PARAMETERIZED TASK GRAPH SCHEDULING ALGORITHM FOR COMPARING ALGORITHMIC COMPONENTS

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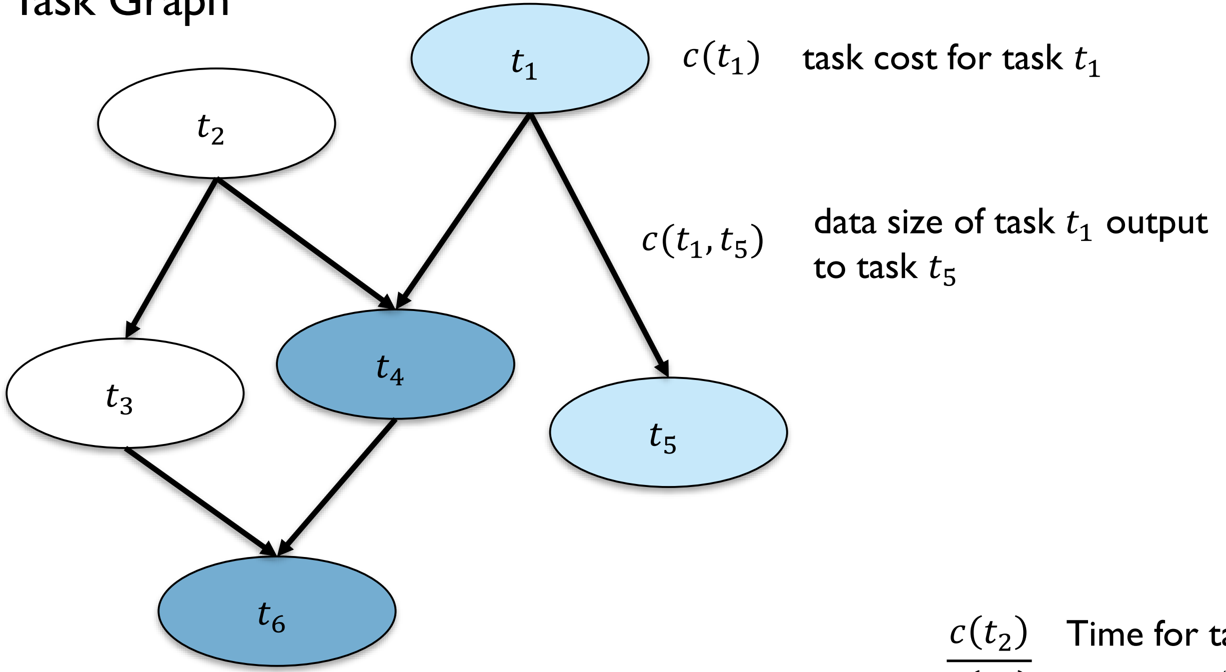
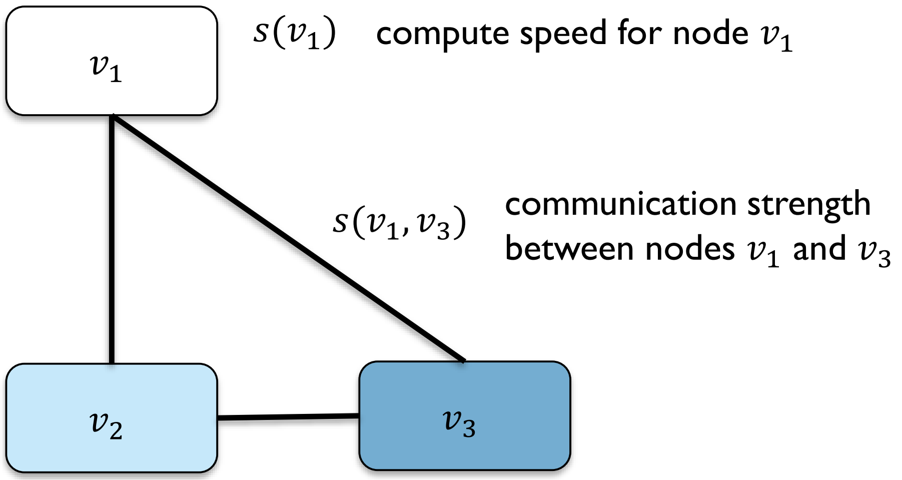
Task Graph



Compute Network



Schedule

$\frac{c(t_2)}{s(v_1)}$ Time for task t_2 to execute on compute node v_1

compute node v_1	task t_2	task t_3				
compute node v_2	task t_1	task t_5				
compute node v_3		task t_4		task t_6		

$\frac{c(t_2, t_4)}{s(v_1, v_3)}$ Time for compute node v_1 to send task t_2 outputs to compute node v_3

A BRIEF HISTORY

- Task scheduling work started in the 1950s
- A survey in 1979 by Graham classified many different variants
  - Did not consider heterogeneous communication
- Hwang et. al. were the first to study heterogeneous communication in 1989
  - Consider homogeneous computation
- Su et. al address fully heterogeneous case in 2019
- Distributed computing goes mainstream – tons of heuristic algorithms are proposed
  - BIL, CPoP, ETF, FCP, FLB, GDL, HEFT, MinMin, MaxMin, MCT, MET, OLB, SMT, WBA, …
- Modern use cases (ML/data science workflows, IoT, etc.) drive benchmarking efforts and theoretical advances
- Bazzi et. al. show scheduling is not approximable within a constant factor in 2015

COMPARING SCHEDULING ALGORITHMS

- Scheduling is NP-Hard and not approximable, but what about for practical situations?
  - Scheduling an ML workflow
  - Running a scientific workflow on a supercomputing system
  - Collecting and processing data from an IoT system
  - Running analyses in a tactical edge environment
- Many tasks scheduling heuristic algorithms have been proposed
  - HEFT, CPoP, BIL, ETF, FCP, FLB, GDL, MinMin, MaxMin, MCT, MET, OLB, SMT, WBA, …
- SAGA: Scheduling Algorithms Gathered
  - 17 Algorithm Implementations
  - 15 Dataset Generators
  - Tools for Benchmarking
  - Tools for Adversarial Analysis

COMPARING SCHEDULING ALGORITHMS

- Many of the heuristic algorithms are similar to each other
- List Scheduling Algorithms (HEFT, CPoP, ETF, etc.):
  1. Compute priorities for tasks
  2. Greedily schedule tasks to node that minimizes/maximizes a cost function
- **Question:** How do individual algorithmic differences affect algorithm performance and runtime?

