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Faithful Performance Prediction of a Dynamic Task-based Runtime System, an Opportunity for Task Graph Scheduling

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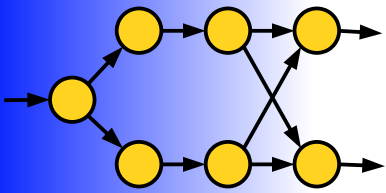
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Faithful Performance Prediction of a Dynamic Task-based Runtime System, an Opportunity for Task Graph Scheduling

Samuel Thibault, Luka Stanisic, Arnaud Legrand

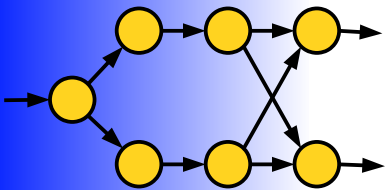
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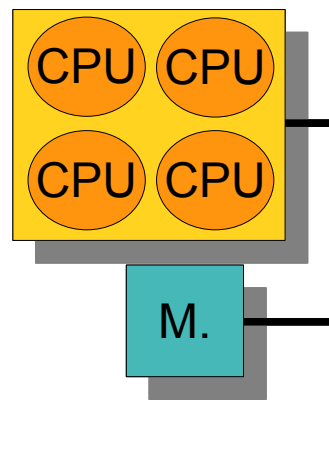

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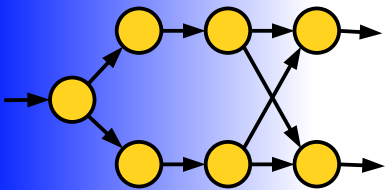


