Scheduling Parallel DAG Jobs Online

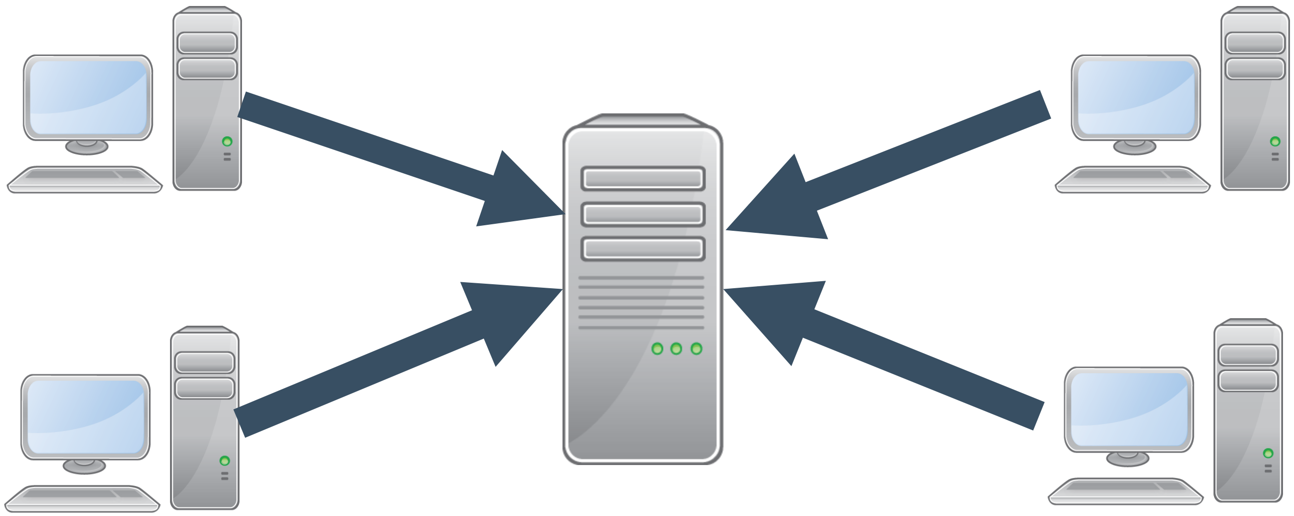
Ben Moseley (CMU)

Joint work with:
Kunal Agrawal (WahsU)
Jing Li (NJIT)
Kefu Lu (WashU/CMU)

Carnegie Mellon
Tepper
SCHOOL OF BUSINESS

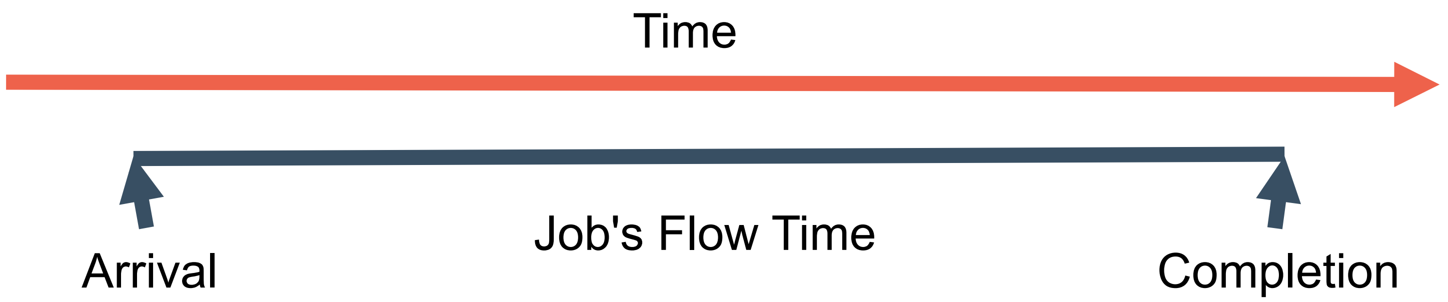
Client-Server Scheduling

- Clients send ***parallel*** jobs to the server
- Jobs schedule on **identical** processors/machines
- Server processes jobs and provides service guarantees
- Jobs arrive over time – **online**
- Jobs can be **preempted**
- **Worst case setting**