COMPARING ALGORITHMIC COMPONENTS

- Algorithmic components:
  - Priority Function: UpwardRank, CPoPRank, ArbitraryTopological
  - Comparison Function: EFT, EST, Quickest
  - Insertion-based vs. append-only scheduling
  - Critical path reservation vs no reservation
  - Sufferage vs no sufferage

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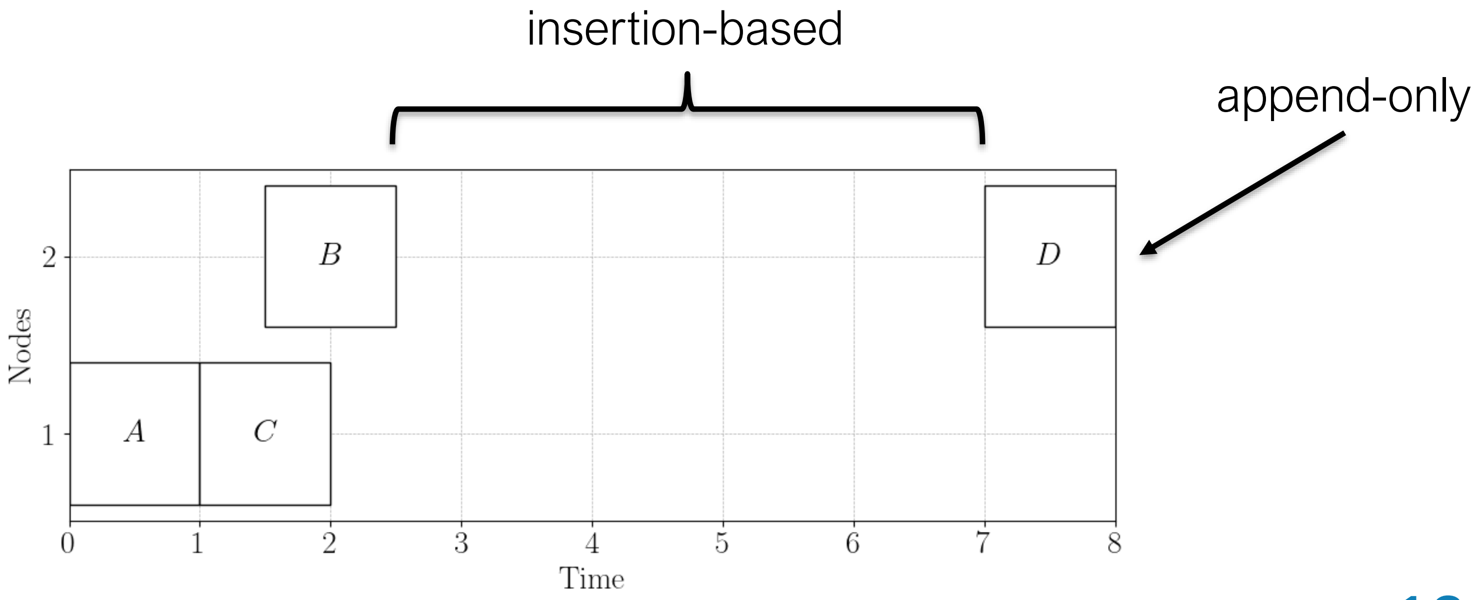

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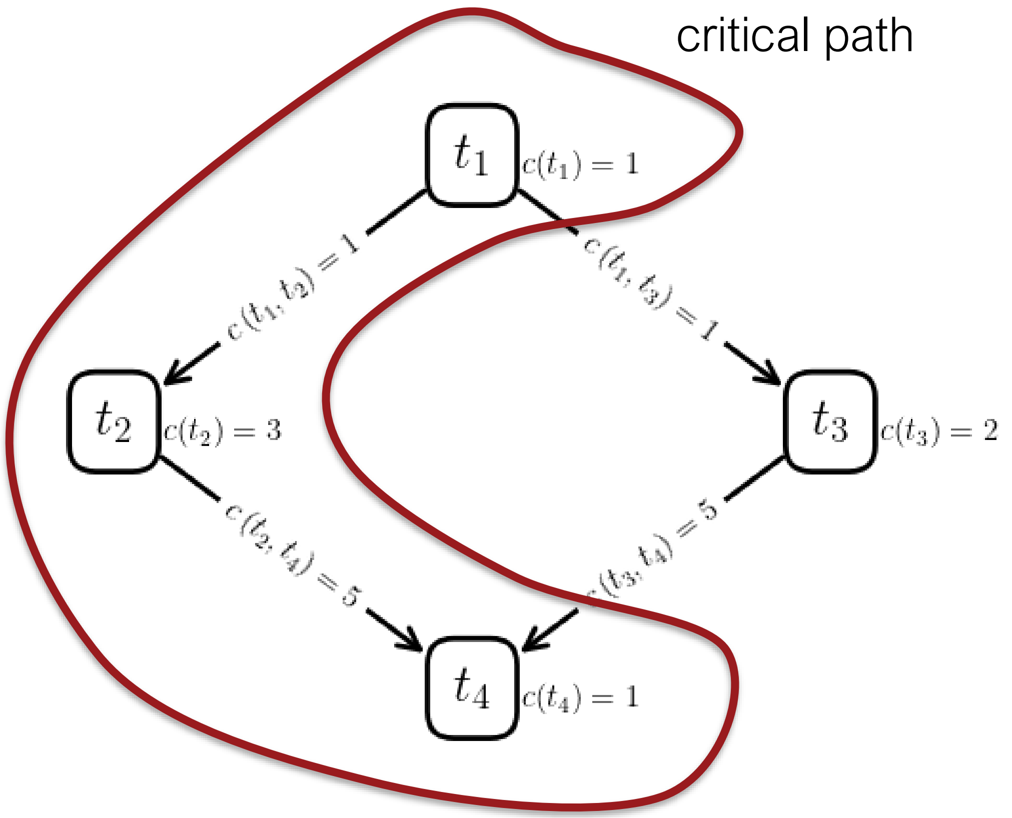

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- 72 possible scheduling algorithms total

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HEFT

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CPoP

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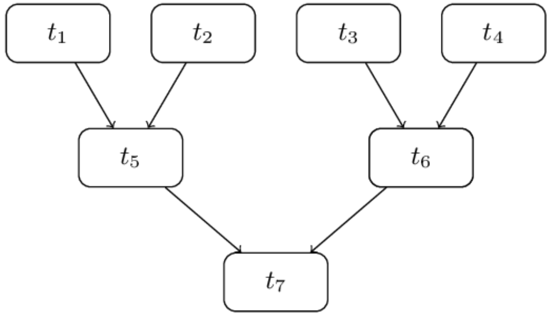
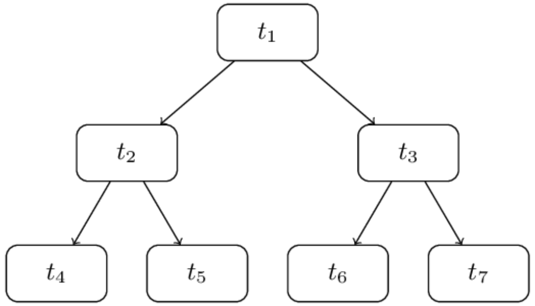
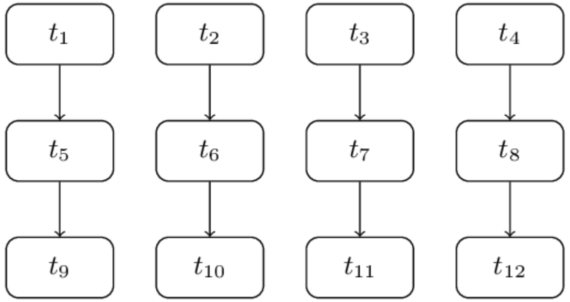
- 72 possible scheduling algorithms total
- 20 datasets
  - 4 types: **in-trees, out-trees, chains**, cycles
  - 5 CCRs: $\left\{\frac{1}{5}, \frac{1}{2}, 1, 2, 5\right\}$
  - 100 problem instances in each dataset
- 144,000 evaluations



