OpenMP®

SC24 Booth Talk Series

Toward Smart Scheduling in OpenMP

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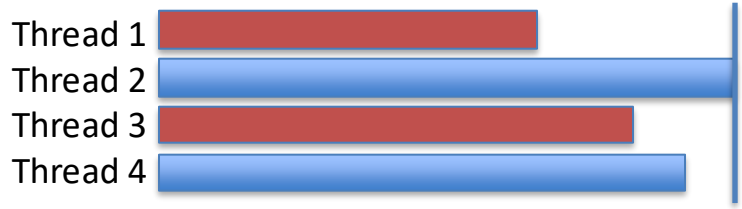
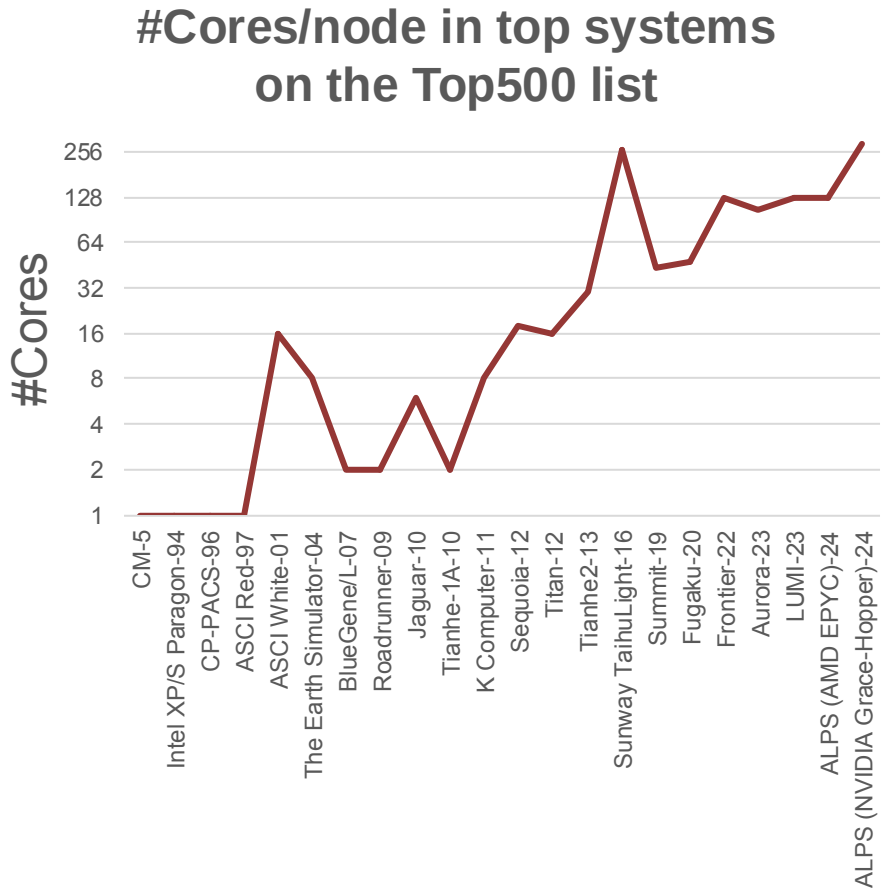
Outline

- Need for Smart Scheduling in OpenMP
- Toward Smart Scheduling in OpenMP via
  - Expert-based Automated Scheduling Algorithm Selection
  - RL-based Automated Scheduling Algorithm Selection
- Results: Expert-based vs. RL-based Selection
- Take Away’s

Performance Degradation due to Load Imbalance

- Increasing #cores/node
- Increased complexity to parallelize and exploit available computing power
- Load imbalance degrades performance, scalability, and wastes energy





Impact of Optimizing OpenMP Parallel for/do Constructs

- **111 Applications** (C, C++, Fortran). Sources: SPEC (CPU/OMP), CORAL2, Mantevo, Rodinia benchmarks, and several large-scale scientific applications available on GitHub
- **OpenMP features searched:**
  - parallel for/do
  - task, taskloop
  - simd
  - sections
  - target
- Most applications rely on parallel **OpenMP for/do** loops for shared memory parallelism

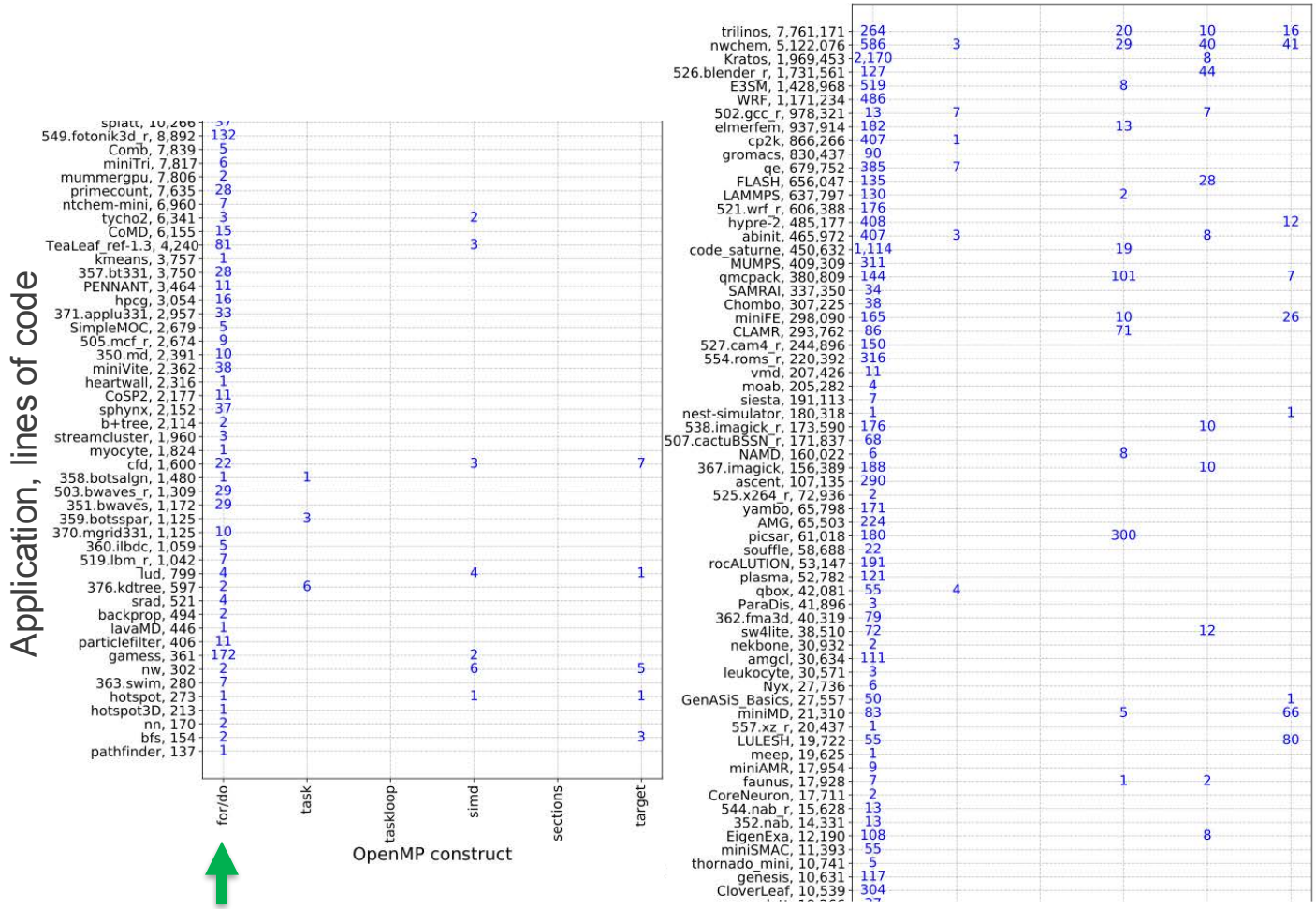
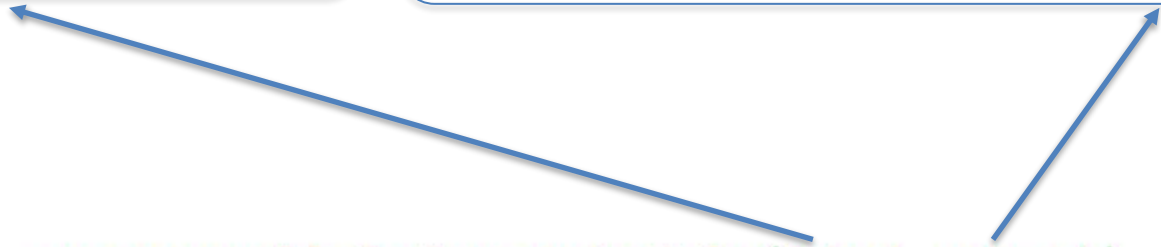