Service Guarantees

- Flow time – difference between arrival and completion of a job
- Common objectives in online scheduling:
  - Average/Sum Flow Time
  - Maximum Flow Time
  - Throughput



Parallelism Models

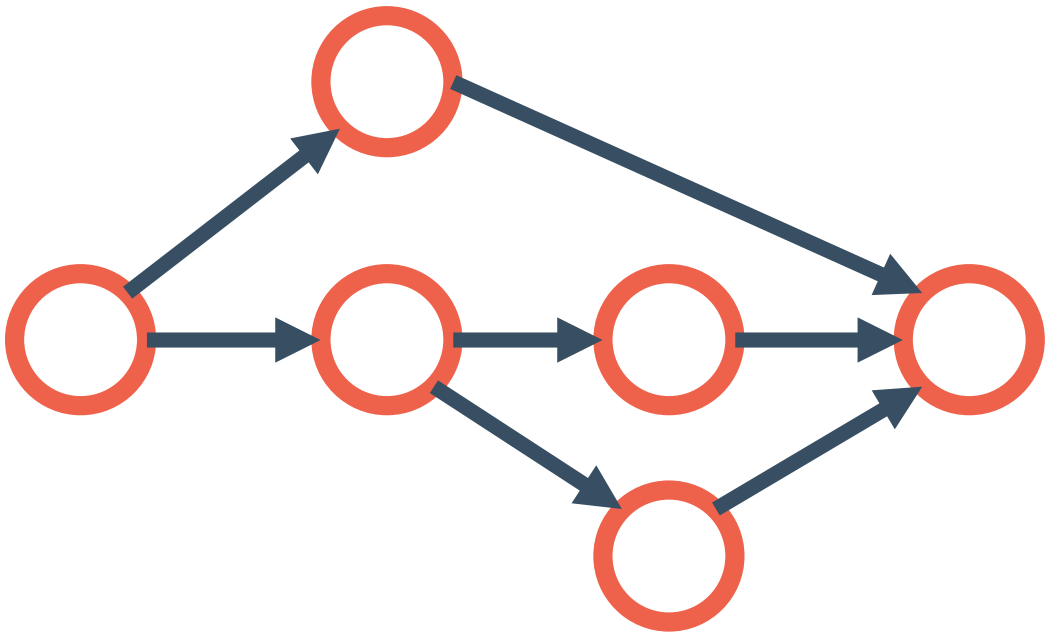
- Speed-up Curves
  - Jobs associated with speed-up functions
- Directed-Acyclic Graph (DAG) Model
  - Jobs have work which correspond to a DAG
    - Each job is modeled as a DAG
    - Job completed when ***last*** node of its DAG is completed
  - Processing rate depends on the number of nodes being worked on

Parallelism Models

- Speed-Up Curves
  - Jobs have total work *W* divided into phases
    - Each phase has work
    - Phases are processed sequentially
  - Processing rate function Γ(m)
    - Function of number of processors given
    - Function is usually positive sub-linear
    - Function can be different depending on the phase the job is currently in.

A Job's Phases

Directed Acyclic Graph Model of Parallelism



- Nodes represent computation
- Arrows represent dependencies

Online Study of Models

- DAG model
  - Well-studied *offline*
  - Only studied recently online

  - Naturally captures programs generated by languages and libraries such as Cilk, Cilk Plus, Intel TBB, OpenMP.
  - Used by applied communities: Cyber-Physical-Systems (Real-Time) community excited (Outstanding paper award ECTRS 2013, Best-Student-Paper Award RTSS 2011)

Results

First results for average flow in DAG model

Average Flow Time [SODA 2016]

- LAPS is $(1+\varepsilon)$ speed $O(1)$ competitive, for fixed $\varepsilon>0$
- Best theoretically possible

Throughput [LATIN 2018]