in-trees



out-trees



chains

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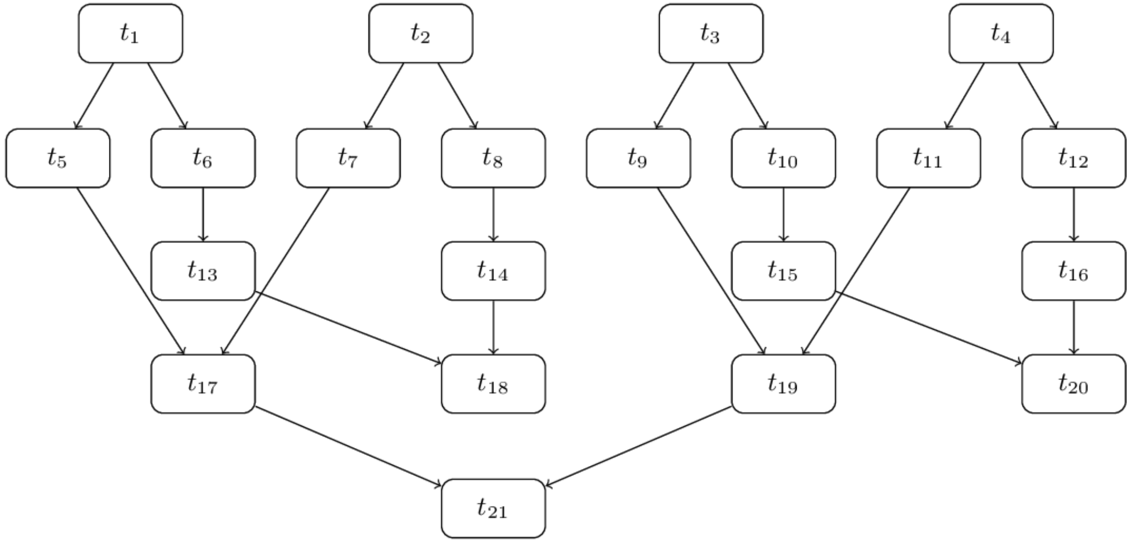


cycles

MAKESPAN/RUNTIME RATIO

» For a network N and task graph G

» Let $M_A(N,G)$ denote the **makespan** of algorithm A for the problem instance (N,G)

» The **makespan ratio** of algorithm A against algorithm B is

$$MR_{A,B}(N,G) = \frac{M_A(N,G)}{M_B(N,G)}$$

* how many times worse A is than B on a particular instance

» The **runtime ratio** of algorithm A against algorithm B is

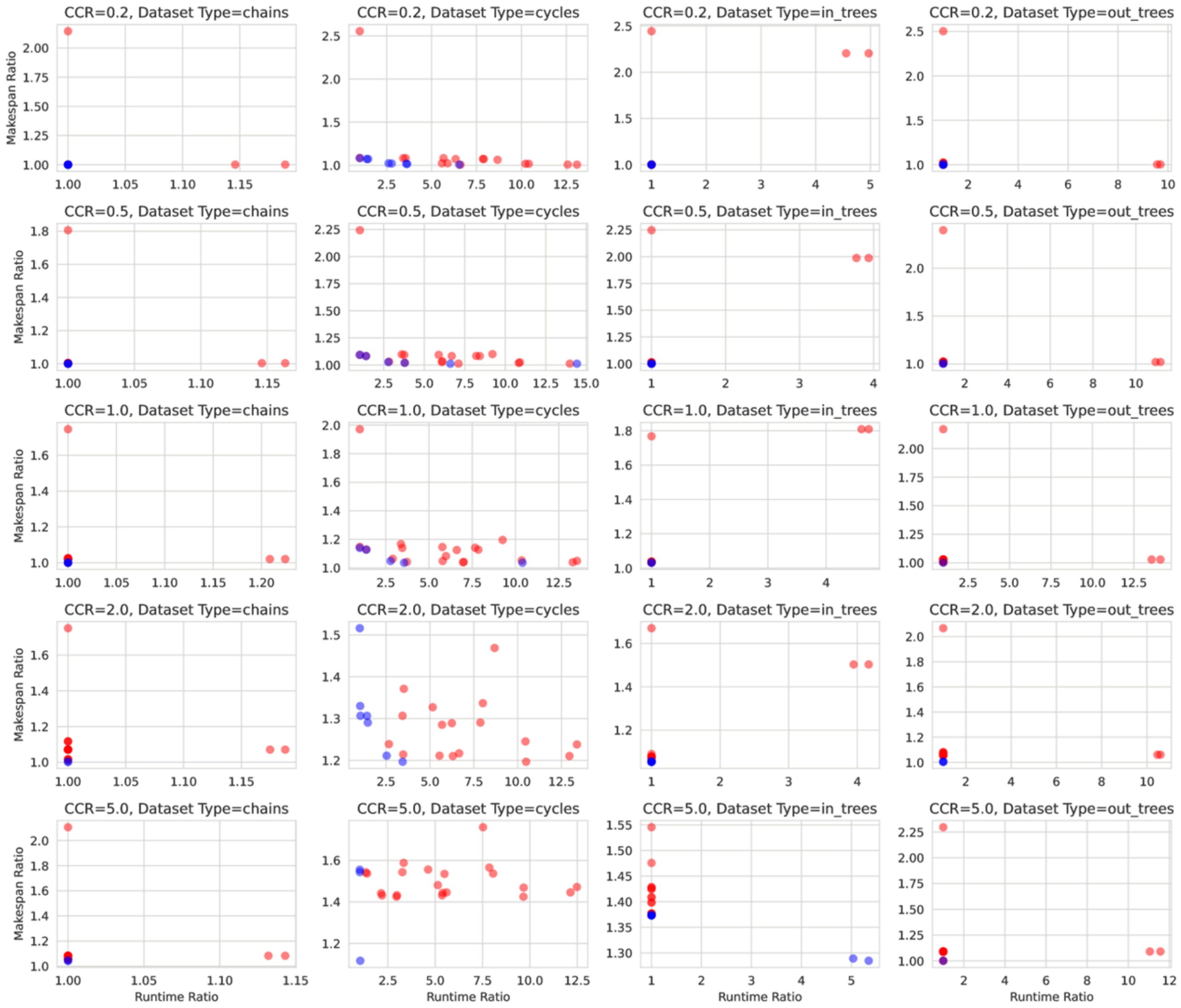
$$RR_{A,B}(N,G) = \frac{T_A(N,G)}{T_B(N,G)}$$

* how many times longer does A take to run than B on a particular instance

PARETO-OPTIMAL SCHEDULERS

- Pareto-optimal: for at least one dataset, no other algorithm exists that has better average makespan ratio **and** average runtime ratio
- 20/24 pareto-optimal schedulers have never been studied before

component	initial_priority	append_only	compare	critical_path	sufferage
scheduler					
EFT_Ins_AT	ArbitraryTopological	False	EFT	False	False
EFT_Ins_AT_Suf	ArbitraryTopological	False	EFT	False	True
EST_Ins_AT	ArbitraryTopological	False	EST	False	False
EST_Ins_AT_Suf	ArbitraryTopological	False	EST	False	True
EST_Ins_CP_AT	ArbitraryTopological	False	EST	True	False
MCT [10]	ArbitraryTopological	True	EFT	False	False
Sufferage [12]	ArbitraryTopological	True	EFT	False	True
EFT_App_CP_AT	ArbitraryTopological	True	EFT	True	False
EST_App_AT	ArbitraryTopological	True	EST	False	False
EST_App_AT_Suf	ArbitraryTopological	True	EST	False	True
MET [10]	ArbitraryTopological	True	Quickest	False	False
EFT_Ins_CR	CPoPRanking	False	EFT	False	False
EFT_Ins_CR_Suf	CPoPRanking	False	EFT	False	True
EST_Ins_CR	CPoPRanking	False	EST	False	False
EST_Ins_CR_Suf	CPoPRanking	False	EST	False	True
EFT_App_CR_Suf	CPoPRanking	True	EFT	False	True
HEFT [6]	UpwardRanking	False	EFT	False	False
EFT_Ins_UR_Suf	UpwardRanking	False	EFT	False	True
EST_Ins_UR	UpwardRanking	False	EST	False	False
EST_Ins_UR_Suf	UpwardRanking	False	EST	False	True
EFT_App_UR	UpwardRanking	True	EFT	False	False
EFT_App_UR_Suf	UpwardRanking	True	EFT	False	True
EST_App_UR	UpwardRanking	True	EST	False	False
EST_App_UR_Suf	UpwardRanking	True	EST	False	True


