Elastic Resource Sharing for Distributed Deep Learning

Changho Hwang,
Taehyun Kim, Sunghyun Kim*, Jinwoo Shin, and KyoungSoo Park

KAIST, MIT*

Networked and Distributed Computing Systems Lab

Multi-tenant Training Workload

- Very expensive workload
  - Deep learning training (DLT) is costly
    - Roughly, $1=1K params training [1]
  - Users often write jobs that scale poorly
  - Many parallel DLT jobs

Need an efficient system that achieves:

- ✓ Low **average job completion time (avg. JCT)**
- ✓ **Fairness** between jobs
- ✓ High resource **utilization**

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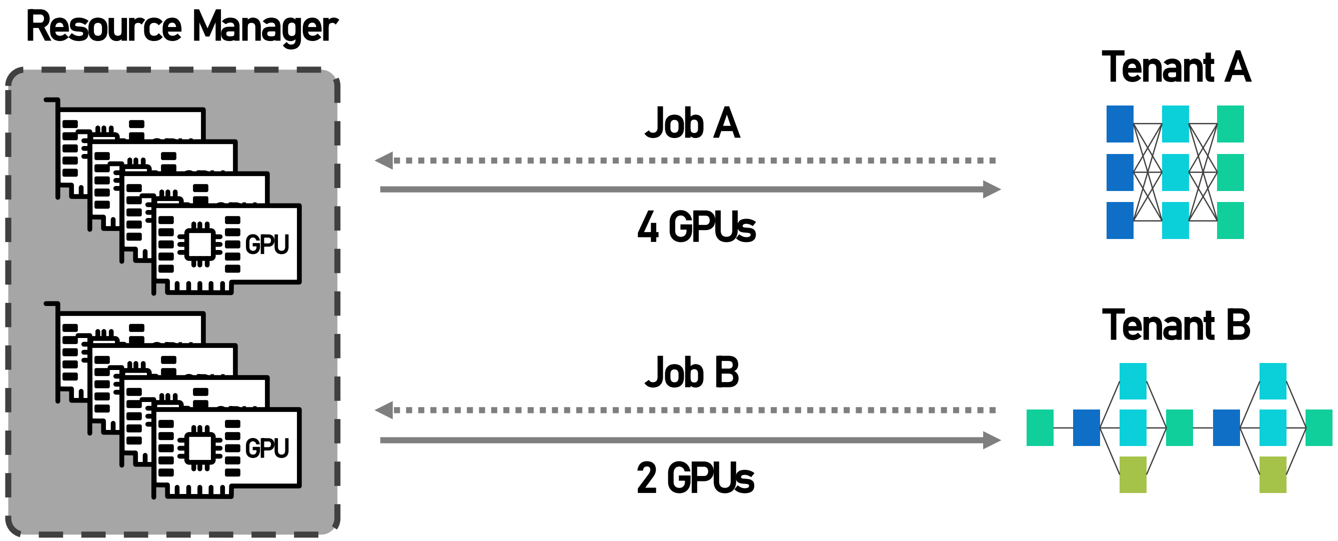
[1] Or Sharir et al. The Cost of Training NLP Models: A Concise Overview. arXiv:2004.08900, 2020.