- A $(1+\varepsilon)$ speed $O(1)$ competitive algorithm for fixed $\varepsilon>0$
- Best theoretically possible

Maximum Flow time [SPAA 2016]

- A $(1+\varepsilon)$ speed $O(1)$ competitive algorithm, for fixed $\varepsilon>0$
- Open if speed is needed
- Algorithm is **practical**

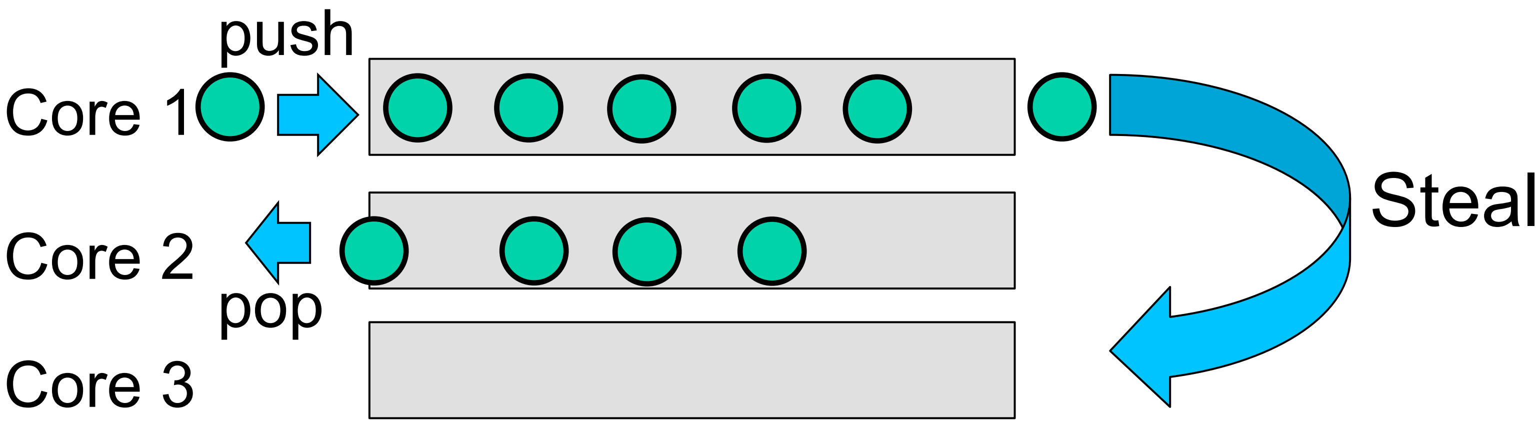
Algortihm Development

- DAG model has been popular because of its connection to practice
  - Well studied for scheduling a ***single*** DAG job to minimize makespan

- Work stealing algorithm: good **practical** and **theoretical** performance
  - Used in numerous systems for scheduling a parallel job
  - Non-clairvoyant
  - Distributed protocol
  - No preemption

- Want to emulate this success and use theory for FIFO to guide a modification of Work-Stealing

Work-Stealing

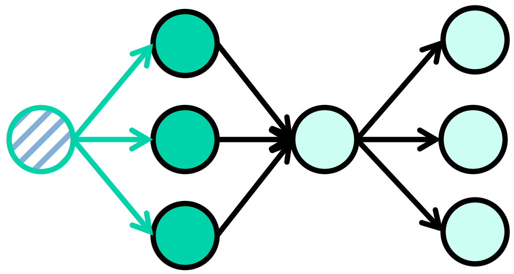


double ended queues

Example: FIFO

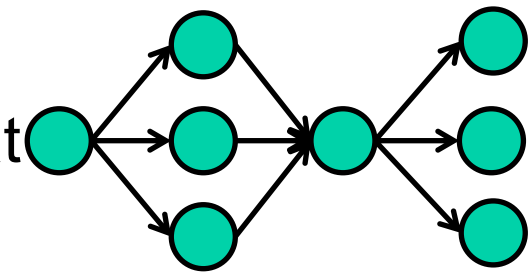
FIFO: Execute available nodes of job(s) with earliest arrival