CCR=0.2, Dataset Type=chains
CCR=0.2, Dataset Type=cycles
CCR=0.2, Dataset Type=in_trees
CCR=0.2, Dataset Type=out_trees
CCR=0.5, Dataset Type=chains
CCR=0.5, Dataset Type=cycles
CCR=0.5, Dataset Type=in_trees
CCR=0.5, Dataset Type=out_trees
CCR=1.0, Dataset Type=chains
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CCR=1.0, Dataset Type=out_trees
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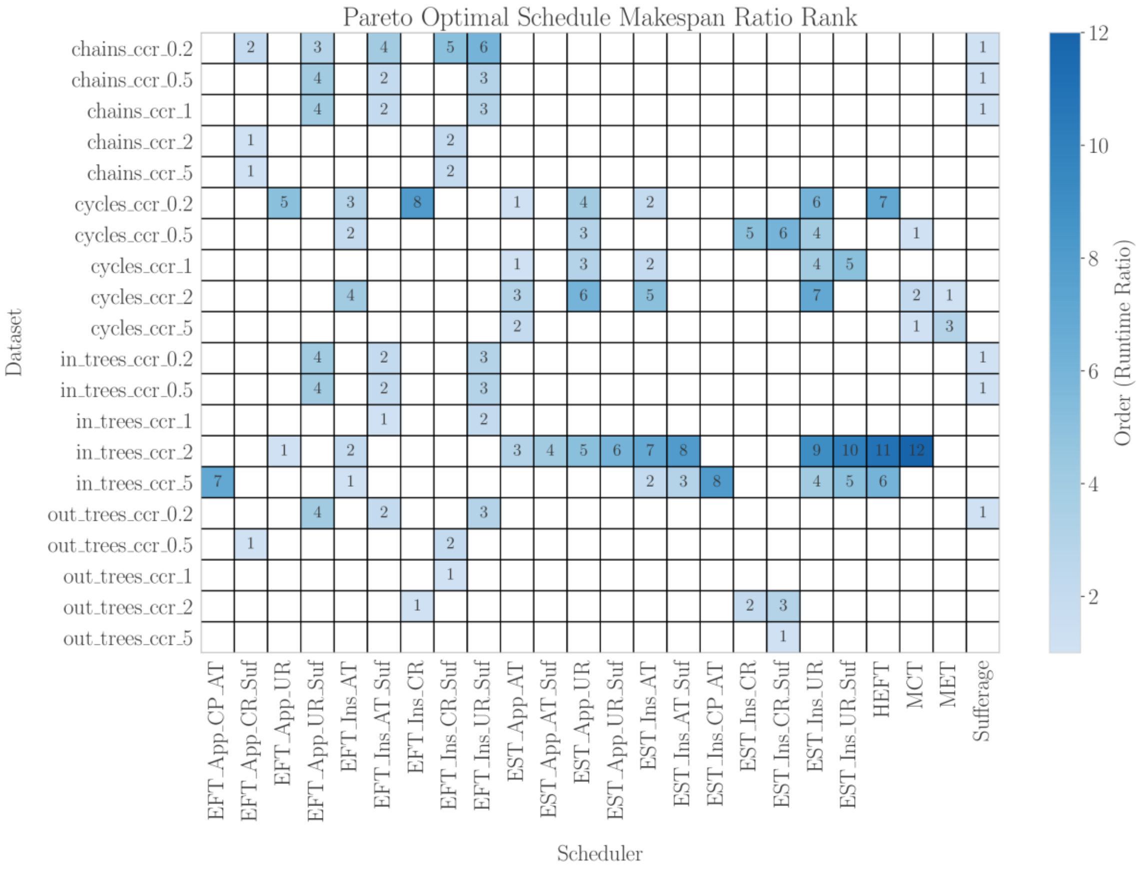
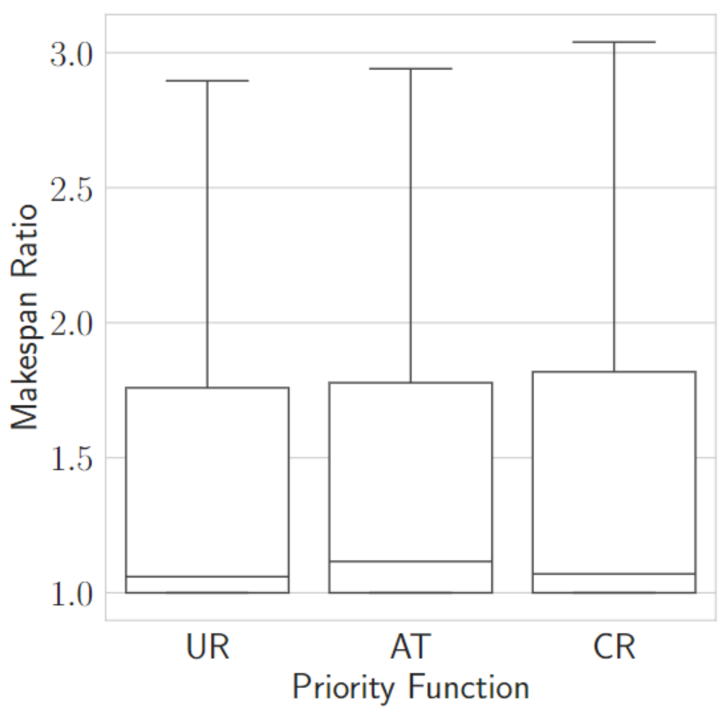
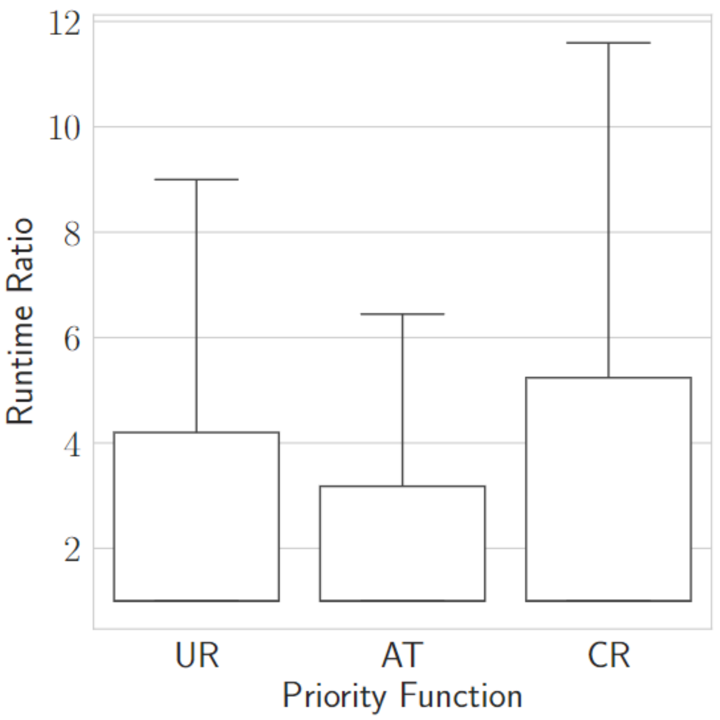
CCR=2.0, Dataset Type=cycles
CCR=2.0, Dataset Type=in_trees
CCR=2.0, Dataset Type=out_trees
CCR=5.0, Dataset Type=chains
CCR=5.0, Dataset Type=cycles
CCR=5.0, Dataset Type=in_trees
CCR=5.0, Dataset Type=out_trees
Makespan Ratio
Runtime Ratio