High-Performance Computing

Combination of hardware

- Classical CPUs

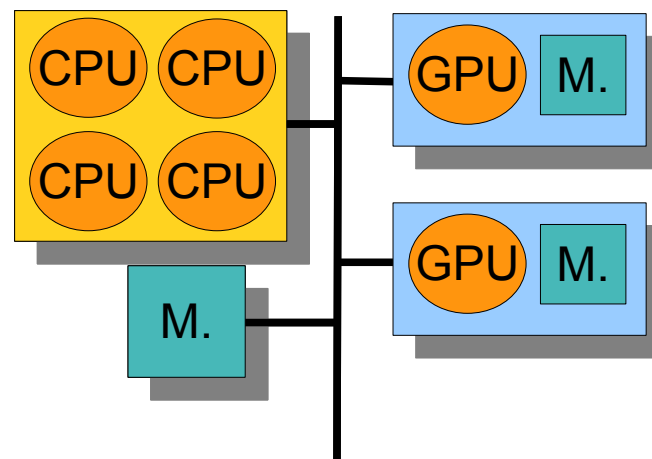


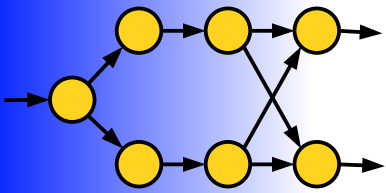


High-Performance Computing

Combination of hardware

- Classical CPUs
- Accelerators: GPUs

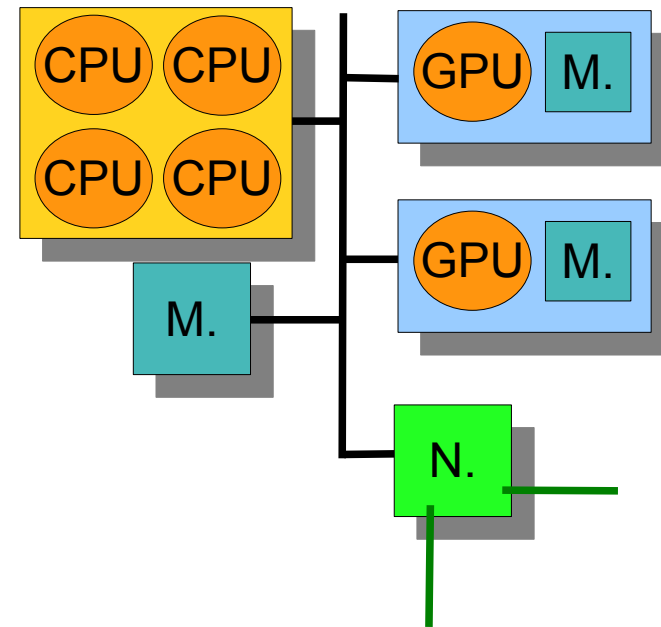


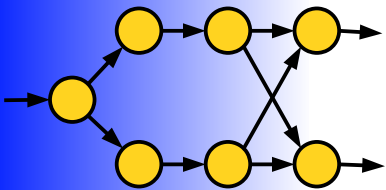


High-Performance Computing

Combination of hardware

- Classical CPUs
- Accelerators: GPUs
- Network card

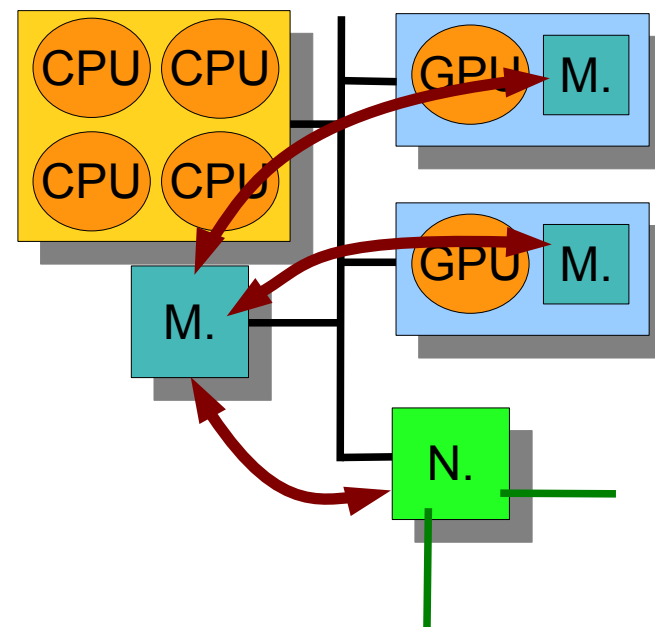


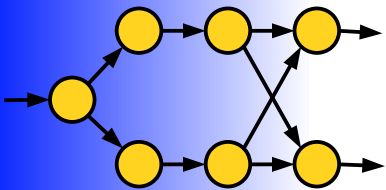


High-Performance Computing

Combination of hardware

- Classical CPUs
- Accelerators: GPUs
- Network card
- Data transfers





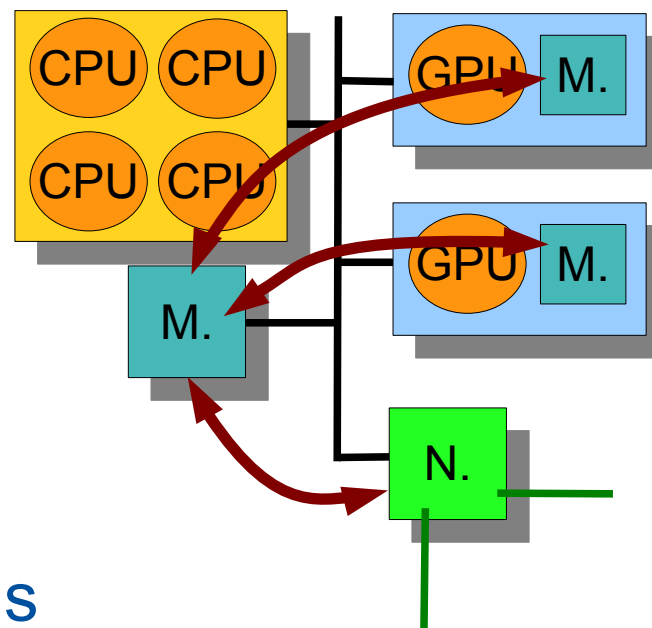
High-Performance Computing

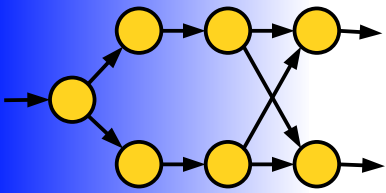
Combination of hardware

- Classical CPUs
- Accelerators: GPUs
- Network card
- Data transfers

Managing it all by hand?!

- New machine with more GPUs





High-Performance Computing

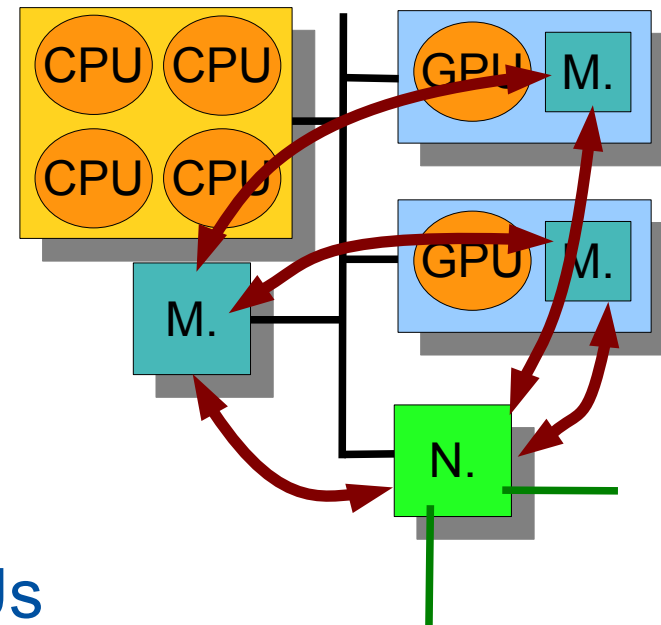
Combination of hardware

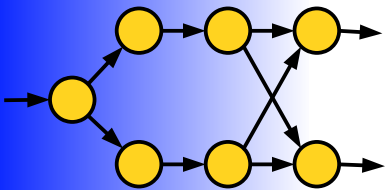
- Classical CPUs
- Accelerators: GPUs
- Network card
- Data transfers

Managing it all by hand?!

- New machine with more GPUs
- New transfer possibilities
- ...