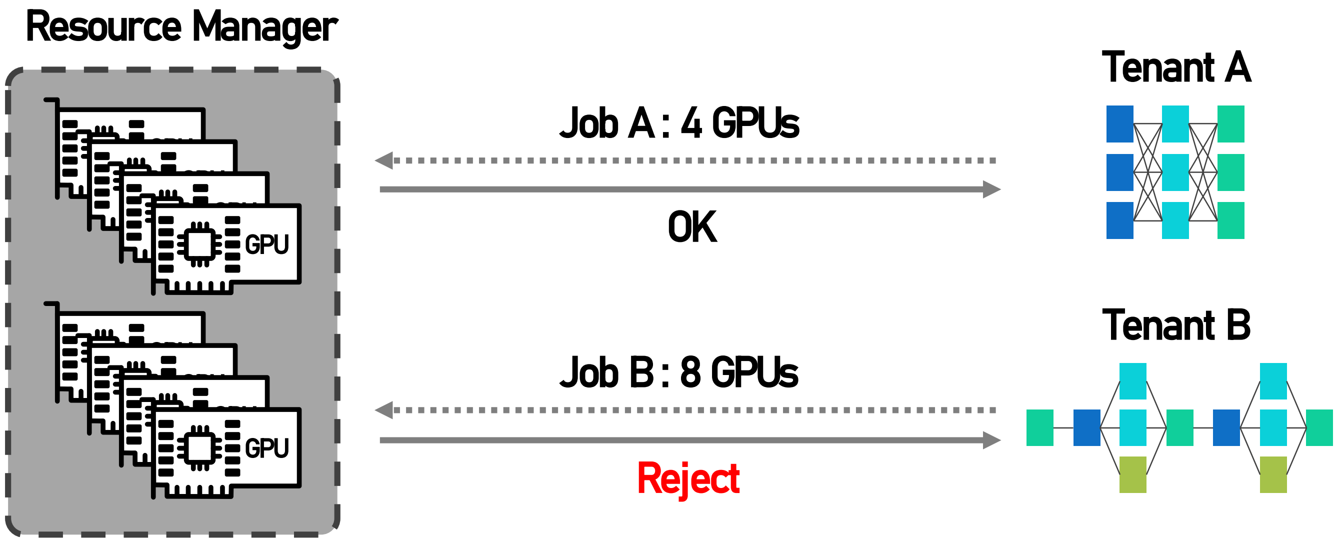
Efficient Resource Sharing



- *Resource sharing*: key to efficient cluster usage

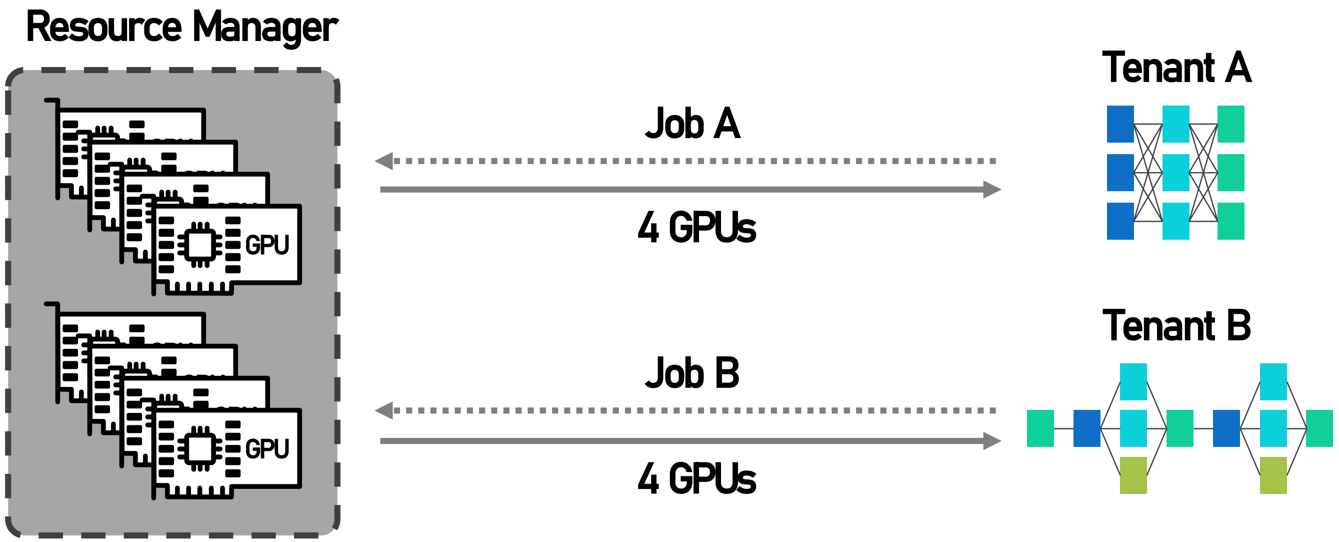
non-elastic sharing* vs. *elastic sharing

Non-elastic Resource Sharing



- Each job declares/requests its own resource share
- *Job-level coarse-grained scheduling*

Elastic Resource Sharing



- System determines the share of every job
- *Resource-level fine-grained scheduling*

Good for optimization, but realizing the benefit is challenging!