Pareto Optimal Schedule Makespan Ratio Rank
Dataset
chains_ccr_0.2
chains_ccr_0.5
chains_ccr_1
chains_ccr_2
chains_ccr_5
cycles_ccr_0.2
cycles_ccr_0.5
cycles_ccr_1
cycles_ccr_2
cycles_ccr_5
in_trees_ccr_0.2
in_trees_ccr_0.5
in_trees_ccr_1
in_trees_ccr_2
in_trees_ccr_5
out_trees_ccr_0.2
out_trees_ccr_0.5
out_trees_ccr_1
out_trees_ccr_2
out_trees_ccr_5
Scheduler
EFT_App_CP_AT
EFT_App_CR_Suf
EFT_App_UR
EFT_App_UR_Suf
EFT_Ins_AT
EFT_Ins_AT_Suf
EFT_Ins_CR
EFT_Ins_CR_Suf
EFT_Ins_UR_Suf
EST_App_AT
EST_App_AT_Suf
EST_App_UR
EST_App_UR_Suf
EST_Ins_AT
EST_Ins_AT_Suf
EST_Ins_CP_AT
EST_Ins_CR
EST_Ins_CR_Suf
EST_Ins_UR
EST_Ins_UR_Suf
HEFT
MCT
MET
Sufferage
Order (Runtime Ratio)

EFFECTS OF INDIVIDUAL ALGORITHMIC COMPONENTS

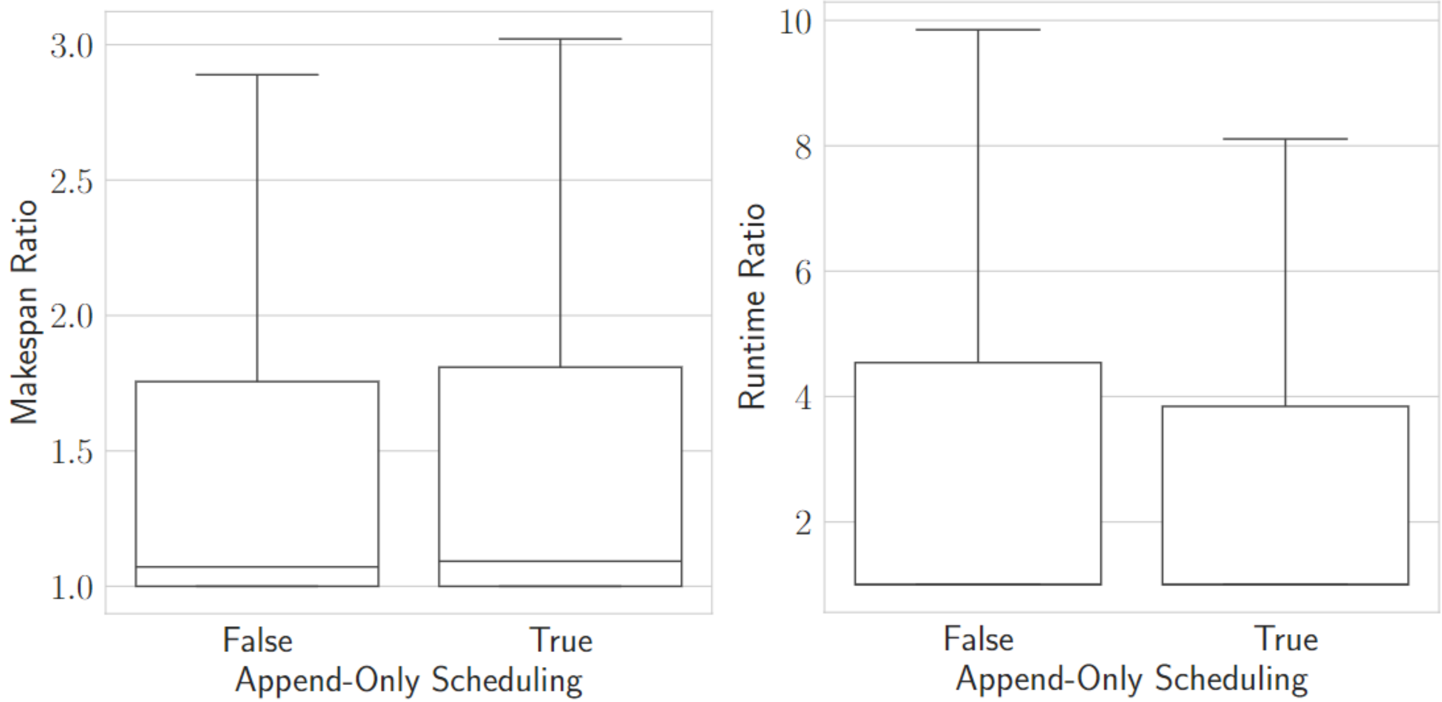
- Priority Function
  - UpwardRank (UR)
  - ArbitraryTopological (AT)
  - CPoPRank (CR)





EFFECTS OF INDIVIDUAL ALGORITHMIC COMPONENTS

- Priority Function
- Append-only vs Insertion-based



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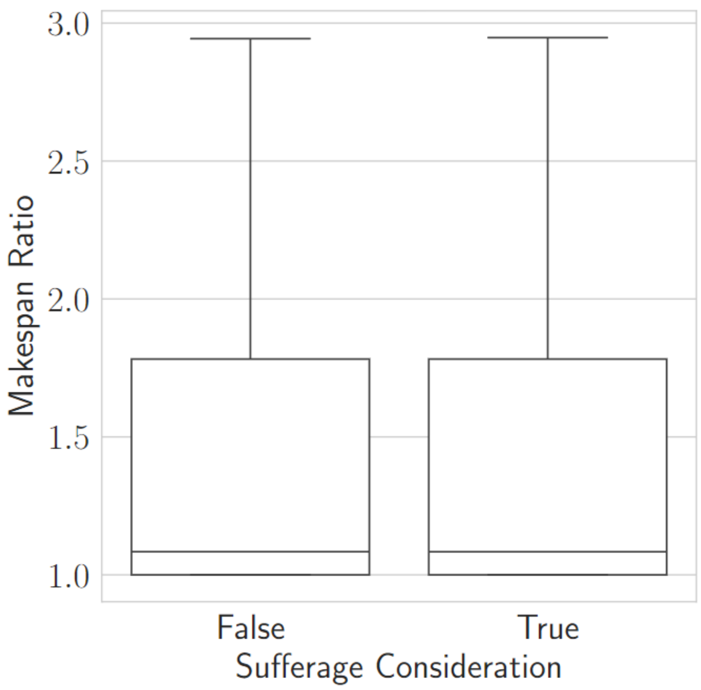