→ Runtime systems

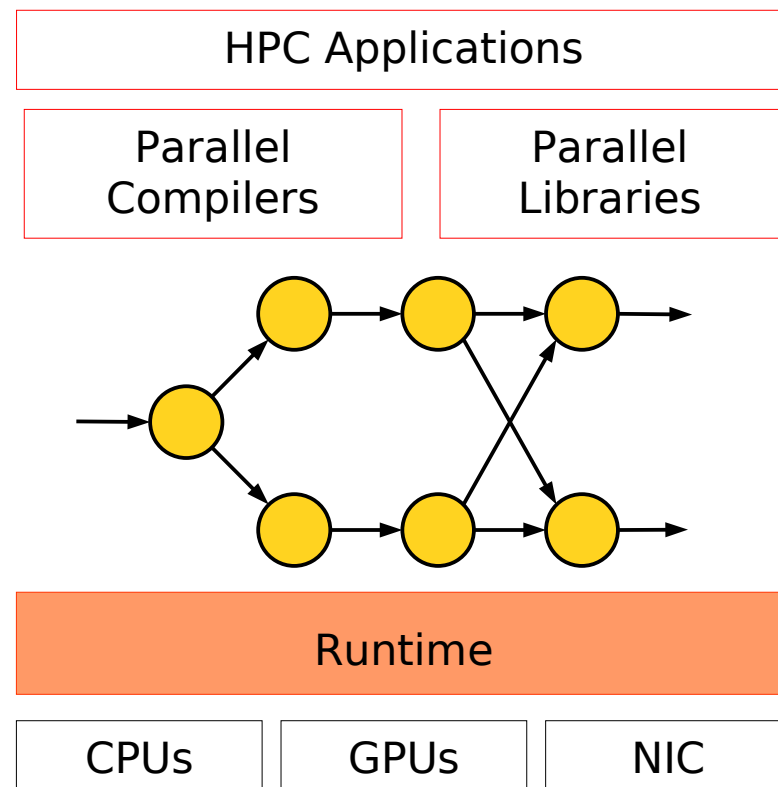


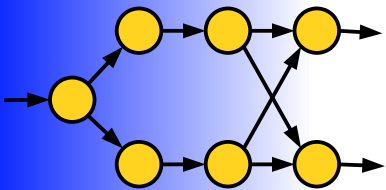


High-Performance Computing

A recent actual trend towards runtime systems & task graphs

- Applications
 - Submit a task graph
- Runtime system
 - Manages & optimizes execution
 - Copes with memory limitation
 - ...

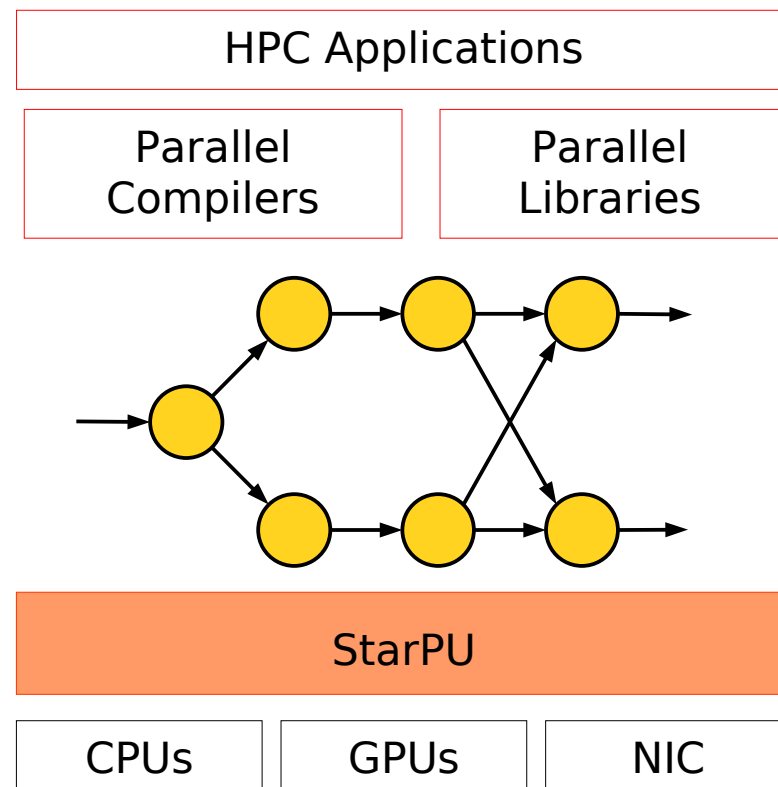


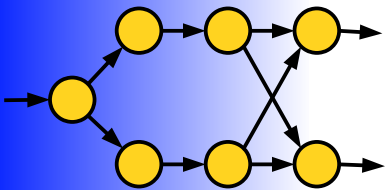


High-Performance Computing

The StarPU runtime system

- **Started in 2008**
 - PhD Thesis of Cédric Augonnet
- **StarPU main core \approx 70k lines**
- **Written in C**
- **Open Source**
 - Release under LGPL
 - Sources freely available
 - [git repository and nightly tarballs](https://starpu.gforge.inria.fr/)
 - See <https://starpu.gforge.inria.fr/>
 - Open to external contributors
- **[Europar'09,CCPE'11]: > 1200 citations**

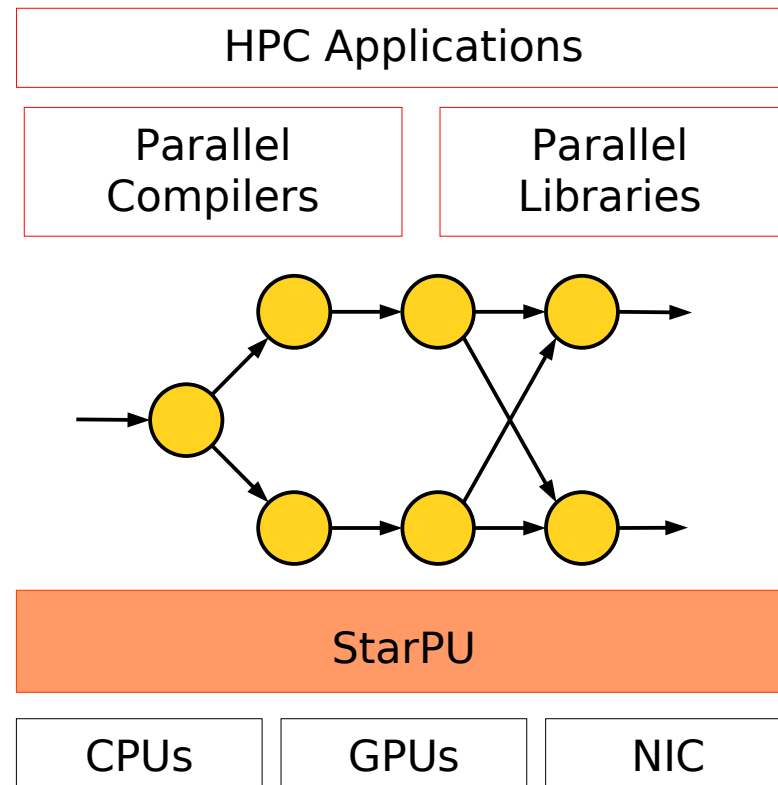




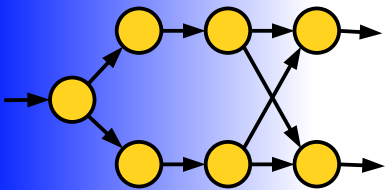
High-Performance Computing

Difficulties shifted

- **Applications**
 - Decide task graph structure
 - Decide task granularity
- **Runtime system**
 - Scheduling heuristics
 - Eviction heuristics
 - ...