Could be more than one job depending on ready nodes

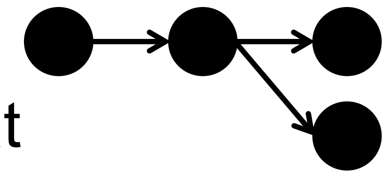


FIFO: Implementation Challenges

Job 1 arrives at time 0



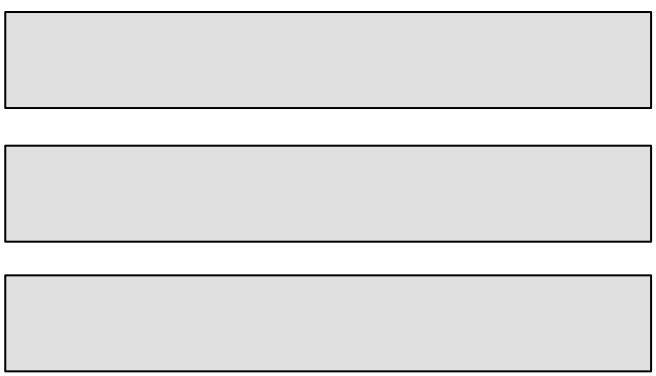
Job 2 arrives at time 1



Core 1

Core 2

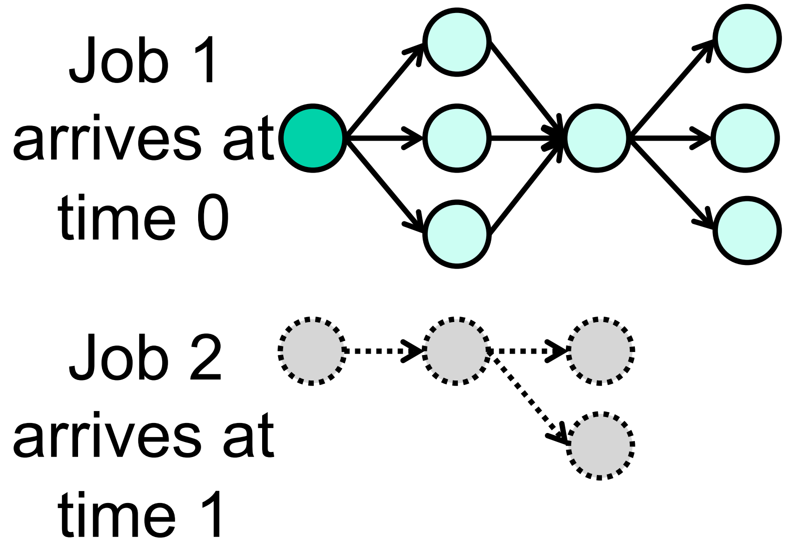
Core 3

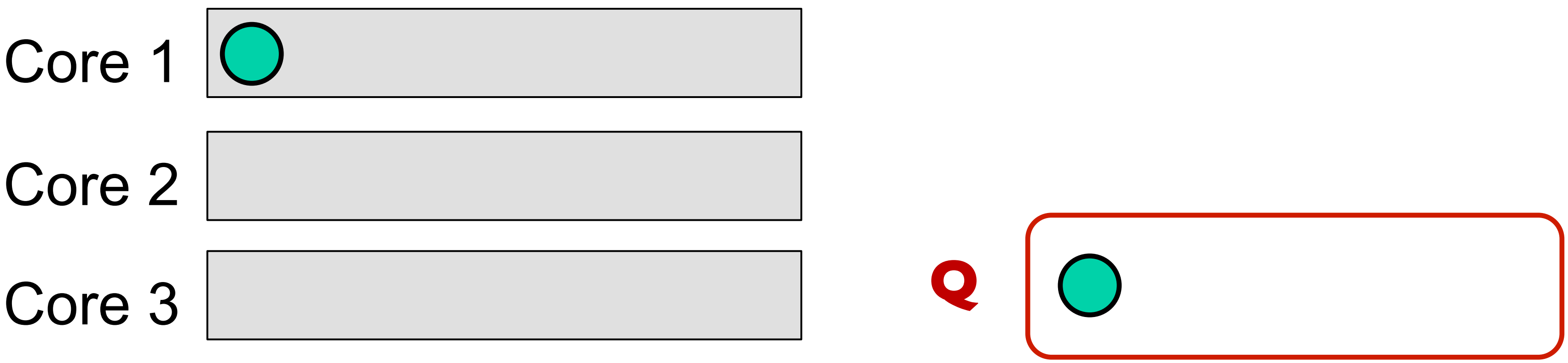


FIFO: Implementation Challenges

A global queue Q

storing all available nodes

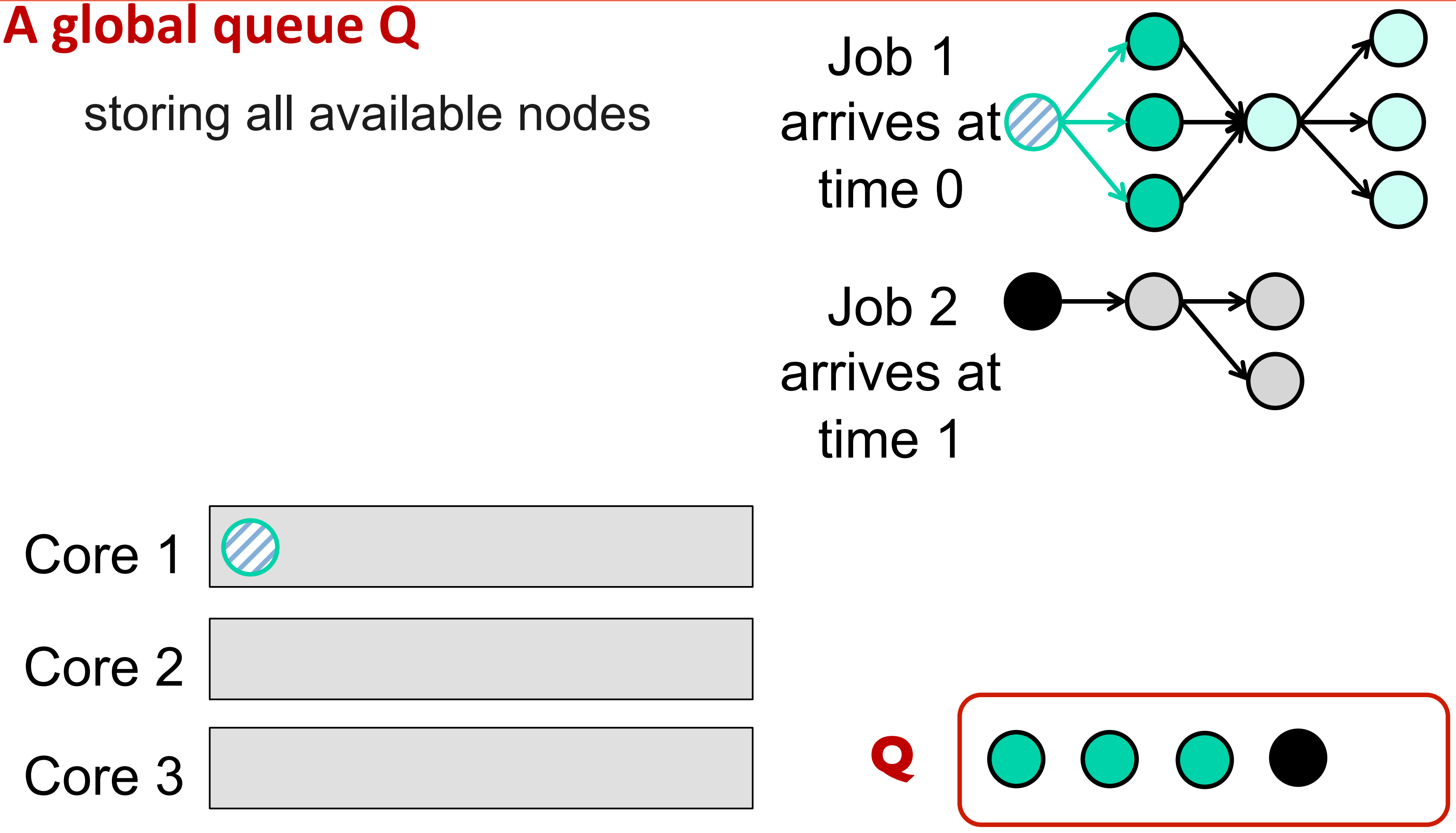