Figure from, [J. H. Müller Korndörfer] Ph.D. Thesis, Multilevel Scheduling and Communication in Large Scale High Performance Computers.

Scheduling of Worksharing (for) Loops in OpenMP

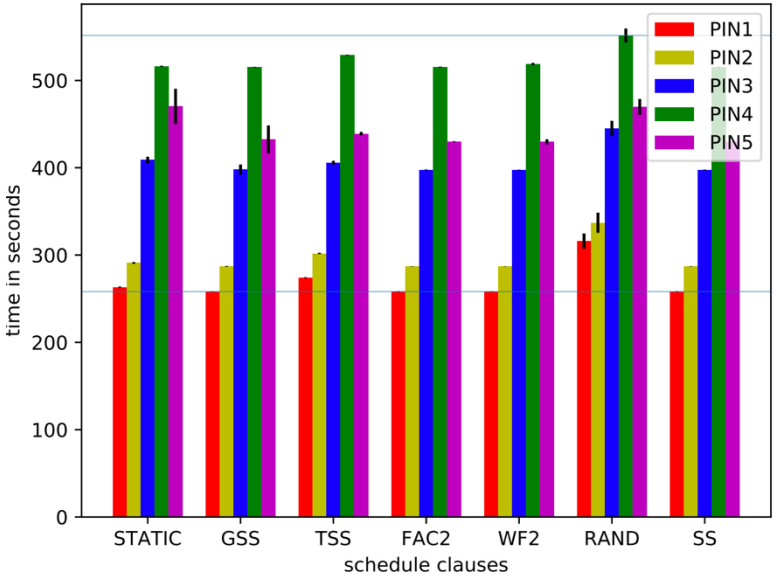
static(default)	
dynamic	runtime
guided	auto

#iteration assigned/round → static/dynamic
threshold for #iteration assigned → guided

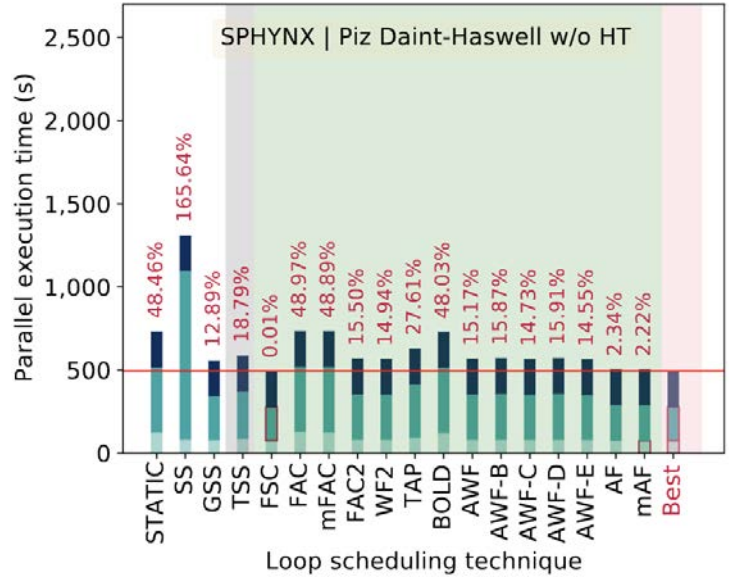


```
#pragma omp parallel for schedule(kind, chunk)
for(i = 0; i < size; i++)
{
    computations ...
}
```

Making a Case for More Efficient Scheduling Algorithms in OpenMP



F. M. Ciorba, C. Iwainsky, and P. Buder, "**OpenMP Loop Scheduling Revisited: Making a Case for More Schedules**"
iWomp 2018, Barcelona, Spain, September 2018.



J. H. Müller Korndörfer, A. Eleliemy, A. Mohammed, F. M. Ciorba. "**LB4OMP: A Dynamic Load Balancing Library for Multithreaded Applications**". TPDS, August 2021.

“Decision Paralysis”: Which Scheduling Algorithm is Most Efficient?

- Many choices for OpenMP `schedule(kind)`
- Too many values for OpenMP `chunk`
- Tuples of scheduling choices needed
  - per loop
  - per time-step
  - per application
  - per system

The schedule kind **`auto`** allows* an OpenMP implementation to choose any possible mapping of iterations in a loop construct to threads in the team.