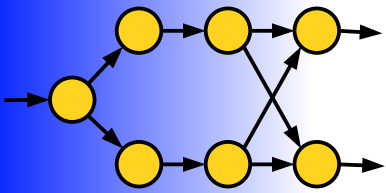
And debug...



High-Performance Computing

Confirming performance improvements with measurements

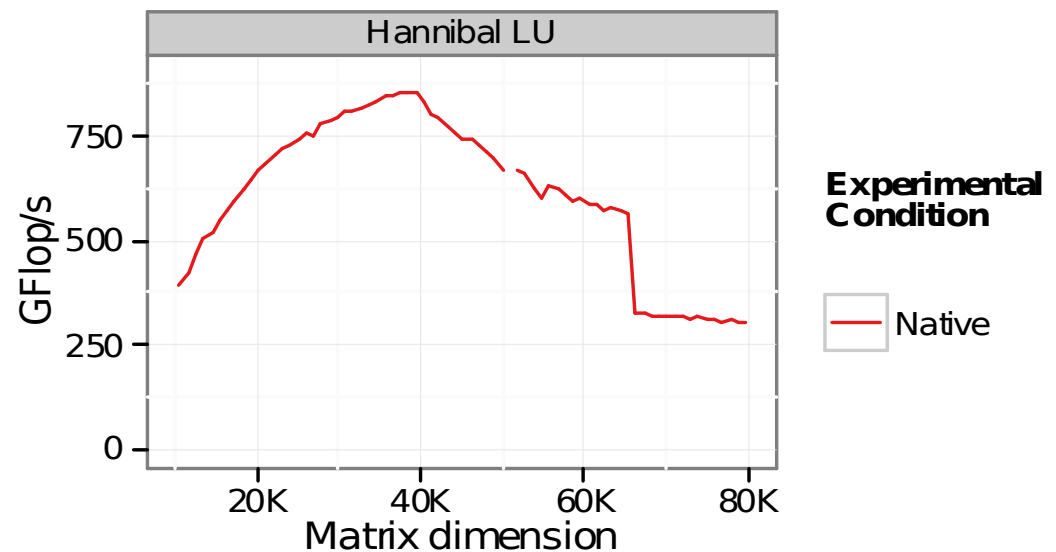
- **Robust? Platform stability**
 - Rogue processes
 - Faulty cables
 - Software upgrades
 - Firmware upgrades
- **Repeatable? Platform availability**
 - CPU.hour allocation
 - Decommissioned platform
- **Reproducible? Different platforms**
 - Getting accounts on various systems
 - Install software stack there

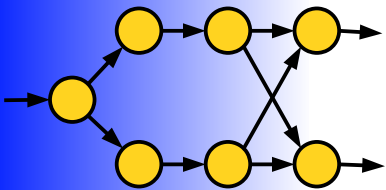


High-Performance Computing

For instance, LU factorization on Hannibal machine

- Odd behavior, stable
- Old GPU, old machine
- Now decommissioned

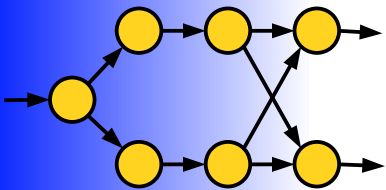




High-Performance Computing

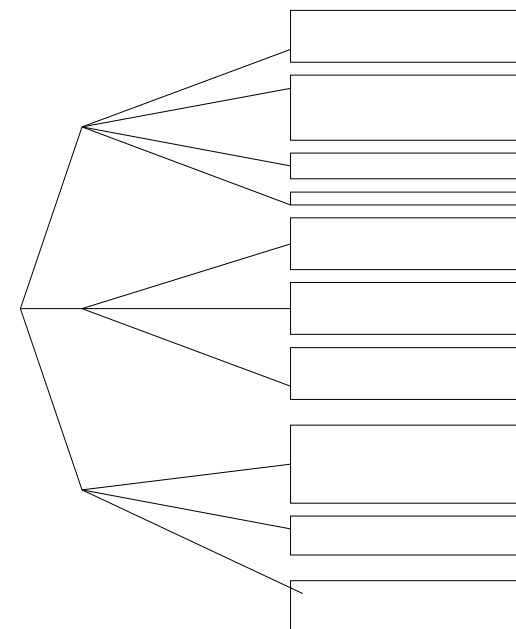
Confirming performance improvements with **simulation**

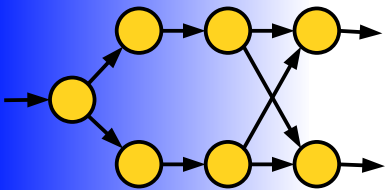
- **Platform stability**
 - Deterministic execution
 - Reproducible performance, and bugs!
- **Platform availability**
 - Can run on commodity laptop
 - No need for platform reservation
- **Different platforms**
 - Sharing platform modeling
 - Predicting performance



Simulating a runtime system

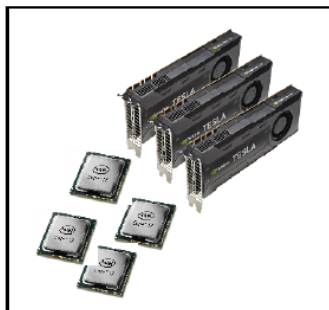
- **Combine emulation and simulation at task level**
 - Task graph control code emulated
 - Both runtime and application main code executed unmodified
 - Task computation and data transfers simulated
 - Performance models