FIFO: Implementation Challenges

A global queue Q

storing all available nodes



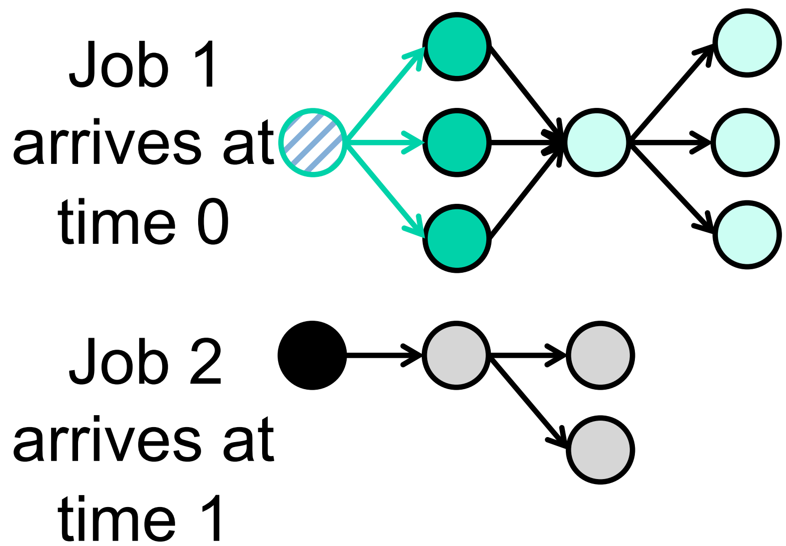
FIFO: Implementation Challenges

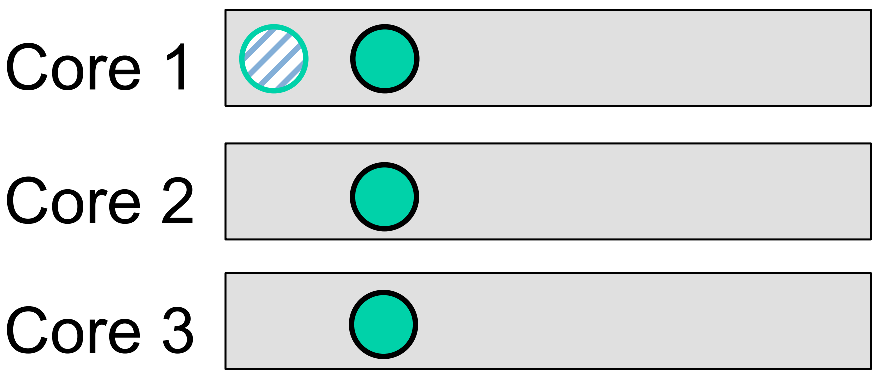
A global queue Q

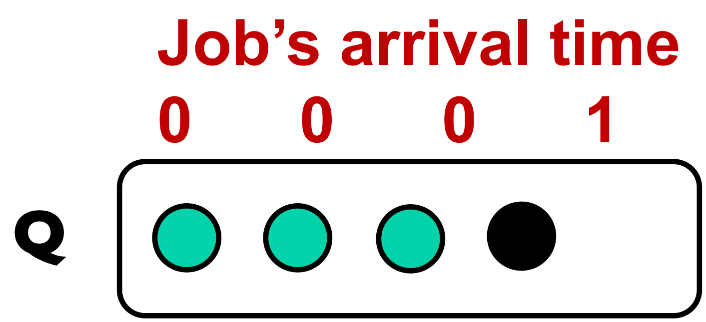
storing all available nodes

Each core at each time step

executes one node in Q from the job with the earliest arrival time







FIFO: Implementation Challenges

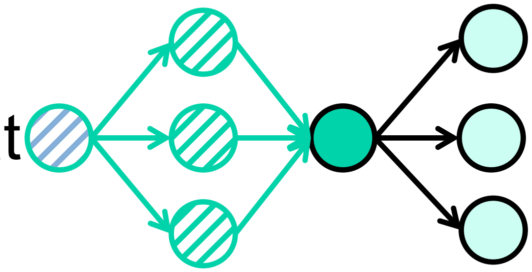