* According to OpenMP Specification 5.2

Toward Smart Scheduling in OpenMP via Automatic Algorithm Selection

For a problem instance $x \in P$, with features $f(x) \in F$, **find** the **selection mapping $S(f(x))$** into algorithm space A, such that the selected algorithm $\alpha \in A$ maximizes performance $y(\alpha(x)) \in Y$ when applied.

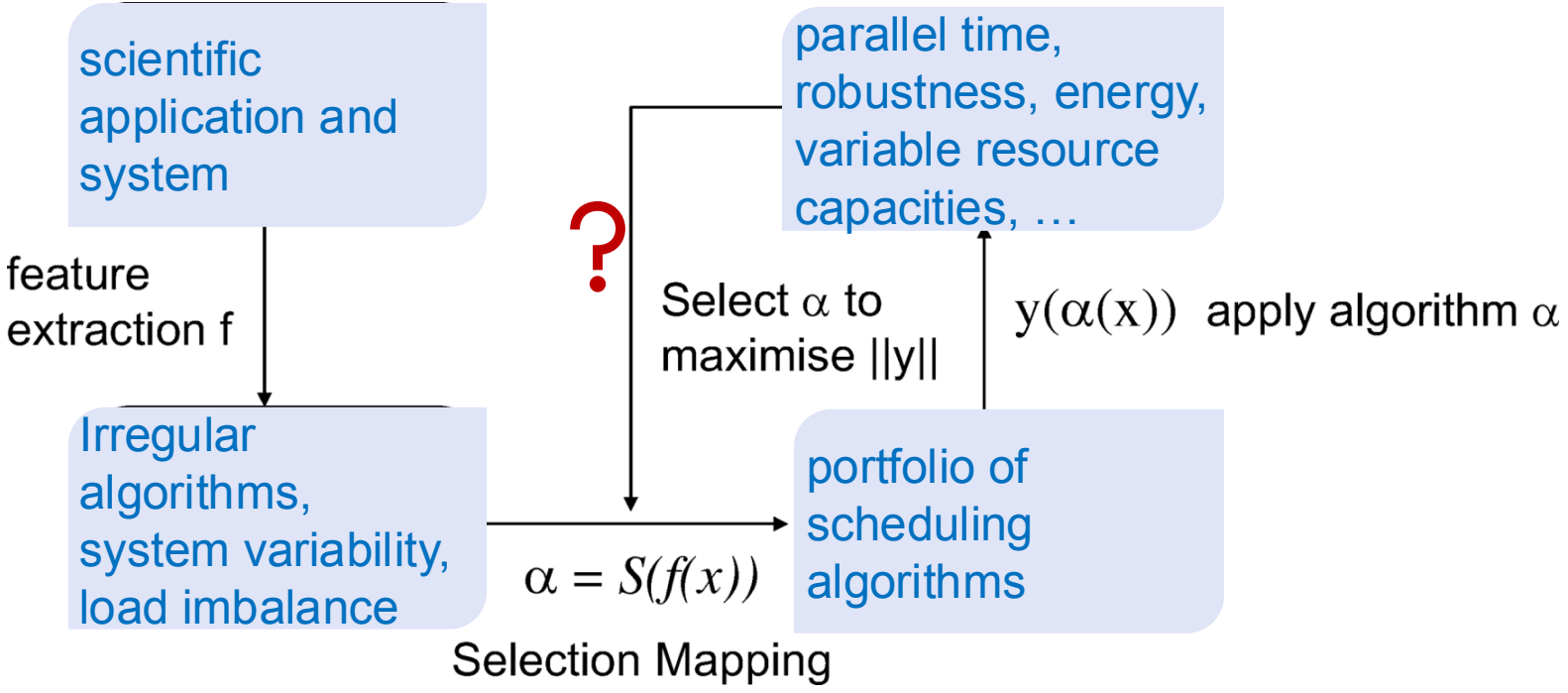
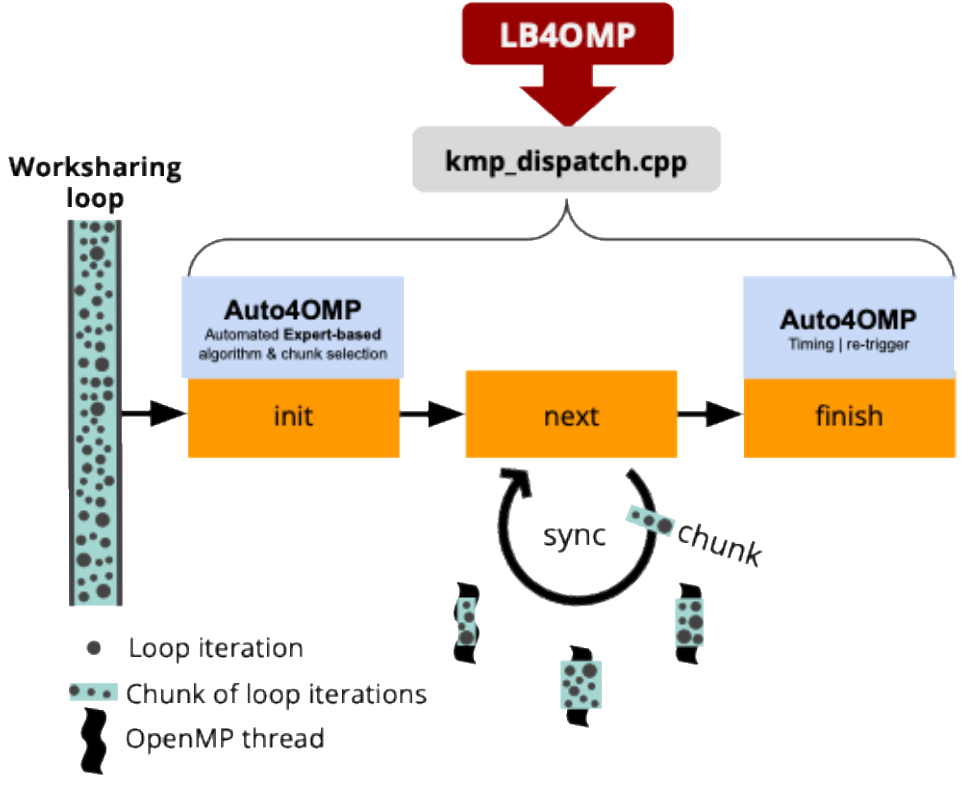