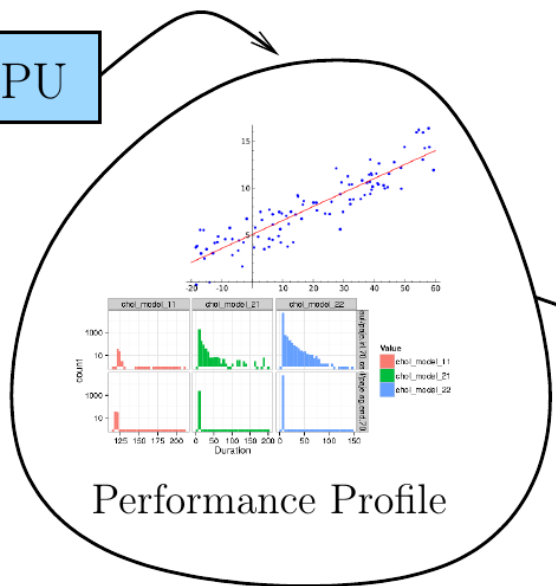


Simulation with SimGrid

Calibration

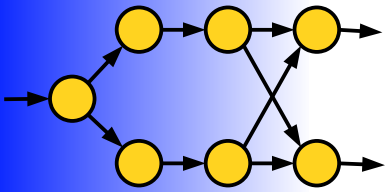


App StarPU



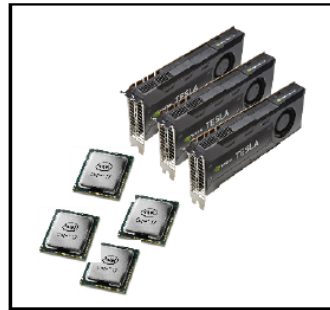
With A. Legrand
and L. Stanisc

Run once!

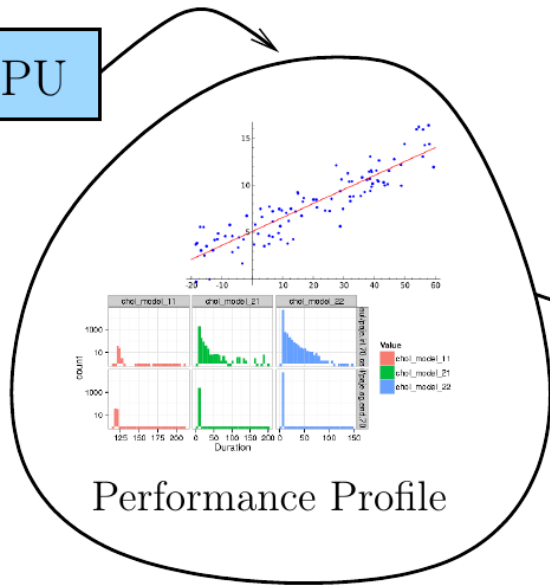


Simulation with SimGrid

Calibration



App StarPU



Performance Profile

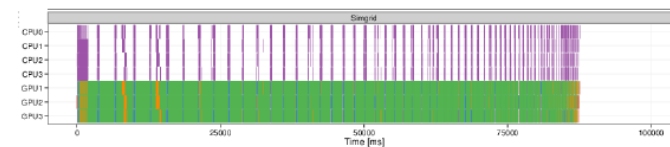
Run once!

Simulation



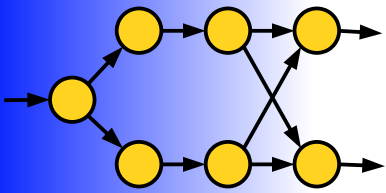
App StarPU

SimGrid



Quickly Simulate Many Times

With A. Legrand
and L. Staniscic



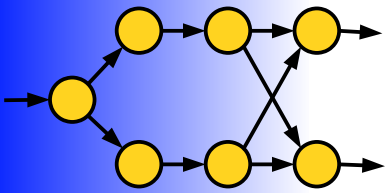
Simulation with SimGrid

The runtime tells SimGrid about

- Threads doing virtual sleeps corresponding to tasks
- Data transfers over the PCI bus

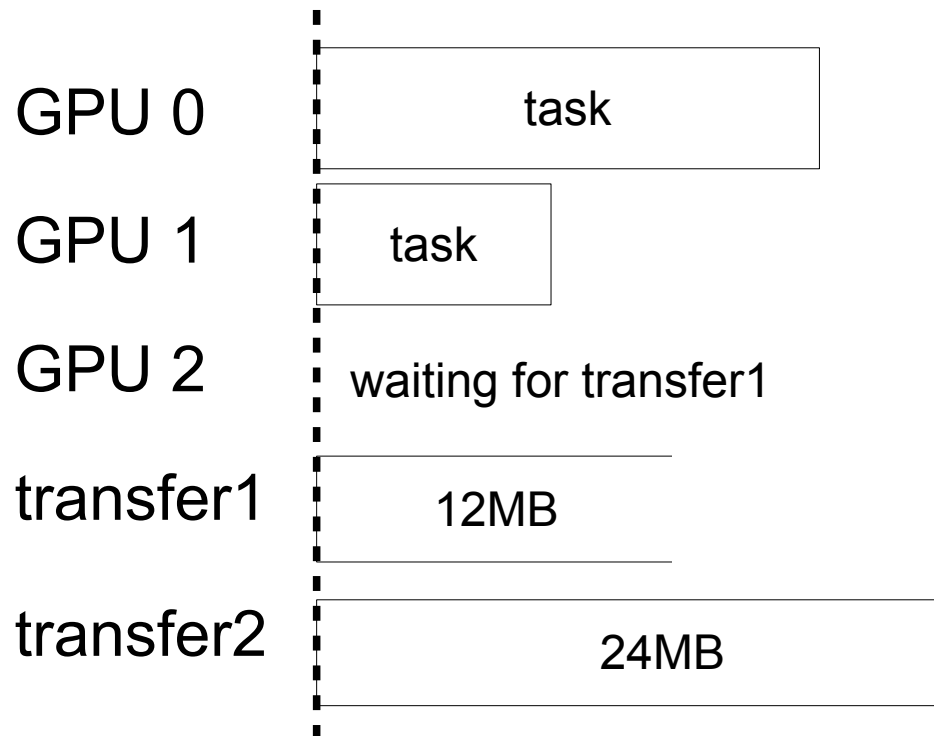
SimGrid manages

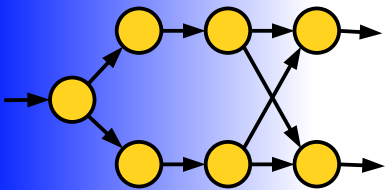
- Synchronization between threads, and with data transfers
- Simulated PCI bandwidth shared between data transfers



