The HCl Scheduler

Going all-in on Heterogeneity

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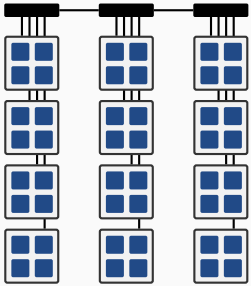
USENIX HotCloud'17

Karlsruhe Institute of Technology

Institute of Telematics

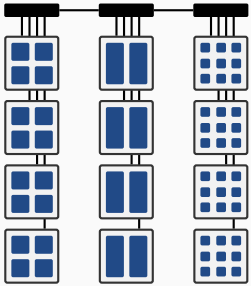
IBM Research - Zurich

Evolution of Clusters - Past



→ Mostly homogeneous hardware

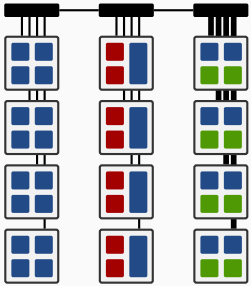
Evolution of Clusters



> Heterogeneity occurs because servers are gradually provisioned and replaced over the typical 15-year lifetime of a DC. At any point in time, a DC may host 3-5 server generations with a few hardware configurations per generation

C. Delimitrou and C. Kozyrakis. "Paragon: QoS-aware scheduling for heterogeneous datacenters." ACM SIGPLAN 2013.

Evolution of Clusters - Today & Future



IBM EXTENDS GPU CLOUD CAPABILITIES, TARGETS MACHINE LEARNING

The Next Platform, 2016-05-19

AWS announces FPGA instances for its EC2 cloud computing service

TechCrunch, 2016-11-30

Google launches GPU support for its Cloud Platform

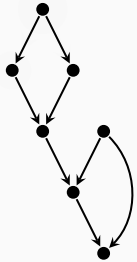
TechCrunch, 2017-02-21

Microsoft Azure ND-series offers more GPUs, power

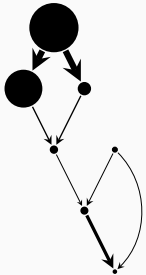
TechGenix, 2017-06-09

What about Applications?

Homogeneous View



Heterogeneous View



Spark stage graph of TPC-DS Query #44

What about Applications?

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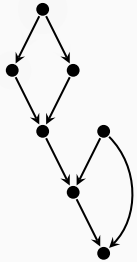
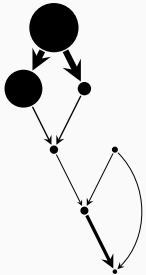


Heterogeneous View



Spark stage graph of TPC-DS Query #44

→ **Applications are heterogeneous as well**

- Runtime and resource requirements vary
- I/O volumes vary

Consequences

> Ignoring heterogeneity can lead to significant inefficiencies, as some workloads are sensitive to hardware configurations.
> *C. Delimitrou and C. Kozyrakis. "Paragon: QoS-aware scheduling for heterogeneous datacenters." ACM SIGPLAN 2013.*

→ We leave a lot of potential untapped, not least due to inefficient task scheduling.

The HCl Scheduler - Goals, Starting Point & Approach

➔ **Goals**

1. Efficient utilization & sharing of (heterogeneous) resources.
2. Minimize application (vs. task) runtime.
3. Reduce costs for clients and operators.

The HCl Scheduler - Goals, Starting Point & Approach

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Starting Point

We primarily aim for maximizing scheduling quality and secondarily for maximizing scaling & throughput and minimizing latency.

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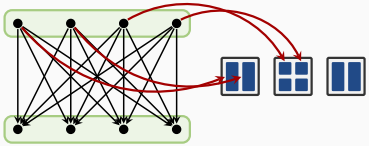
Approach

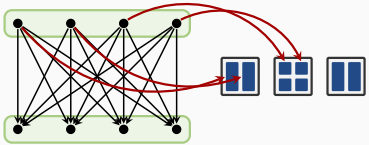
Exploit detailed resource and application information in order to find globally optimal application schedules.