Figure from [Smith-Miles, 2008] Cross-disciplinary perspectives on meta-learning for algorithm selection. ACM Comput. Surv. 41(1)
[Rice, 1976] "The algorithm selection problem," in Advances in Computers, 1976, pp. 65–118

Expert-based Automated Scheduling Algorithm Selection

http://github.com/unibas-dmi-hpc/LB4OMP

- **Leverages** `auto` as a scheduling option for `schedule(kind)`
- **3 expert-based** scheduling algorithm selection methods
  - `RandomSel`
  - `ExhaustiveSel`
  - `ExpertSel`
- **Selects** from a portfolio of scheduling algorithms
  - STATIC, SS, GSS, GAC, TSS, Static Steal, mFAC2, AWF-B, AWF-C, AWF-D, AWF-E, mAF



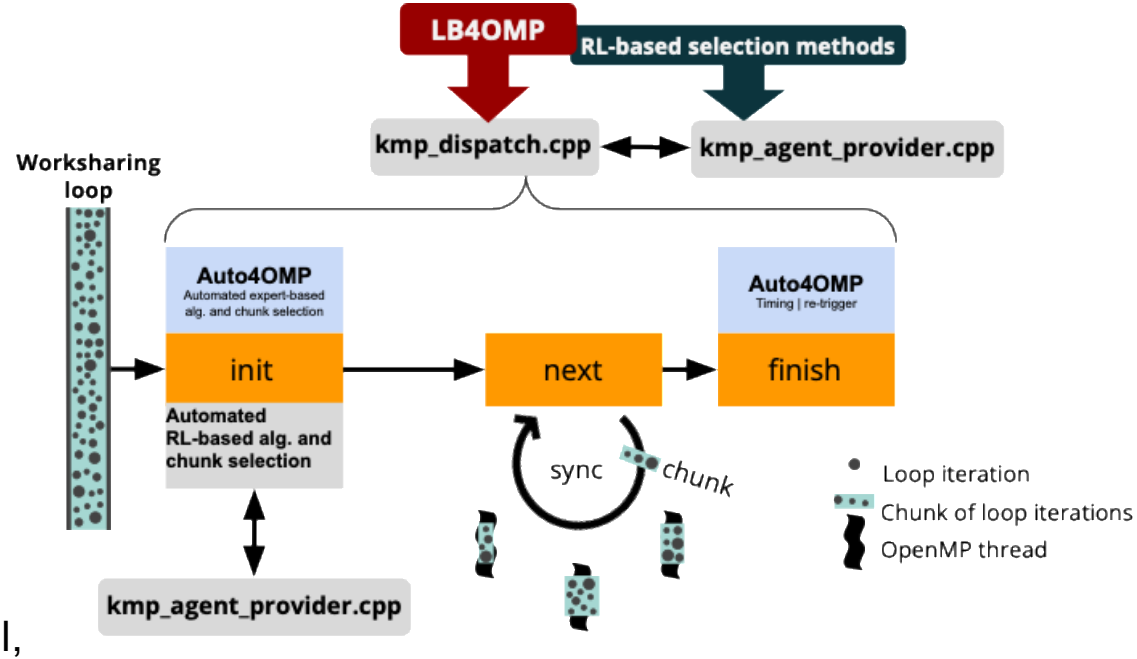
A. Mohammed, J. H. Müller Korndörfer, A. Eleliemy, F. M. Ciorba. "**Automated Scheduling Algorithm Selection and Chunk Parameter Calculation in OpenMP**". TPDS, December 2022.

- Extends the LLVM OpenMP runtime library with the `expert chunk parameter`

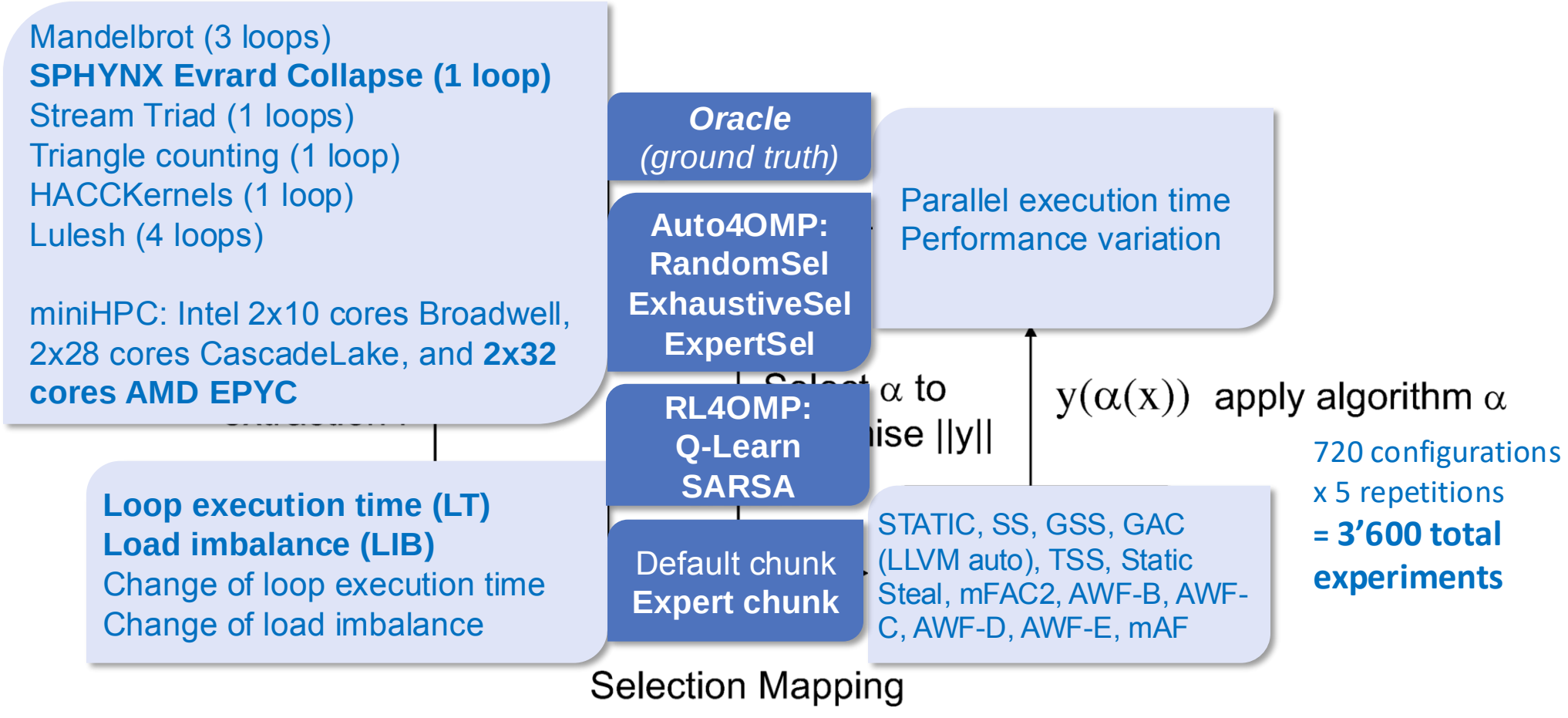
RL-based Automated Scheduling Algorithm Selection

