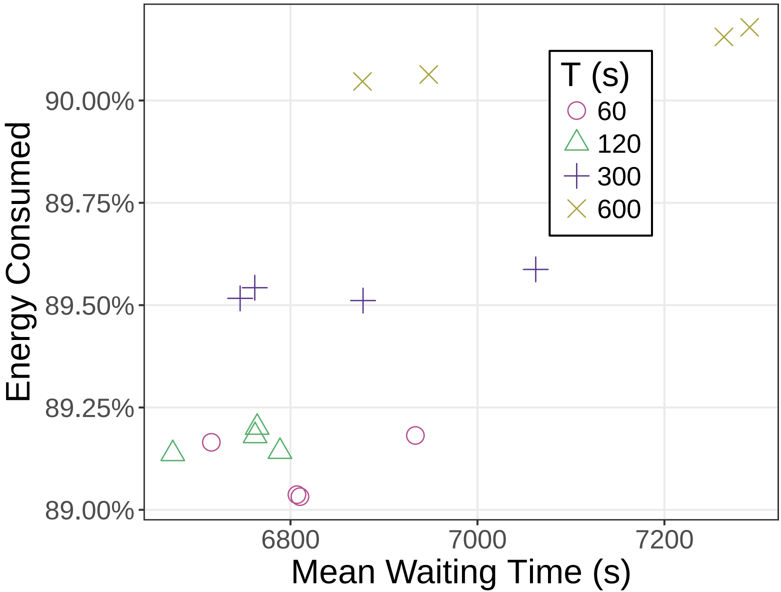
Inertial: Impact of $\overline{\upsilon}_{ub}$ (KTH_SP2)



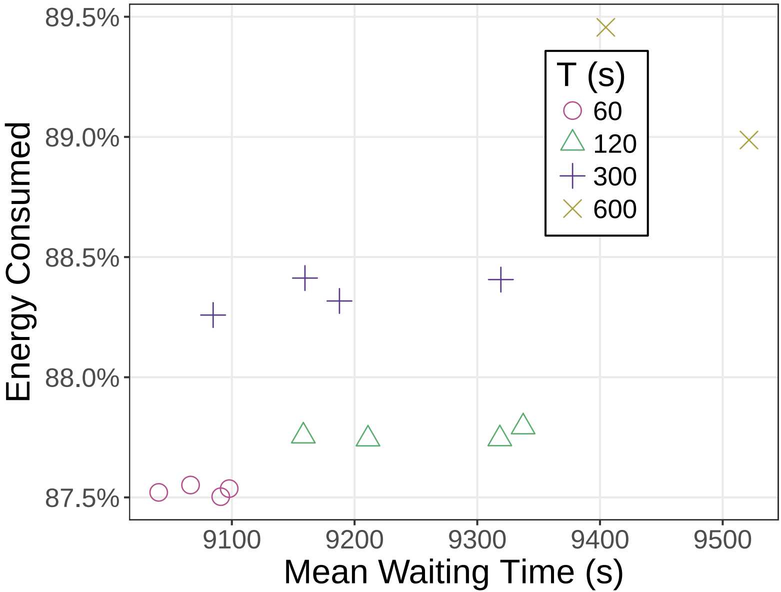
Inertial: Impact of $\overline{\upsilon}_{ub}$ (SDSC_SP2)



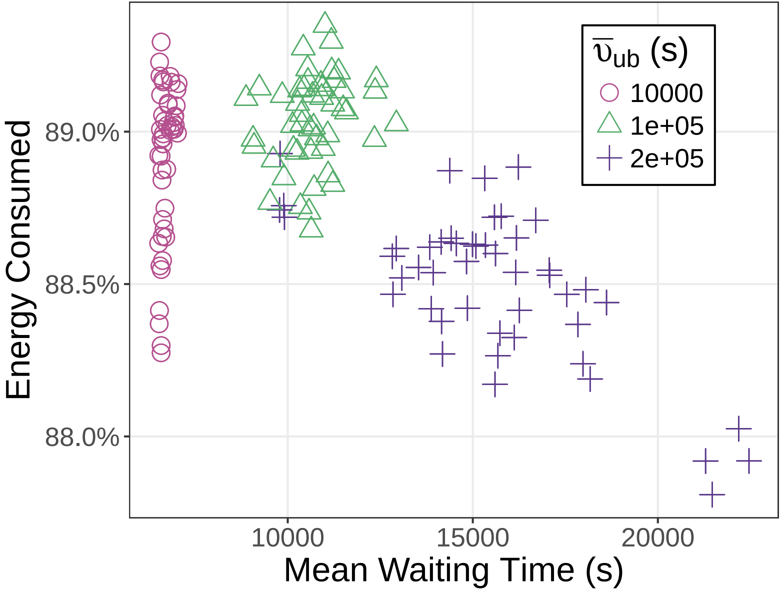
Inertial: Impact of T (KTH_SP2)