Closer Look at the Problems



P1. Stragglers due to h/w selection

Closer Look at the Problems



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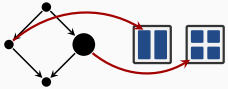
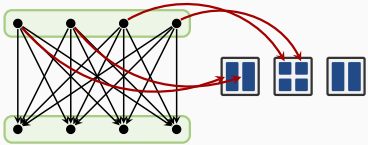


P2. Priority inversion

Closer Look at the Problems



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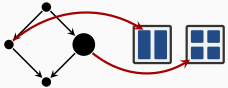

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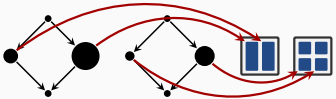
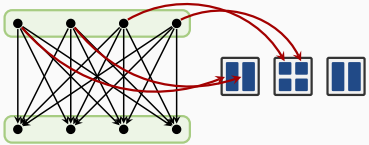


P3. Non-beneficial *stealing* of preferred resources

Closer Look at the Problems



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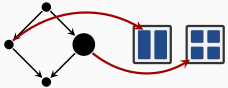

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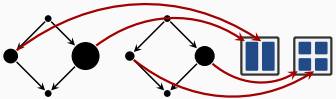

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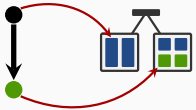
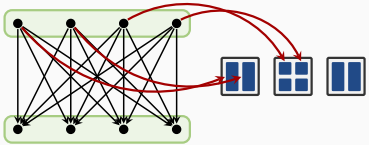


P4. Dominating I/O costs

Closer Look at the Problems



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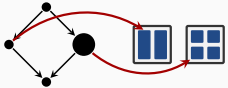

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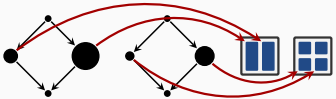

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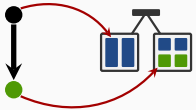

P4. Dominating I/O costs

The HCl Scheduler - Related Work

Scheduler	Year	H/W	App	Task	P1	P2	P3	P4
LHEFT	2010	(✔)	✔	✔	-	✔	-	(✔)
Mesos	2011	(✔)	-	-	-	-	-	-
Paragon	2013	✔	-	✔	-	-	-	-
Kubernetes	2014	(✔)	-	(✔)	-	-	-	-
Tetris	2014	-	(✔)	(✔)	(✔)	-	-	-
TetriSched	2016	(✔)	(-)	(✔)	(✔)	(✔)	-	-
Graphene	2016	(✔)	✔	(✔)	(✔)	(✔)	-	(✔)
Carbyne	2016	(✔)	✔	✔	(-)	-	(✔)	-
HCl	2017	✔	✔	✔	✔	✔	✔	✔

→ Heterogeneity of **applications and resources** is rarely a primary concern.

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Kubernetes	2014	(✔)	-	(✔)	-	-	-	-
Tetris	2014	-	(✔)	(✔)	(✔)	-	-	-
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HCl	2017	✔	✔	✔	✔	✔	✔	✔

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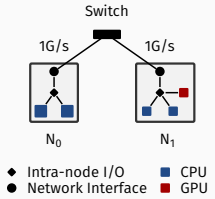
The HCl Scheduler - Overview

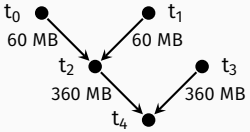
➔ HCl combines 3 sources of information that are usually separated.

Detailed Cluster Model



➔ Extracted from OS / Resource Manager

Annotated Application DAG



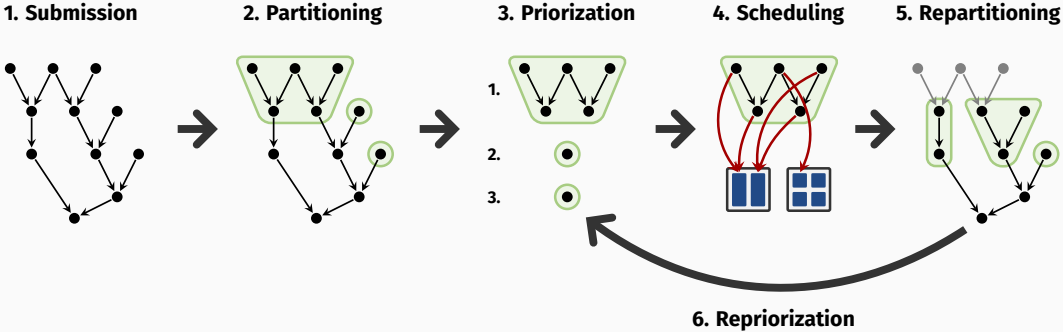
➔ Extracted from App Framework (e.g. Spark)

➔ Soft/hard constraints

Performance Database

Task	$N_{0_{cpu}}$	$N_{1_{cpu}}$	$N_{1_{gpu}}$
t_0	4.0s	5.0s	2.0s
t_1	4.0s	5.0s	2.0s
t_2	1.0s	1.5s	-
t_3	8.0s	10.0s	5.0s
t_4	1.0s	1.5s	-

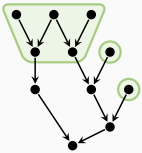
The HCl Scheduler - 10,000 Foot View



The HCl Scheduler - Heuristics

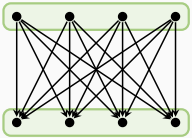
→ DAG scheduling is an NP-complete problem, hence heuristics are necessary to reduce the cost of scheduling to desired levels.