http://github.com/unibas-dmi-hpc/LB4OMP

- **Leverages `auto`** as a scheduling option for `schedule(kind)`
- **2 RL-based** scheduling algorithm selection methods
  - `Q-learn`
  - `Sarsa`
- 2 reward types
  - `Loop execution time (LT)`
  - `Loop load imbalance (LIB)`
- **Selects** from a portfolio of scheduling algorithms
  - STATIC, SS, GSS, GAC, TSS, Static Steal, mFAC2, AWF-B, AWF-C, AWF-D, AWF-E, mAF



Results: Comparison between Expert-based vs. RL-based selection



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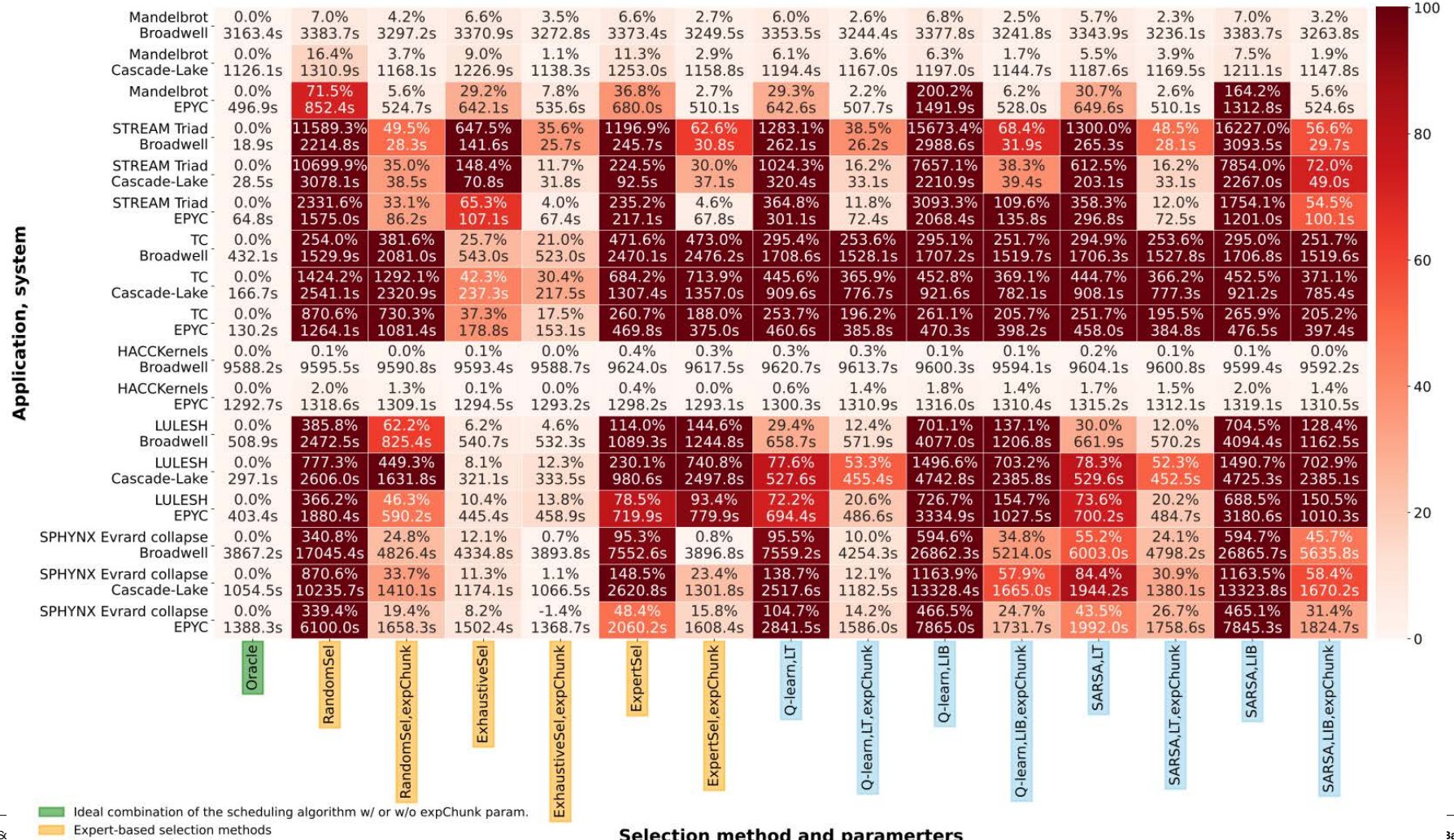