Our Work: Algorithms + Systems

1. *Apathetic Future Share (AFS):* elastic sharing for reducing avg. JCT

2. *CoDDL:* resource management system optimized for elastic sharing

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Reducing Average Job Completion Time

- Prioritize short jobs!

> The SJF scheduling algorithm is provably *optimal*, in that it gives the minimum average waiting time for a given set of processes. Moving a short process before a long one decreases the waiting time of the short process more than it increases the waiting time of the long process. Consequently, the *average* waiting time decreases.

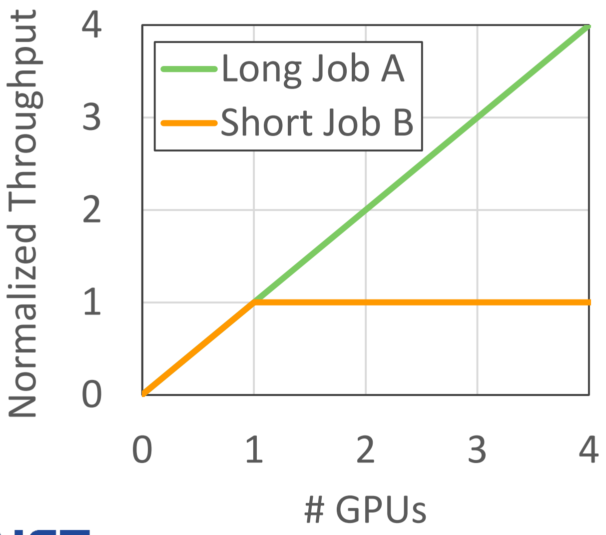
– Operating System Concepts, 8th ed.

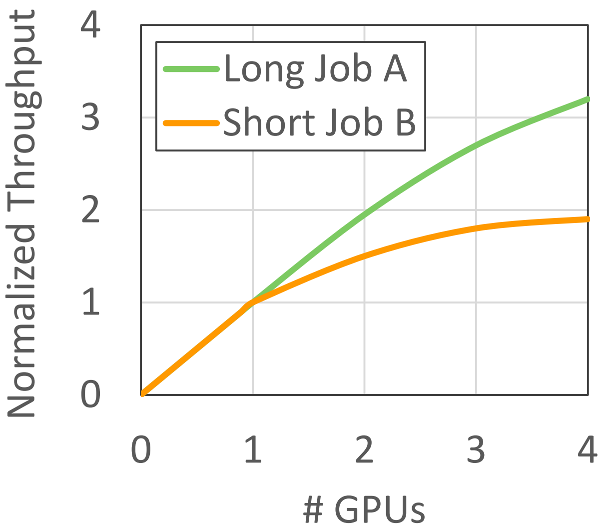
- Use shortest-remaining-time-first (SRTF, or preemptive SJF)

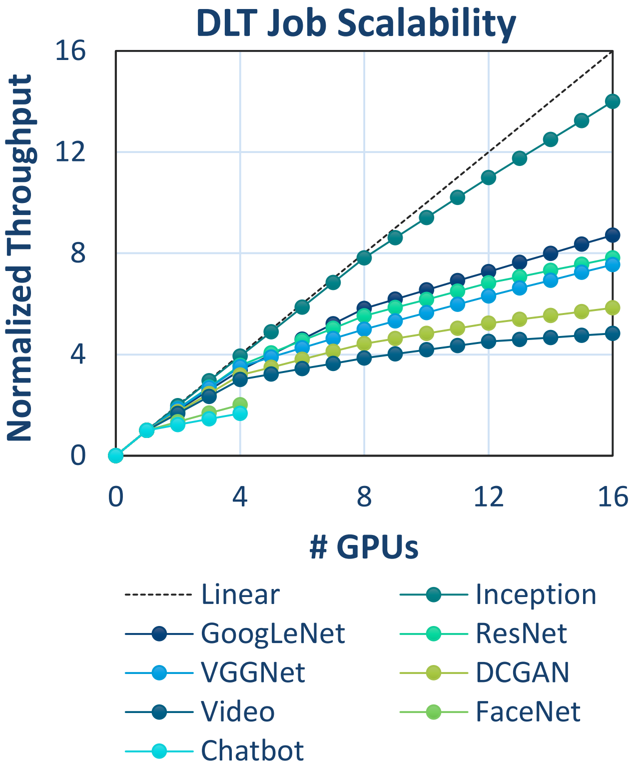
No, SRTF is often suboptimal for DLT jobs!