A global queue Q

storing all available nodes

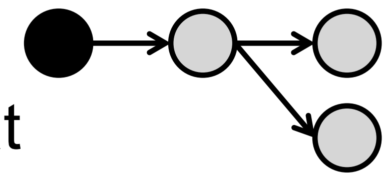
Each core at each time step

executes one node in Q
from the job with the
earliest arrival time

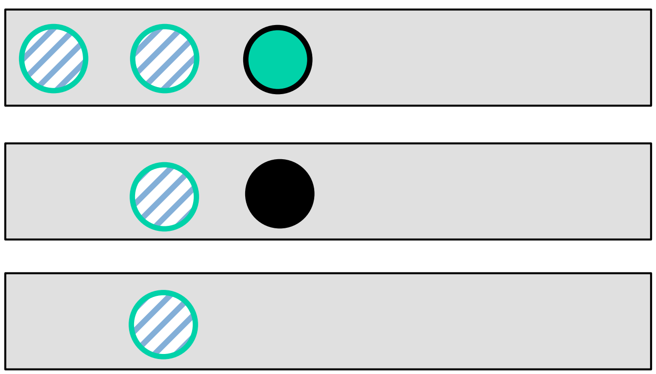
Job 1 arrives at time 0



Job 2 arrives at time 1



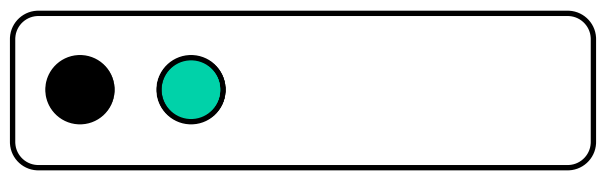
Core 1
Core 2
Core 3



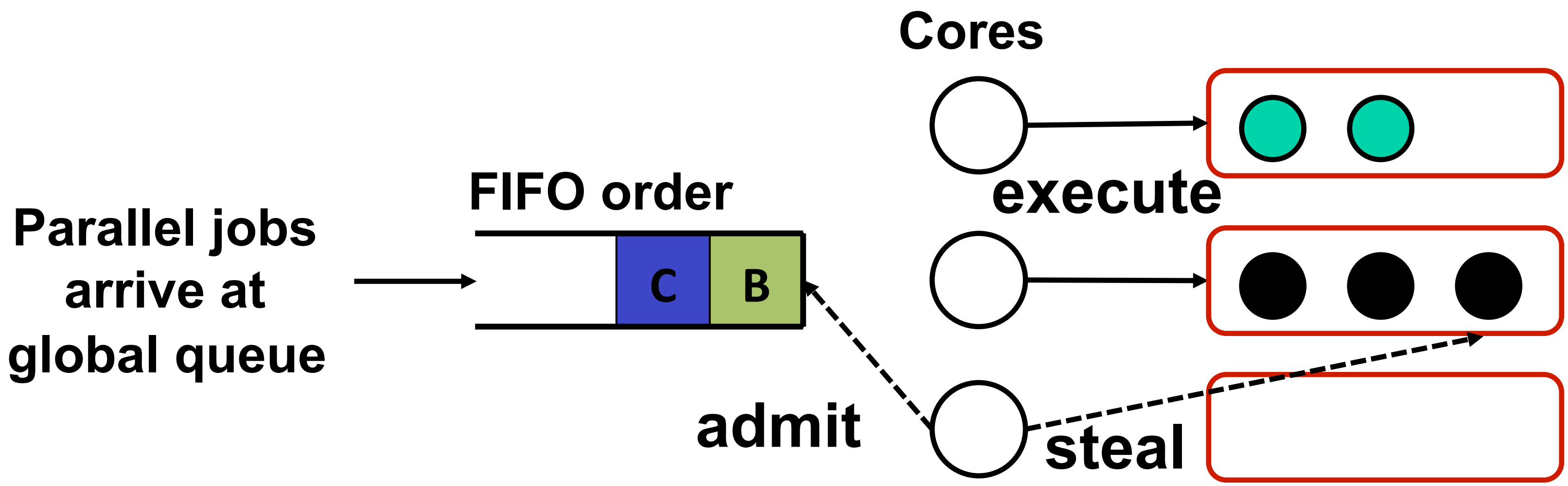
Job's arrival time

1 0

Q



Work Stealing for Multiple jobs