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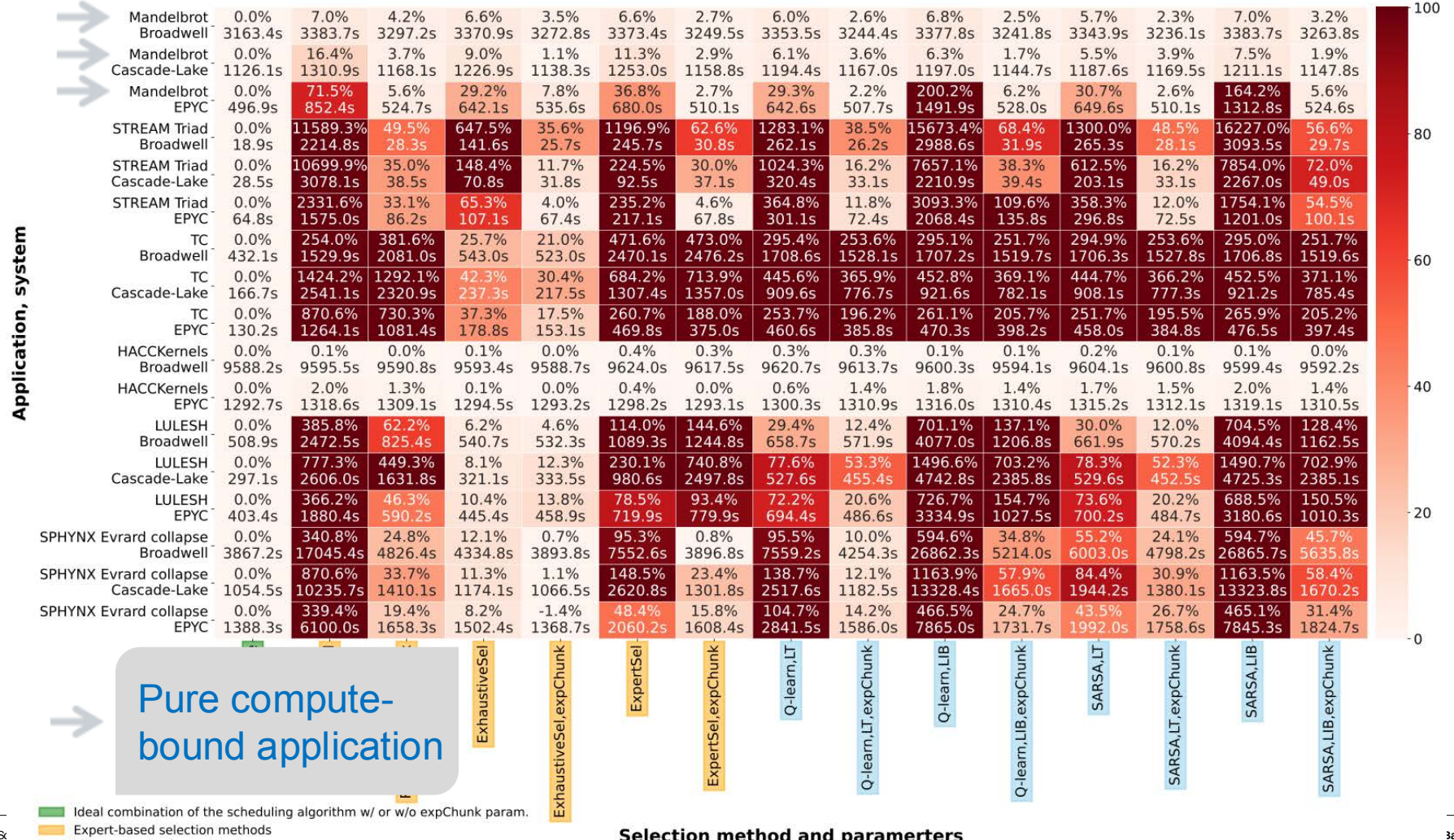
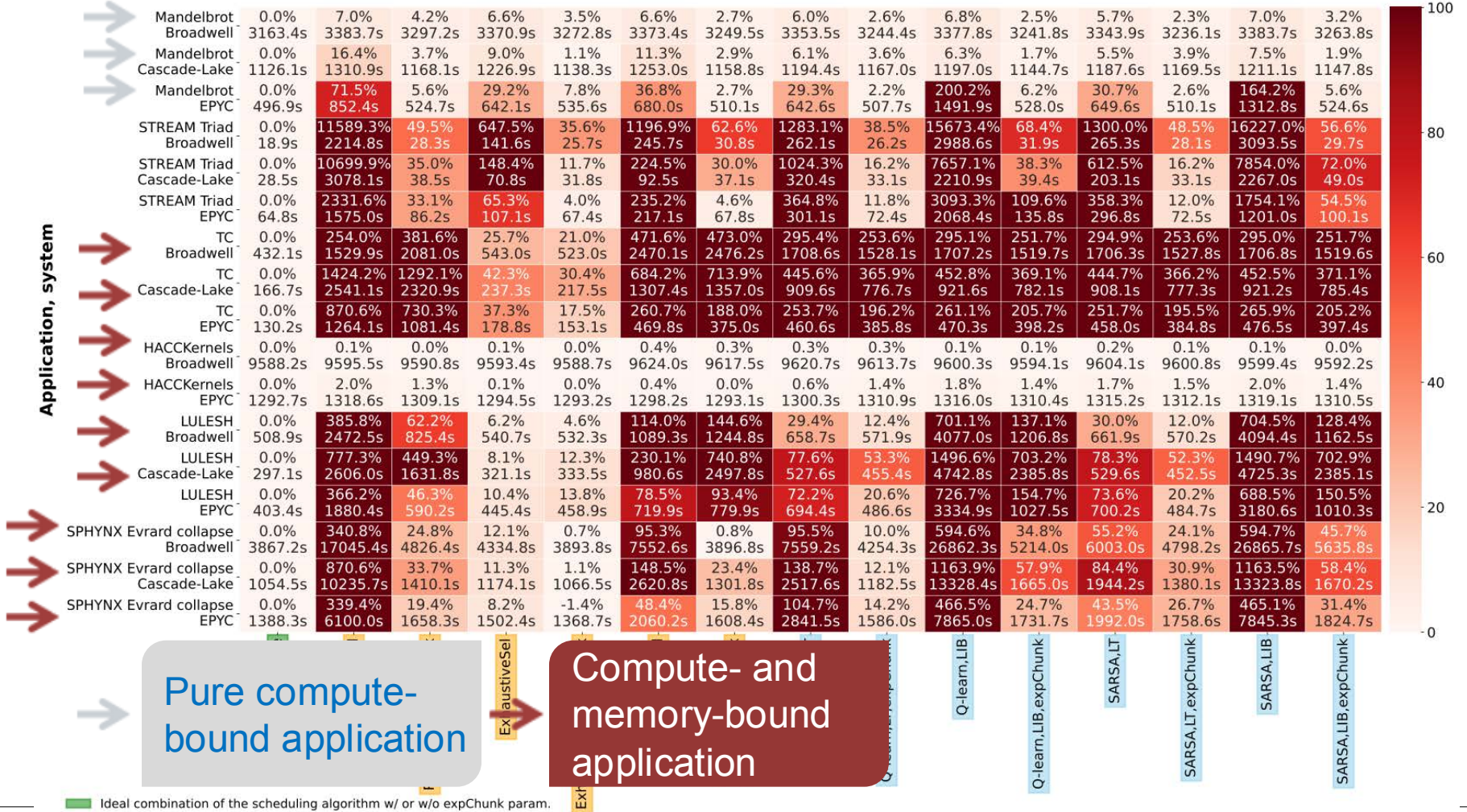
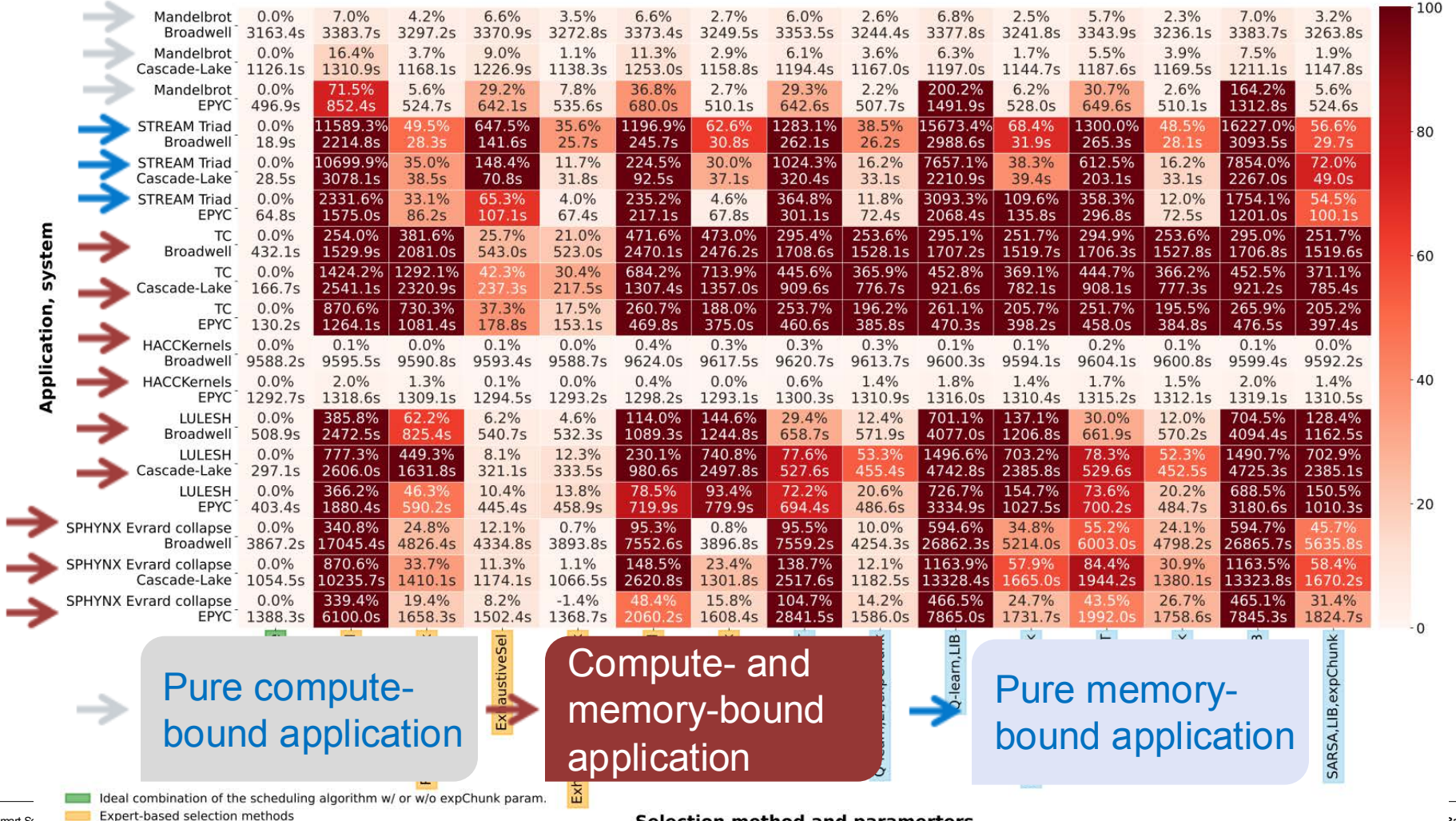