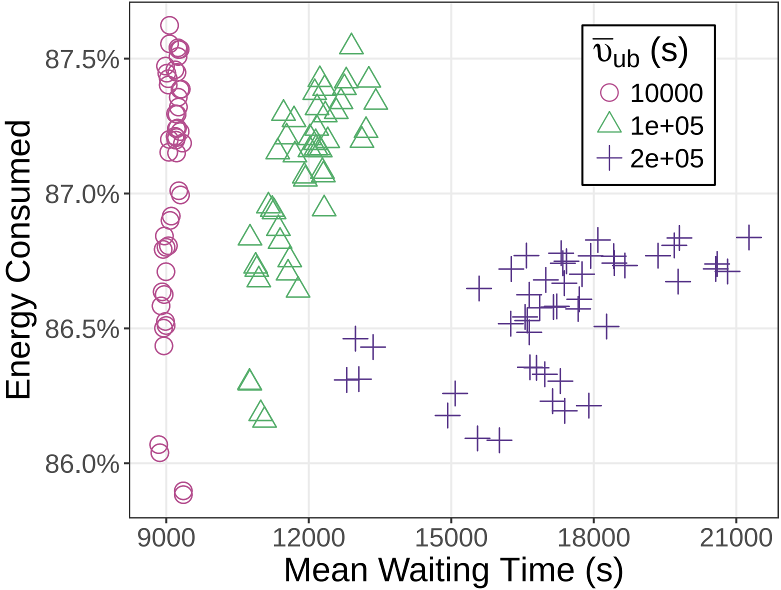
Inertial: Impact of T (SDSC_SP2)



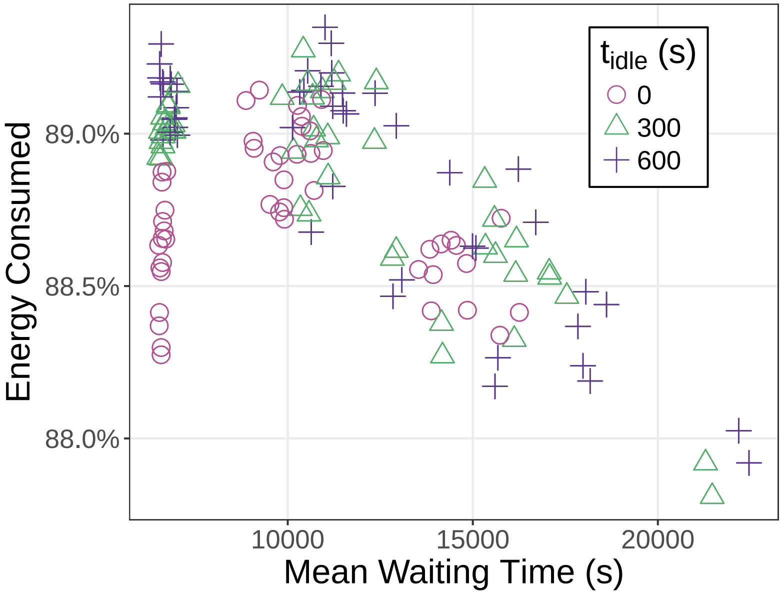
Inertial+Opportunistic: Impact of $\overline{\upsilon}_{ub}$ (KTH_SP2)



Inertial+Opportunistic: Impact of $\overline{\upsilon}_{ub}$ (SDSC_SP2)



Inertial+Opportunistic: Impact of t_{idle} (KTH_SP2)



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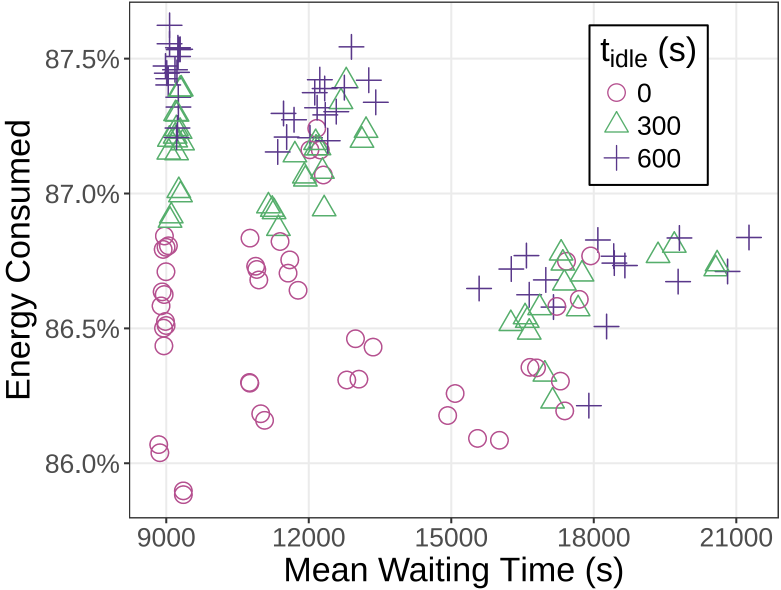

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