Motivating Questions

- What if the shortest job's throughput does not scale?
  - → **No more throughput, no more resources! (Of course.)**
- What if it is somewhere in between?
  - → **Non-trivial**







Handling Shortness & Efficiency

- ***Resource efficiency*** introduced in the picture!

Algorithms	Prioritize short job	Prioritize efficient job	Elastic Sharing
SRTF	✅		
Max-min		△	✅
Optimus [EuroSys '18]		✅	✅
SRSF/Tiresias [NSDI '19]	✅	△	
Themis [NSDI '20]	✅	△	✅
AFS (this work)	✅	✅	✅

✅ **: handled explicitly** △ **: handled implicitly**

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AFS Resource Sharing

- Strike a balance between shortness & efficiency
  - Say that job b remains longer than job a, then:

$$\frac{p'_b - p_b}{p'_b} - \frac{p'_a - p_a}{p_a} \begin{cases} > 0, & \textit{prioritize } b \textit{ over } a \ (\textbf{efficiency wins}) \\ \leq 0, & \textit{prioritize } a \textit{ over } b \ (\textbf{shortness wins}) \end{cases}$$

p_x: current throughput of job x
p'_x: throughput of job x with one more GPU

  - What does this mean?
  - At first, do not bias into either side
  - **Lighter** resource contention → bias towards **short** jobs
  - **Heavier** resource contention → bias towards **efficient** jobs

Refer to rigorous analysis in our paper!

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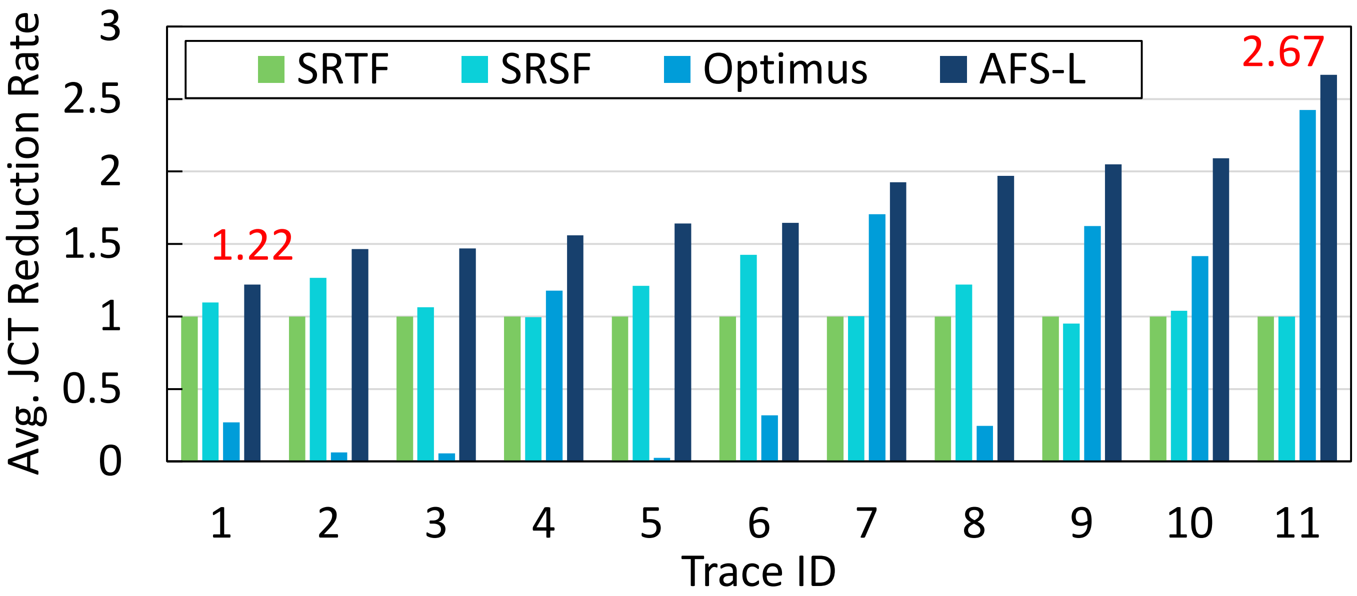
AFS Scheduling Algorithm – AFS-L