(1) Each core has a queue and executes work from it

(2) Only when the local queue runs out of work, a core will admit a job from global queue

(3) Algorithm can steal for other queues or from the global queue

Has the same theoretical guarantees as FIFO and gave good practical performance

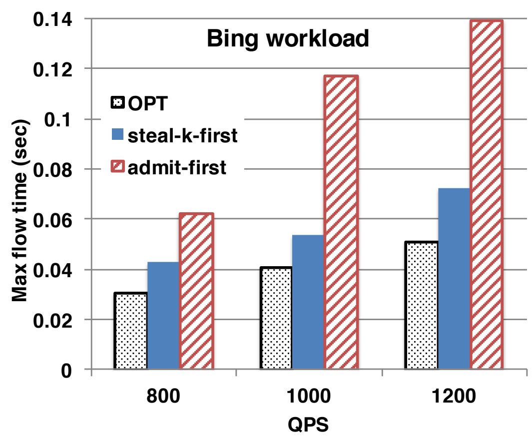
Conclusion

- New results for scheduling DAG jobs online
- Results have lead to practically usable algorithms for minimizing maximum flow time
- Recent results submitted for average flow time
  - Much harder due to the need for preemptions

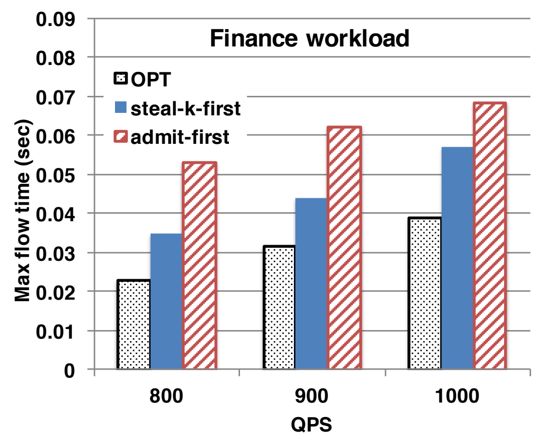
- Open Questions:
  - Is resource augmentation needed for maximum flow time in the DAG and speed up curve model (knowing parallelism)?
  - Practical algorithm for throughput maximization?

Thank You!

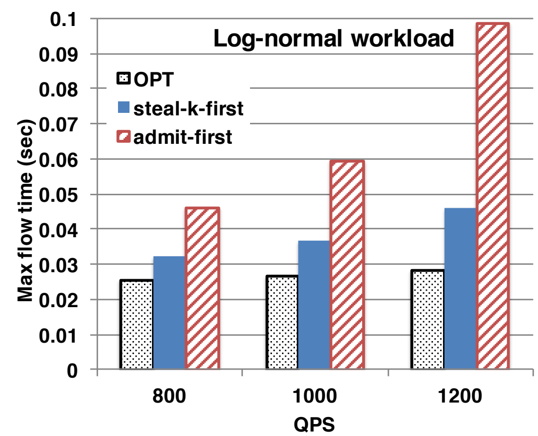
Questions?



(a) Bing workload



(b) Finance workload



(c) Log-normal workload