Simulation with SimGrid

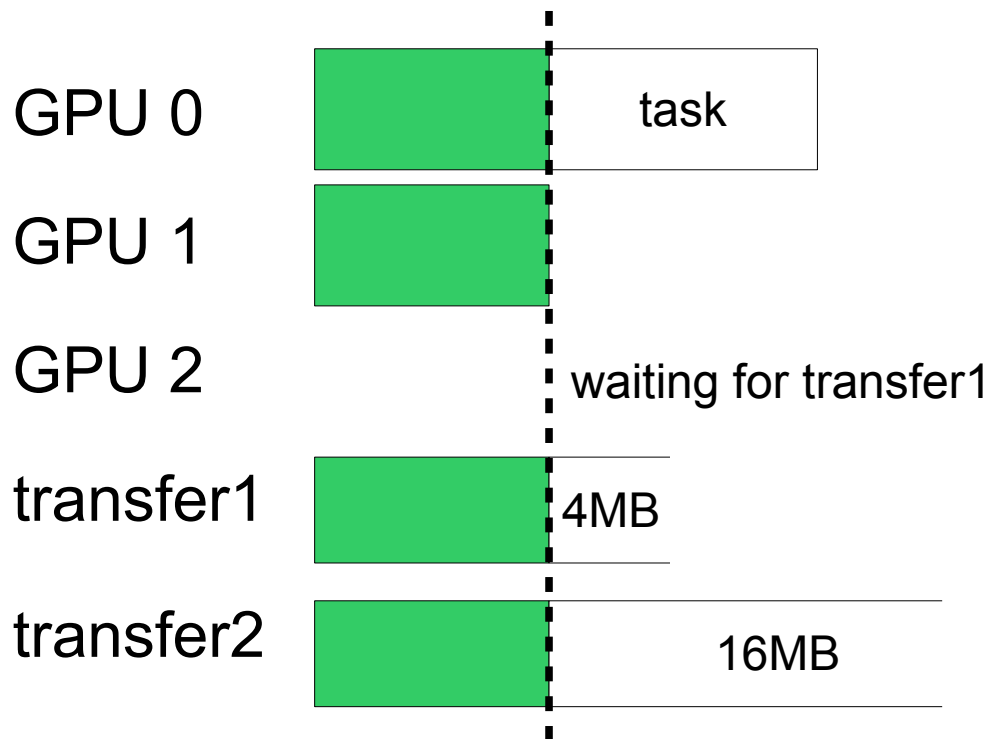
- At each timestep, SimGrid determines next event to trigger
 - thread sleep completion,
 - or data transfer completion
- And advances simulated time accordingly

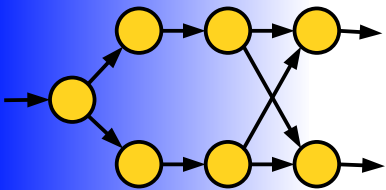




Simulation with SimGrid

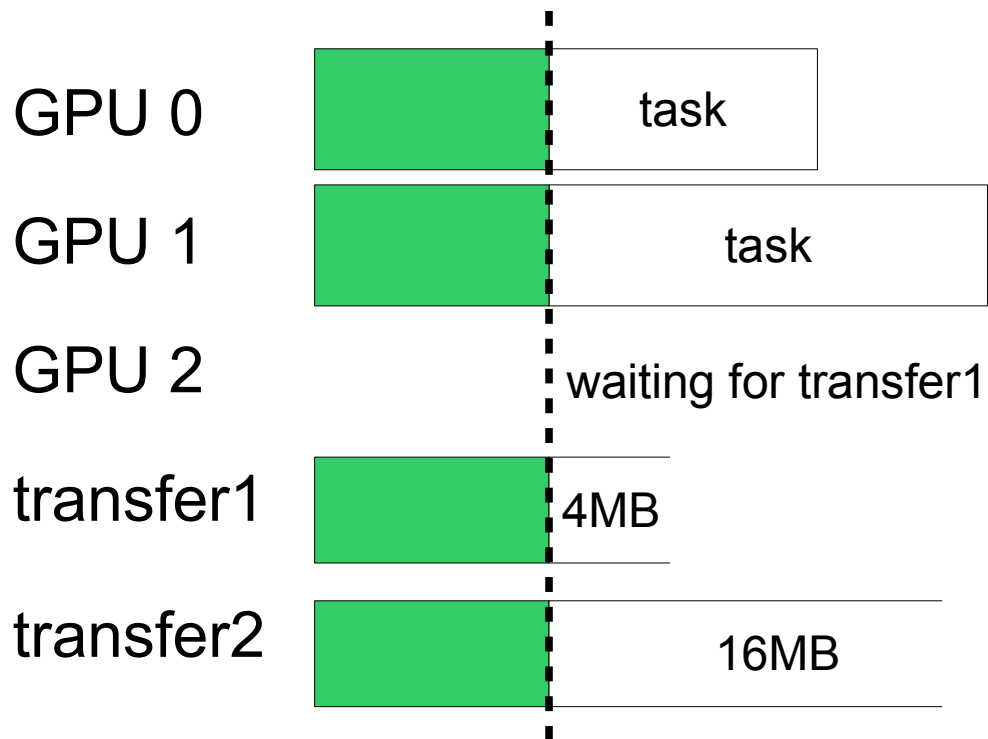
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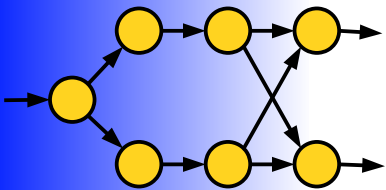