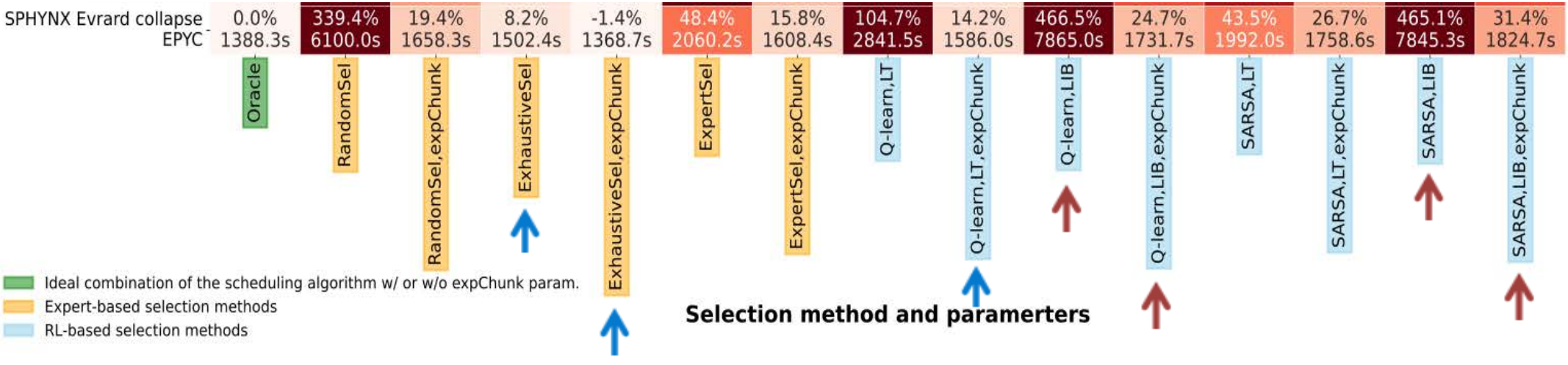
Results: Comparison between Expert-based vs. RL-based selection