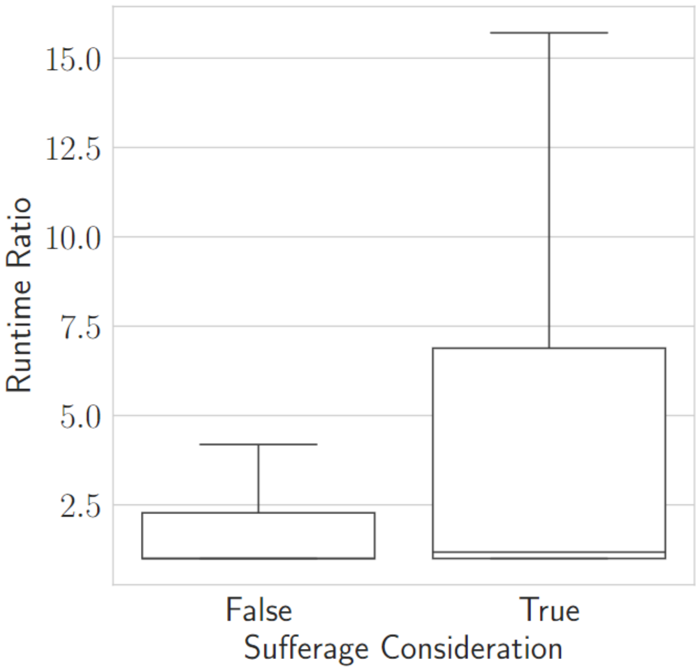

EFFECTS OF INDIVIDUAL ALGORITHMIC COMPONENTS

- Priority Function
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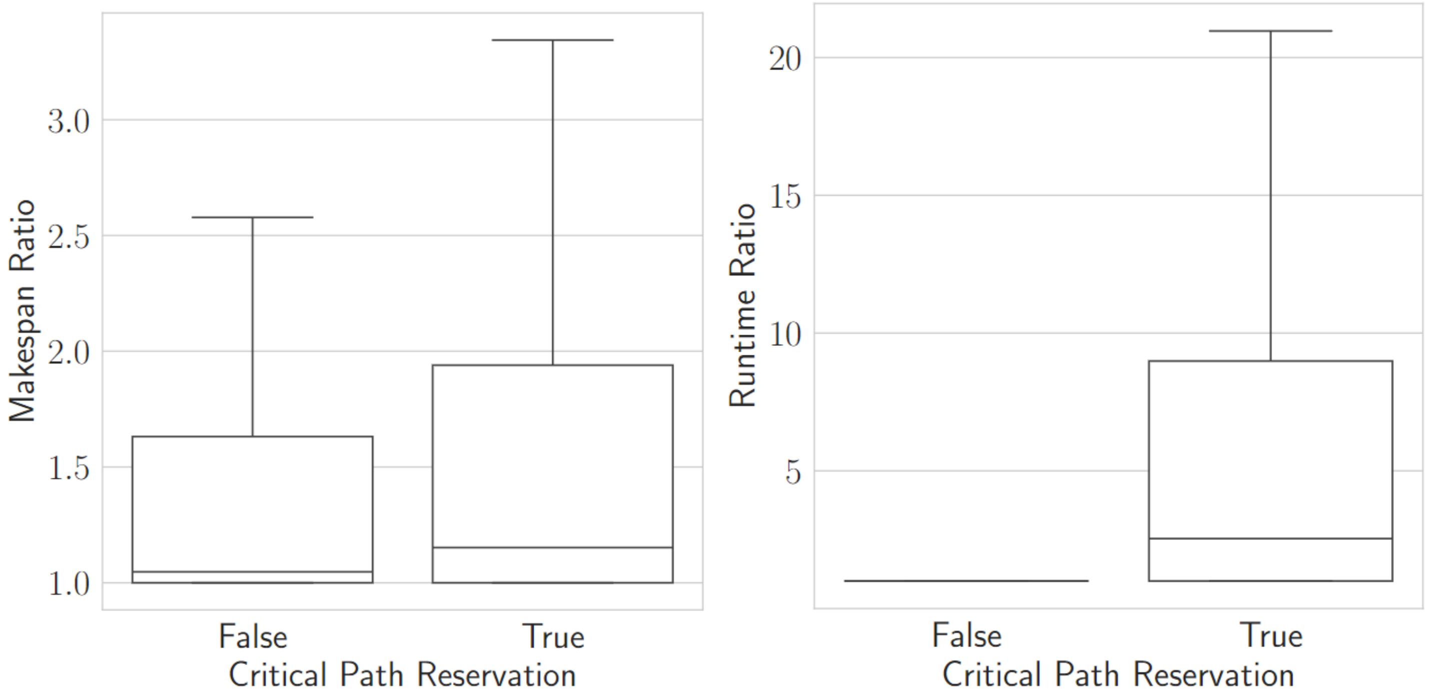
- Sufferage
- Critical path reservation



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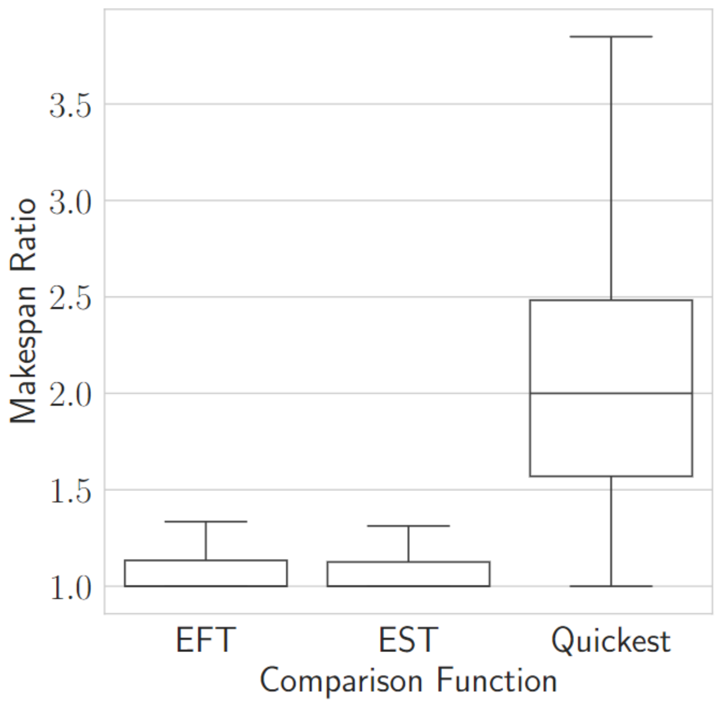