Simulation with SimGrid

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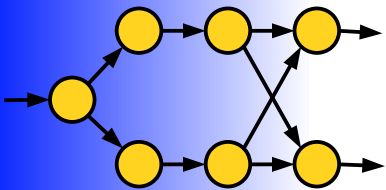




Simulation with SimGrid

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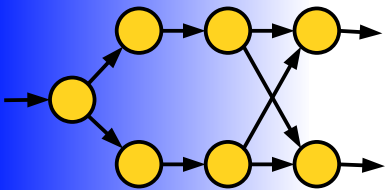




Simulation with SimGrid

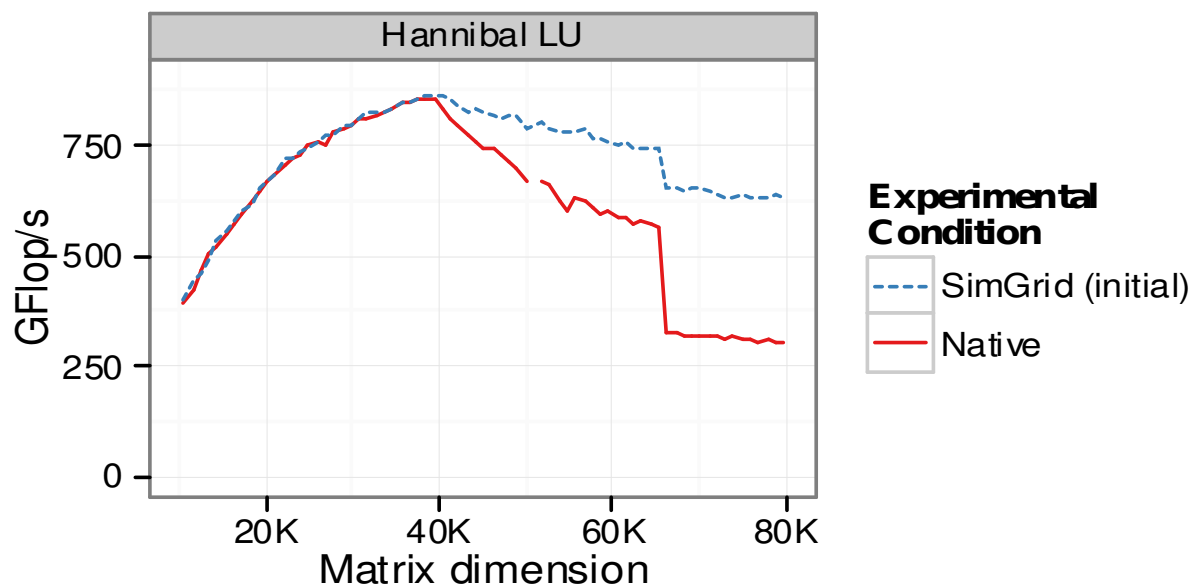
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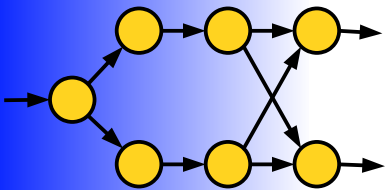
Simulation with SimGrid

Result on LU factorization on Hannibal machine



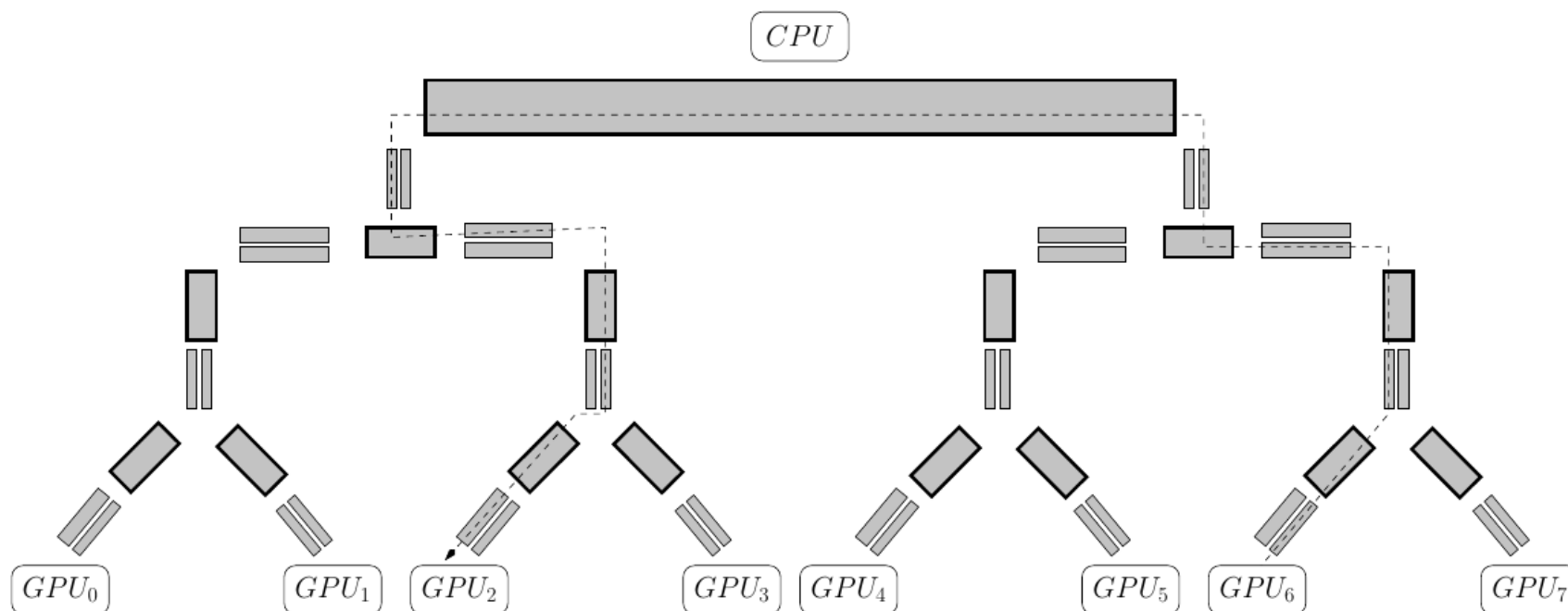
Accurate until matrix too big for all data transfers to overlap