- Leverages the exact remaining time, like SRTF
  - For apple-to-apple comparison with SRTF
- Real-world trace evaluation (simulated)

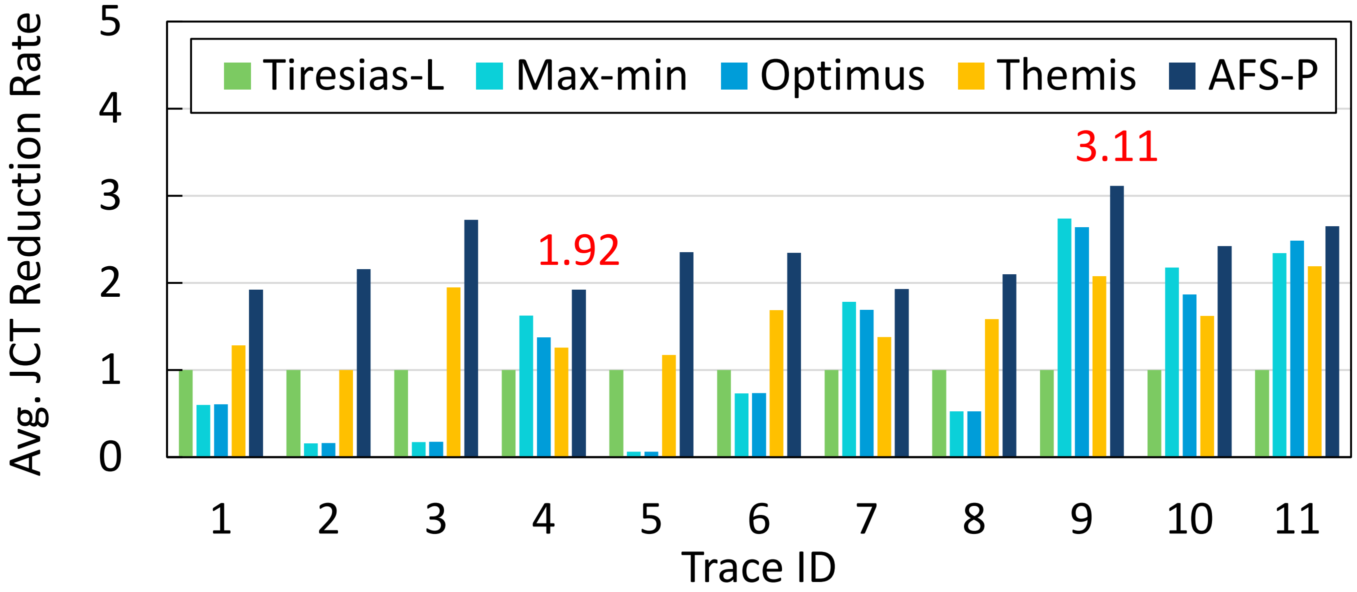


SRSF [NSDI '19]
Optimus [EuroSys '18]

AFS Scheduling Algorithm – AFS-P

- Can run without job length information
  - Leverage processor sharing
  - More practical than AFS-L
- Real-world trace evaluation (simulated)

More details of algorithms in the paper!