1. Partitions



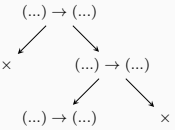
2. Node Classes

3. Task Classes



4. Sampling

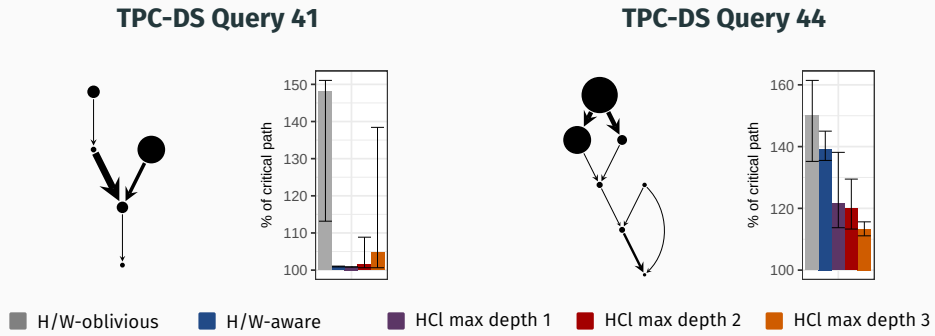
5. Early Termination*



* = Not a heuristic

Evaluation - Preliminary TPC-DS Benchmark Results (Excerpt)

- Single-application, model-based evaluation (extracted from Spark) on an 8 node cluster (2 fast, 6 slow nodes, factor 1.5).



- HCl schedules are within **15%** of the critical path on average.
- HCl schedules are **48%** shorter on average.

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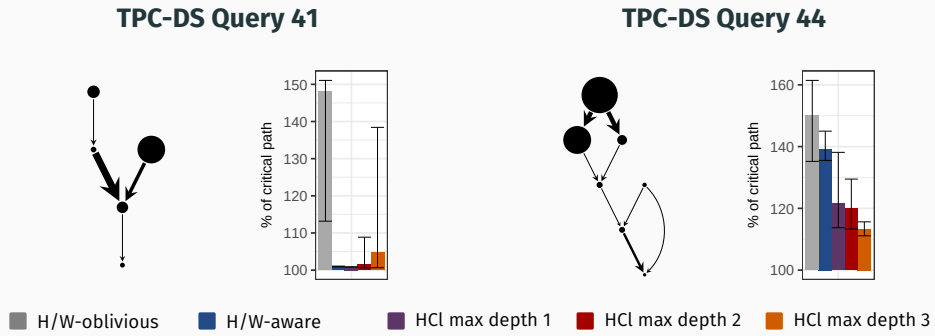

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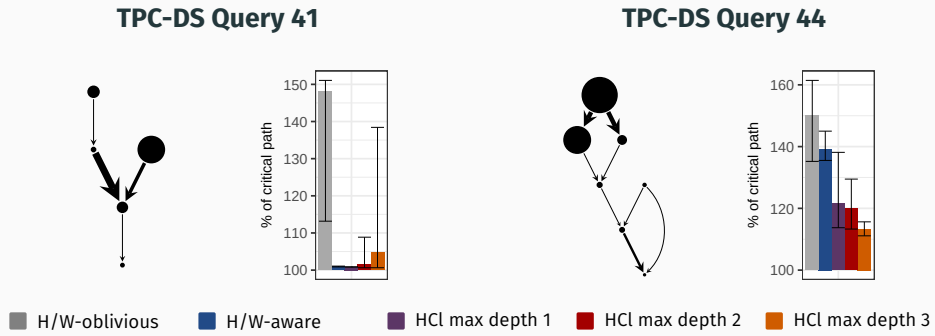

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Conclusion

- Current cluster schedulers leave potential untapped.
  - We need to consider H/W and S/W heterogeneity in order to solve scheduling problems.
- The HCl Scheduler is our attempt at exploring the potential of a fully heterogeneity-aware scheduler.
  - Preliminary evaluation shows that we can significantly shorten schedules.
  - Few additionail faster resources can help to speed up applications significantly.
- Lots of work left to be done.

Outlook

Thank you! Questions?

Outlook

→ **Ongoing & Future Work**

- Improve performance (heuristics & implementation)
- Implement multiple resources support
- Integrate into distributed application framework (Apache Spark, TensorFlow)
- Evaluate opportunities at edge between scheduling, I/O (Crail Store integration) and H/W acceleration.

Backup

The HCl Scheduler - Example (Problem 3: Non-beneficial *stealing* of preferred resources)