Results: Comparison between Expert-based vs. RL-based selection



Results: Comparison between Expert-based vs. RL-based selection

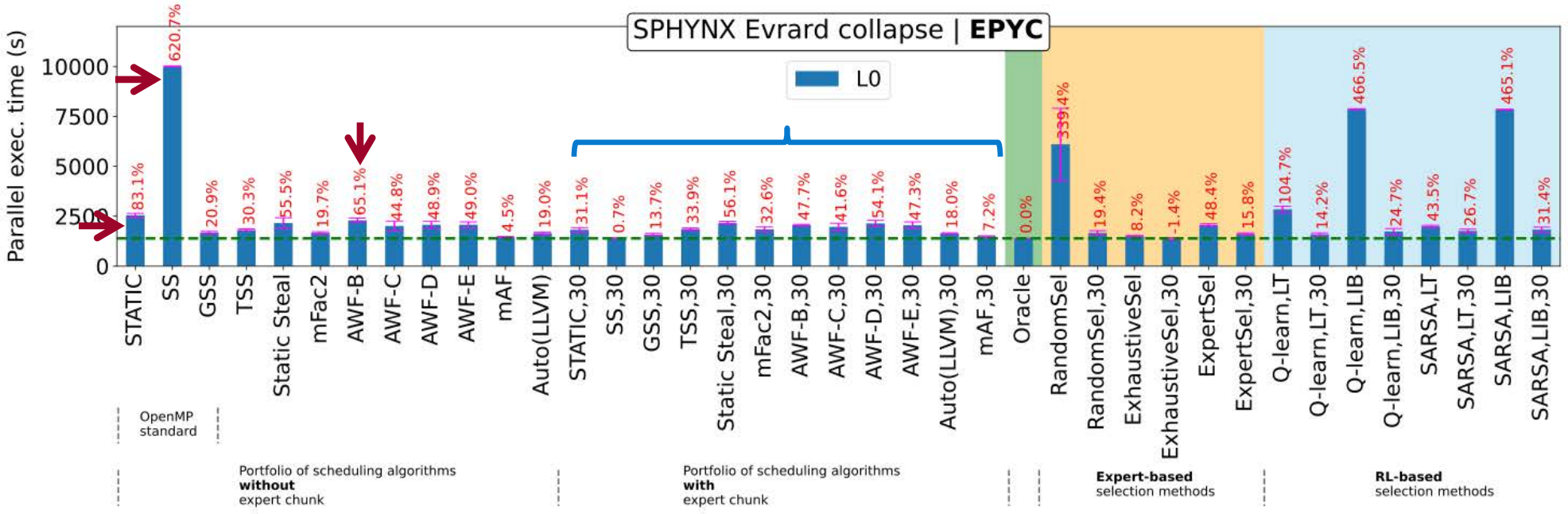


→ Highest performing **expert-based** (and overall) method

→ Highest performing **RL-based** (and overall) method

→ LIB reward achieves low performance

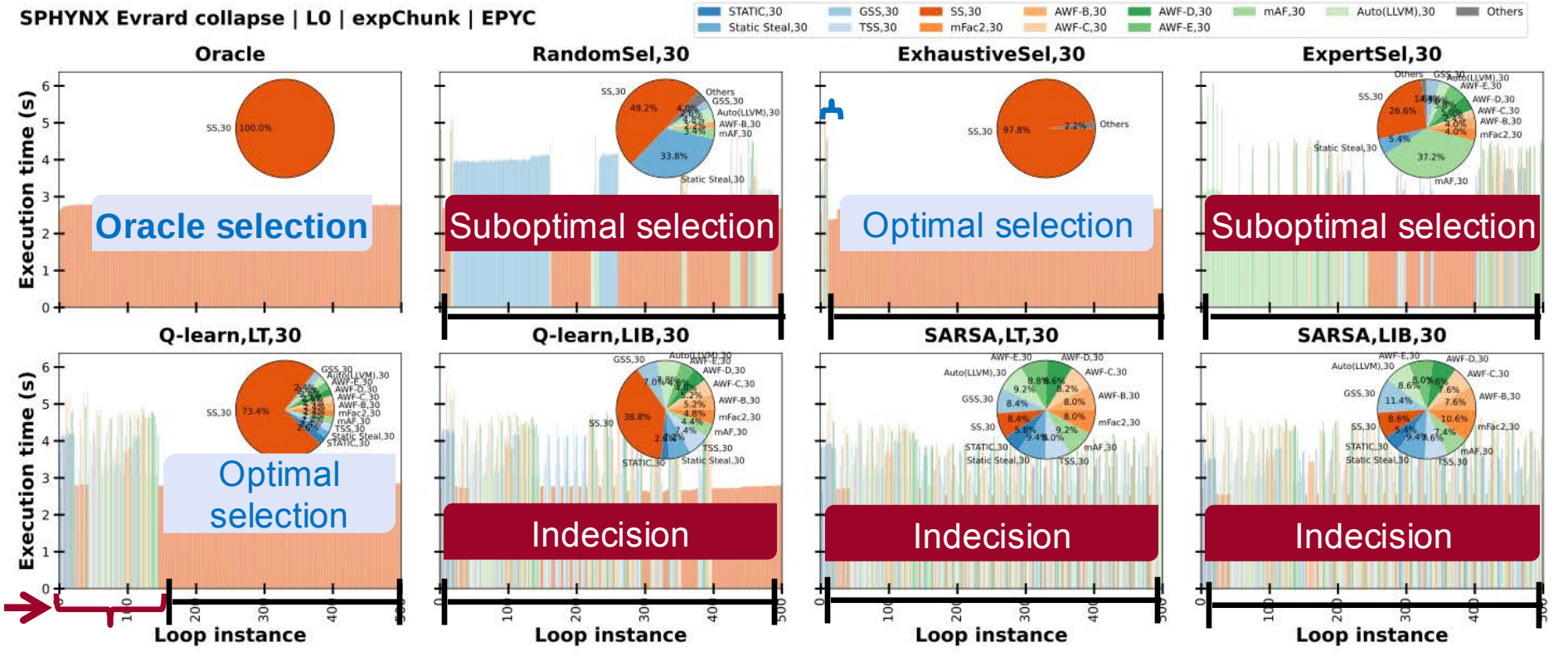
Results: Comparison between Expert-based vs. RL-based selection



Certain algorithms cause extreme overhead (>60% compared to oracle)

Expert chunk parameters improves performance in most cases

Results: Comparison Between Expert-based vs. RL-based Selection



Long exploration phase

Short exploration phase

Exploitation phase

Take Away's

DaphneSched | DMI HPC Group website | LB4OMP | LB4OMP w/ Auto4OMP

Auto4OMP Random, Exhaustive, Expert

Autotuning 1 expert chunk parameter

RL4OMP Q-Learn, SARSA

LB4OMP

http://github.com/unibas-dmi-hpc/LB4OMP

Q-learn and SARSA are not ideal for scheduling algorithm selection in OpenMP

For now, **expert-based** selection **outperform RL-based**

Exploration of **RL-based** algorithms that require **less steps for learning is required**

LB4OMP portfolio of **scheduling algorithms** is already available in **DAPHNE** (DaphneSched)

Next steps

Scheduling algorithm selection for **OpenMP tasks**

Smart scheduling algorithm selection in **DAPHNE**

Smart scheduling algorithm selection in **LB4MPI**

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