Tiresias-L [NSDI '19]
Optimus [EuroSys '18]
Themis [NSDI '20]

Our Work: Algorithms + Systems

1. ~~*Apathetic Future Share (AFS):* elastic sharing for reducing avg. JCT~~

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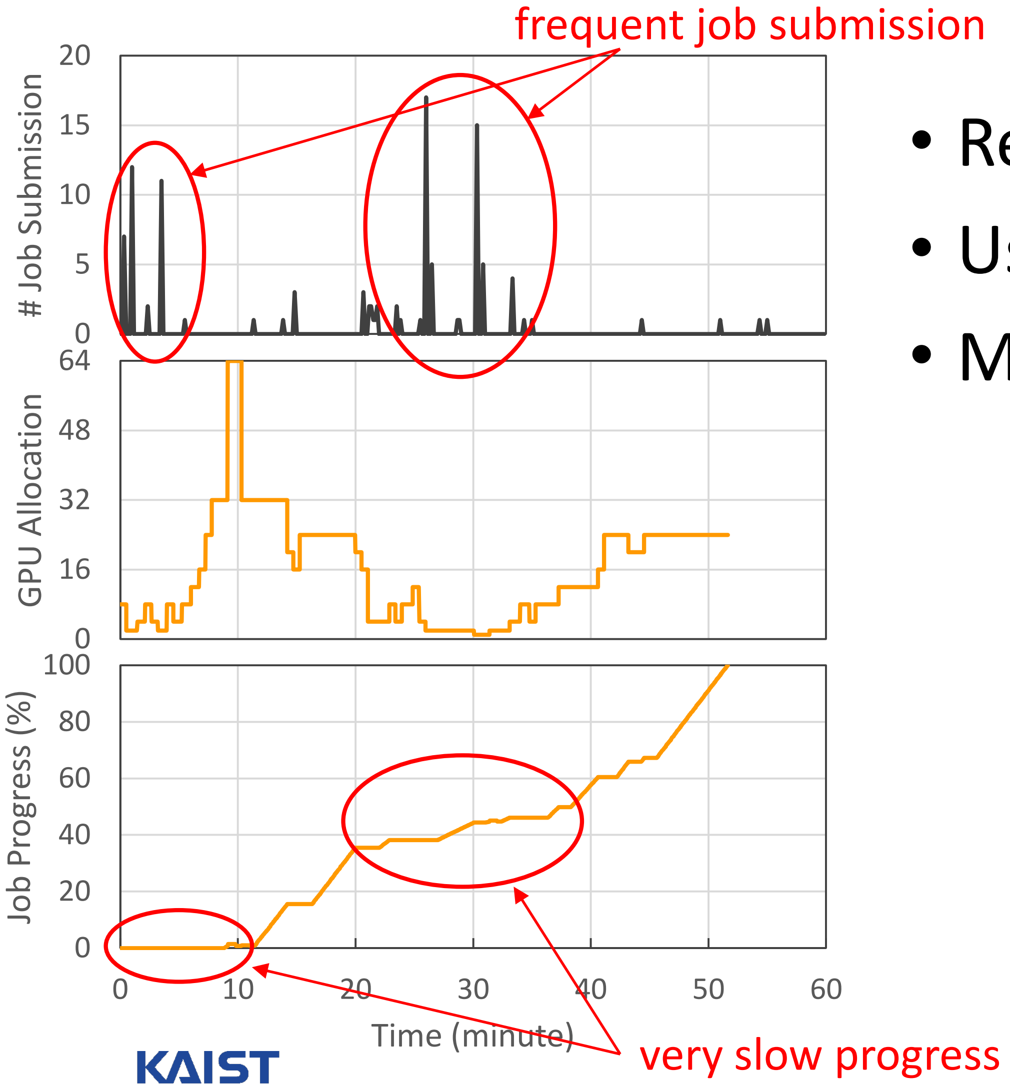
Realizing Elastic Resource Sharing

- Frequent job reconfigurations drop the performance
  - **6.3x on average, & up to 22x** more than non-elastic sharing
  - Severe thrashing on a burst of reconfigurations

Experiment: Cluster Thrashing



- Replay a full-scaled trace in a real 64-GPU cluster
- Use AFS-P scheduler
- Monitor a single job submitted at time zero