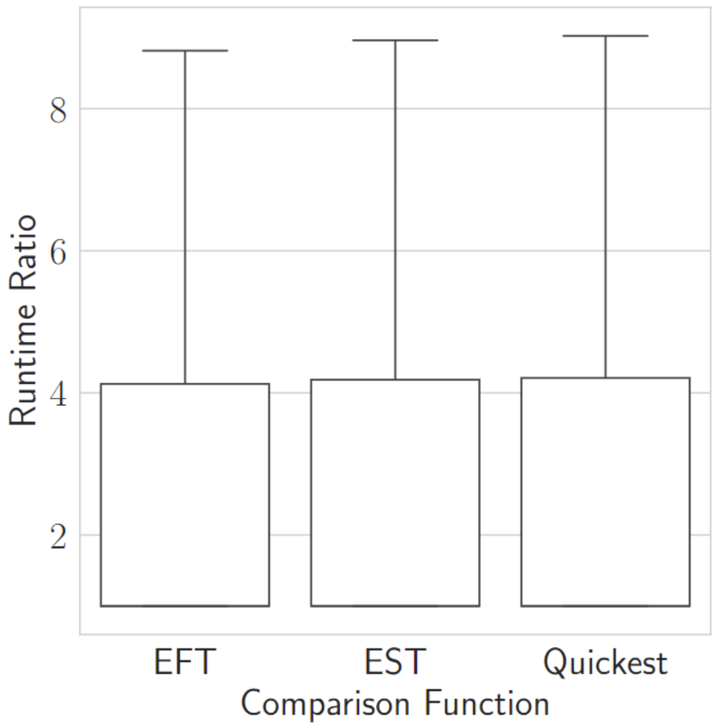

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component scheduler	initial_priority	append_only	compare	critical_path	sufferage
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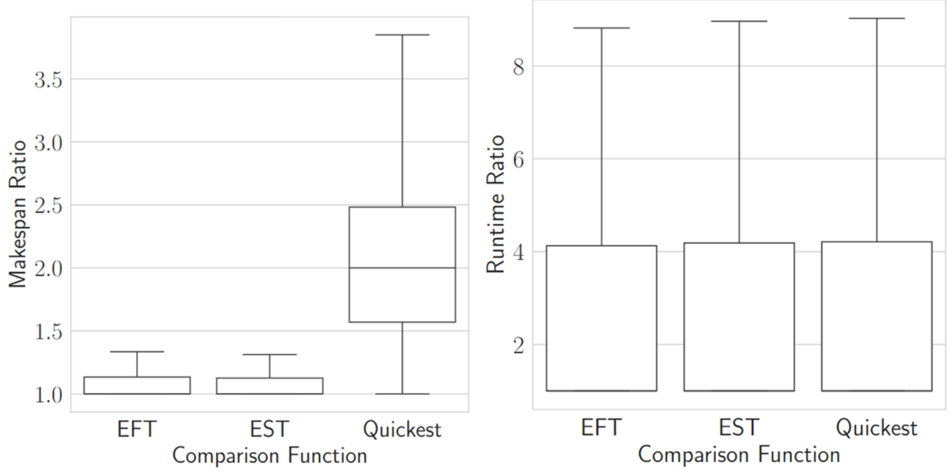
EST_App_UR_Suf	UpwardRanking	True	EST	False	True

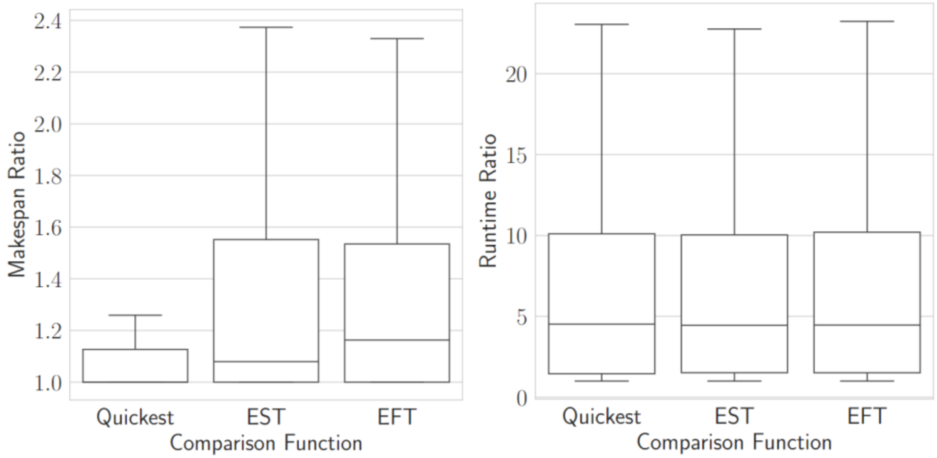
EFFECTS OF INDIVIDUAL ALGORITHMIC COMPONENTS

- » Priority Function
- » Append-only vs Insertion-based
- » Sufferage
- » Critical path reservation
- » Comparison Function
  - » Results look different for specific datasets!

Overall

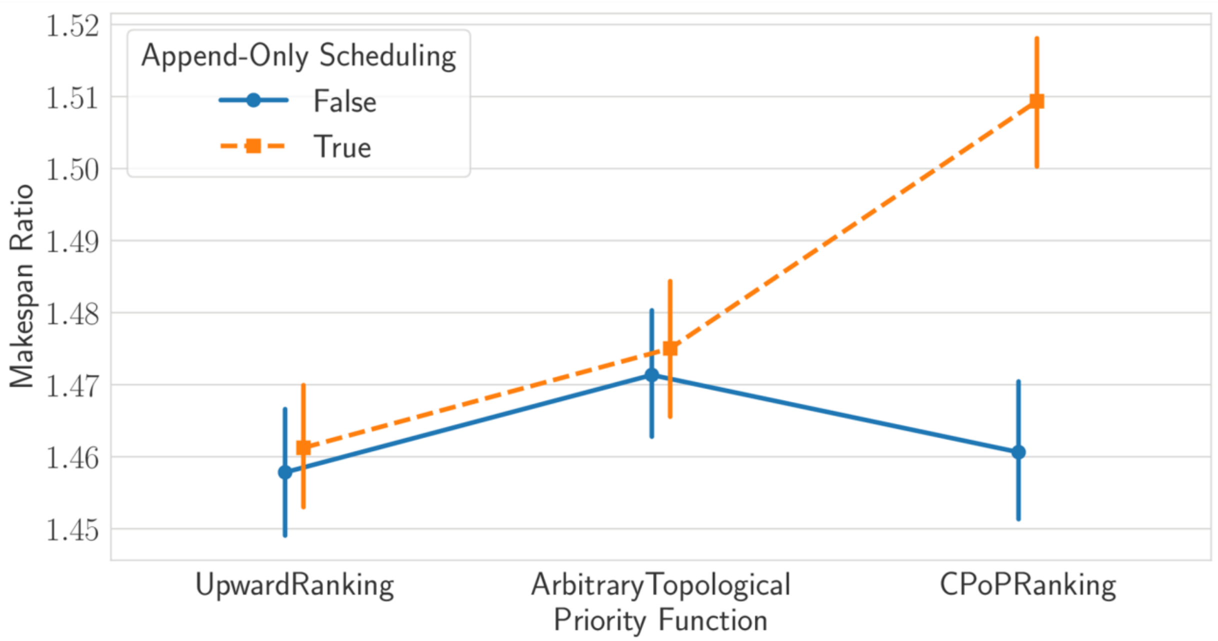


cycles dataset w/ CCR=5



INTERACTIONS

- Append-only Strategy and Priority Function
  - Append-only strategy is *particularly* bad with CPoP ranking