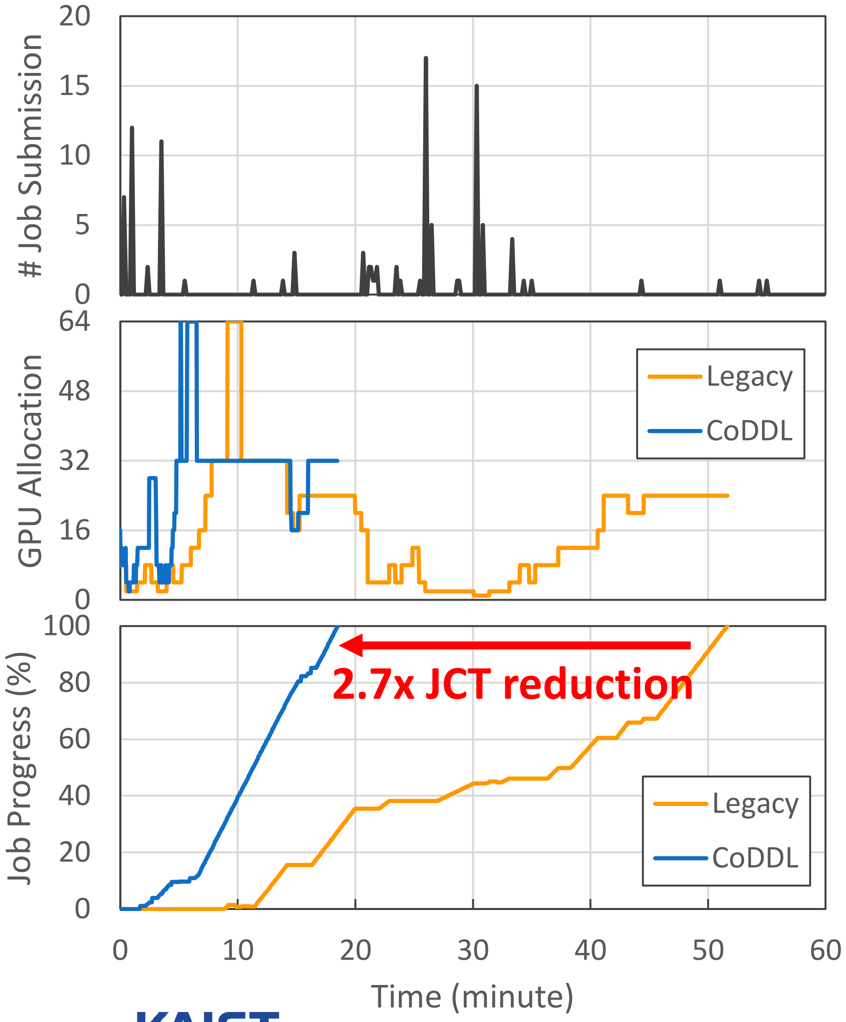
CoDDL Resource Manager

CoDDL: **Co**ordinator for **D**istributed **D**eep **L**earning

- Overview
  - Front-end: accepts user-written DL models
  - Back-end: run the scheduler & auto-scale models
- Minimize the job reconfiguration overhead
  1. Concurrent reconfiguration with job execution
  2. Fast cancelling stale configuration commands

See other system details in the paper:
failure handling, GPU placement, throughput measurement, etc.

Experiment: Relaxed Thrashing



- Accelerate job progress by relaxing thrashing

Find avg. JCT evaluation
over CoDDL in the paper!

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Summary

- Elastic resource sharing for multi-tenant DLT jobs
  - Enables significant improvement of scheduling performance
- **Apathetic Future Share (AFS)**: elastic resource sharing algorithm
  - Balanced prioritization of short jobs & efficient jobs for reducing avg. JCT
  - Reduce avg. JCT up to 2.67x and 3.11x over SRTF and Tiresias-L, respectively
- **CoDDL**: optimized resource management system for elastic sharing
  - Mitigate cluster thrashing via efficient job reconfiguration