INTERACTIONS

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- CCR and Comparison Function
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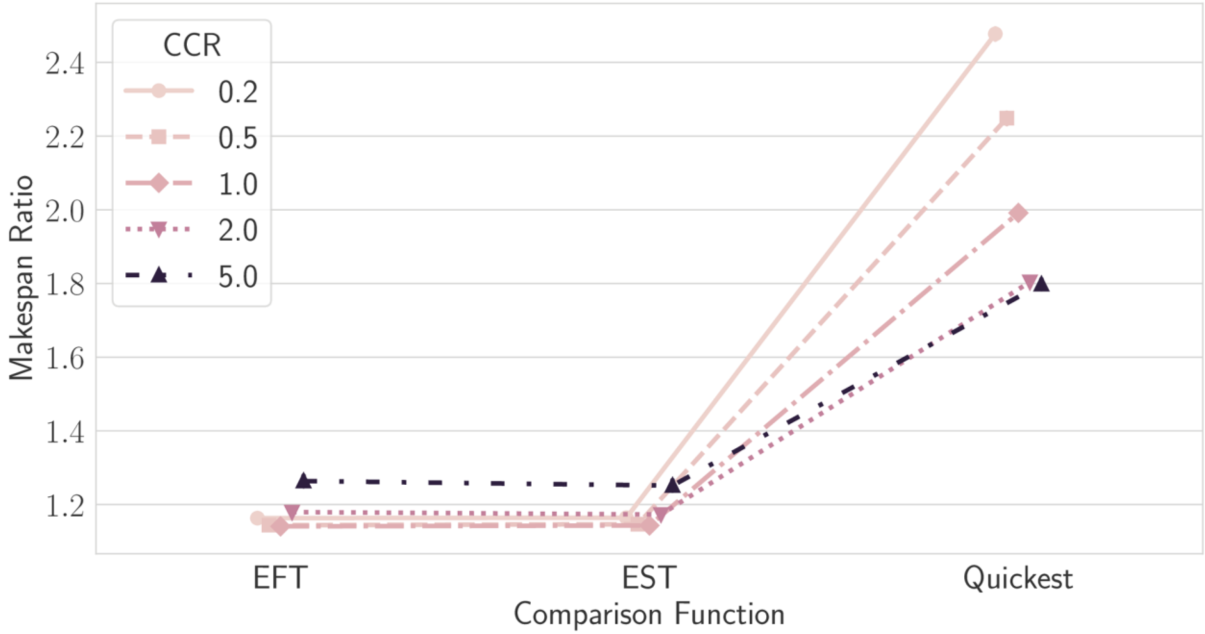

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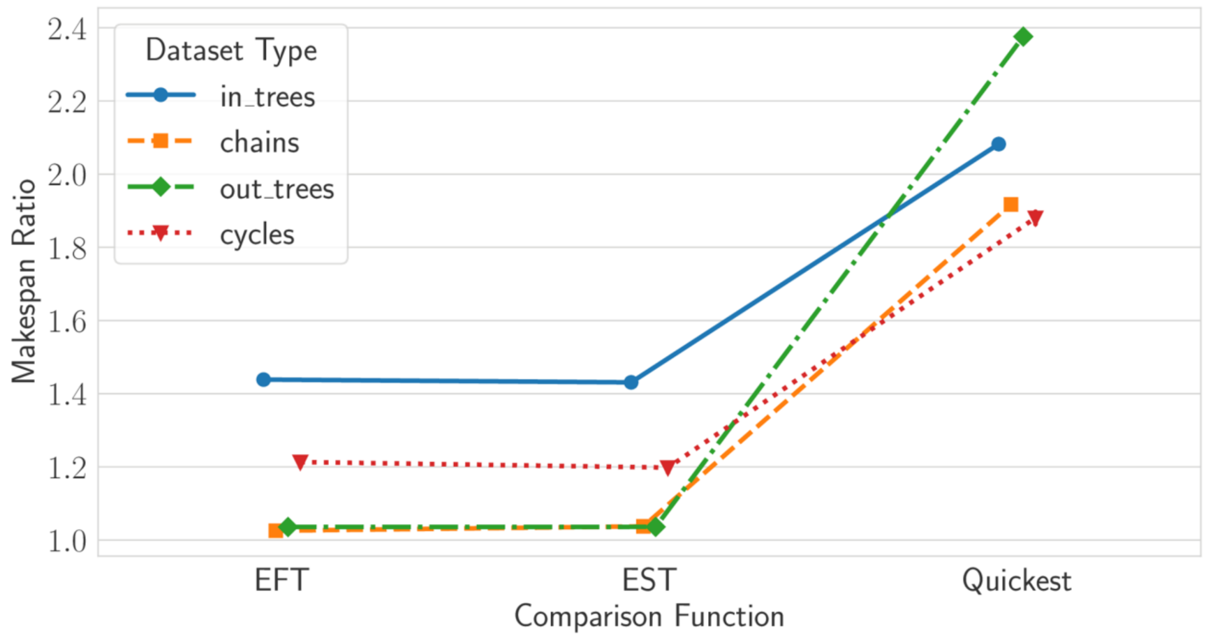
  - The quickest strategy is particularly bad for the out-tree task graph structure



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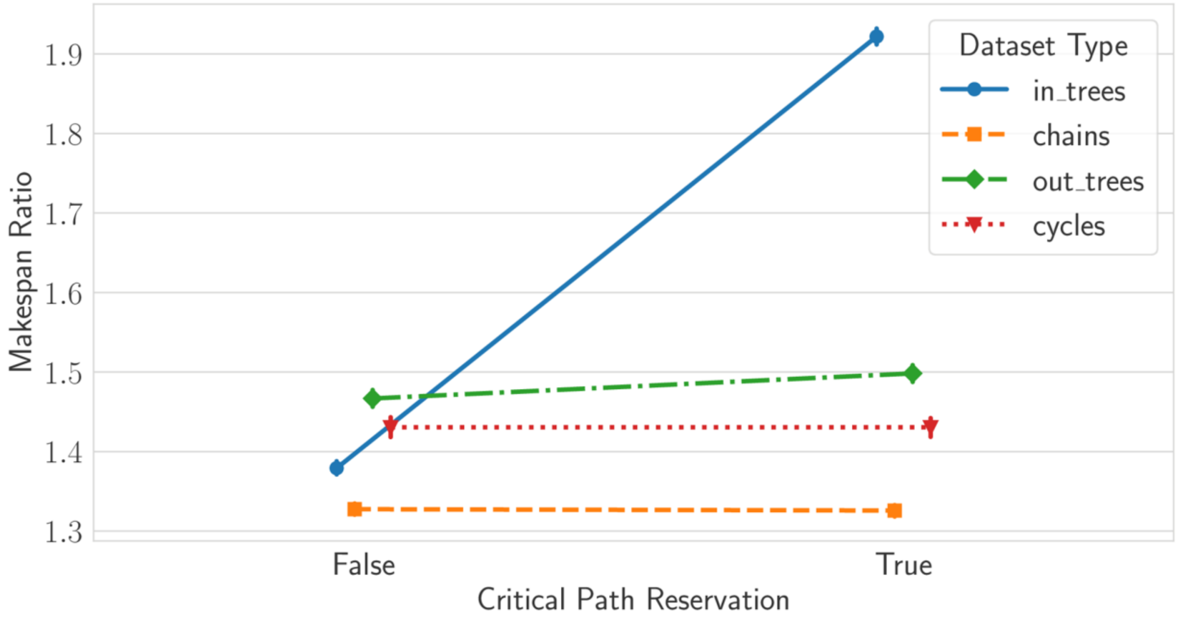
- Dataset Type and Critical Path
  - Critical path reservation is particularly bad for in-tree task graph structures



CONCLUSION

- **Generalized Parametric Scheduler:** Proposed a modular list-scheduling algorithm that enables flexible combination of five key algorithmic components.
- **Benchmarking**: Evaluated **72 unique schedulers** generated from all component combinations on **20 datasets**, encompassing diverse graph structures and CCRs.
- **Component-level Insights**: Analyzed both **individual** and **combined effects** of components on makespan and runtime across datasets.
- **Dataset-specific Behavior**: Revealed how component effectiveness is **problem-dependent**, highlighting complex interactions between components and dataset characteristics.
- **Future Work**:
  - Implement new algorithmic components (e.g., k-depth lookahead)
  - Incorporate additional datasets
  - Leverage findings to design adaptive or hybrid schedulers tuned to application characteristics

SCAN ME

ACKNOWLEDGEMENTS

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