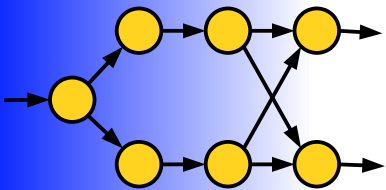
Take GPU memory limitation into account (2.5 GB)



Refining data transfers

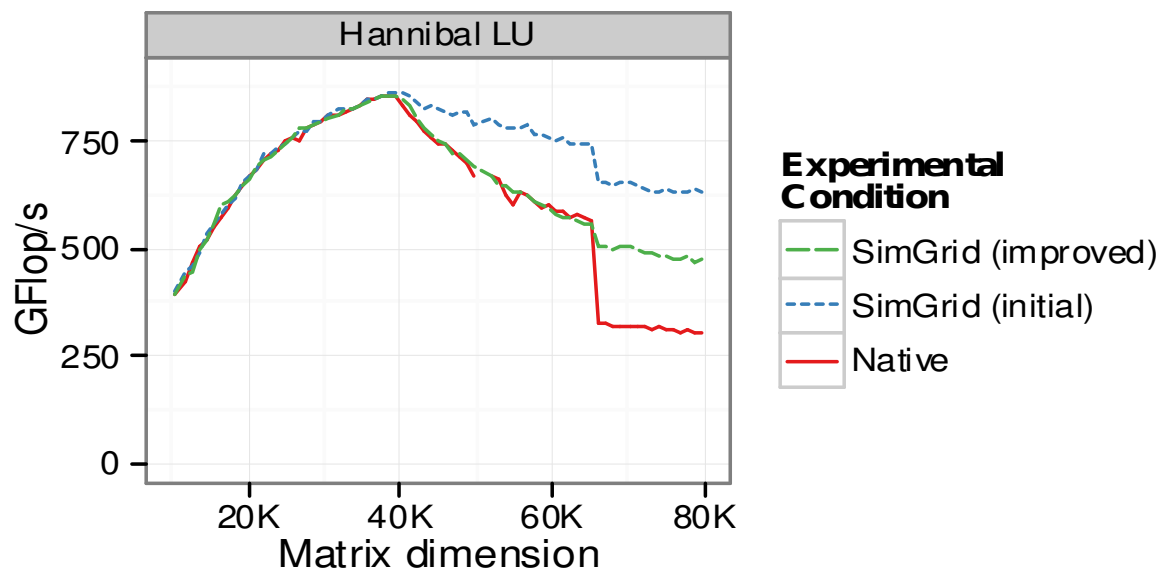
- Improve PCI network model
 - Support direct GPU-GPU transfers
 - Generated by StarPU from measurements on target system
 - And even PCI tree from hwloc information



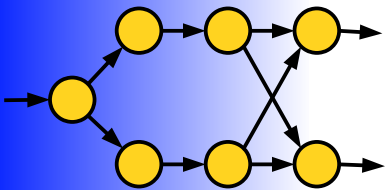


Refining data transfers

Result on LU factorization on Hannibal machine



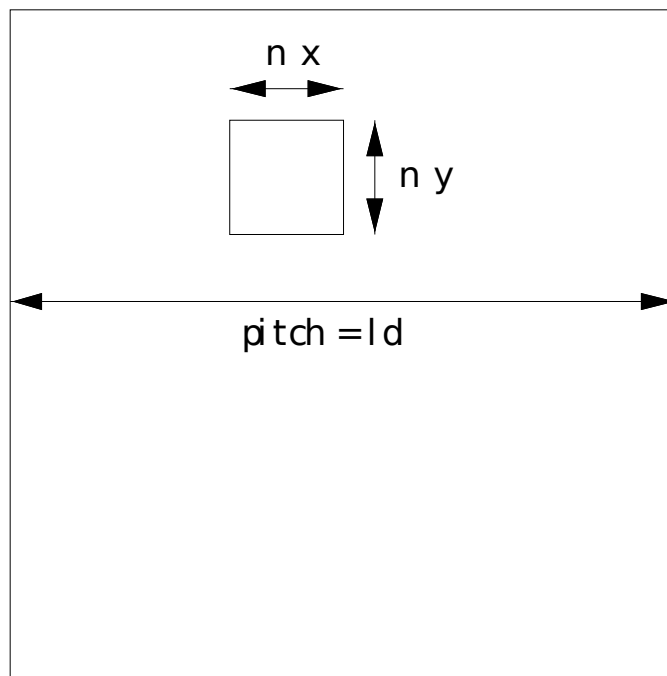
- Way more accurate
- Still odd behavior beyond 66K

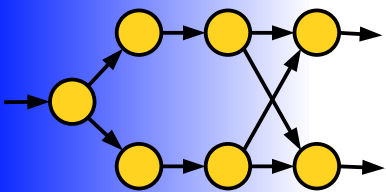


Pitch issue with Quadro FX5800

Tile within big matrix \rightarrow pitch (LD: leading dimension)

Old QuadroFX5800 does not work well with pitch $\geq 264\text{KB}$

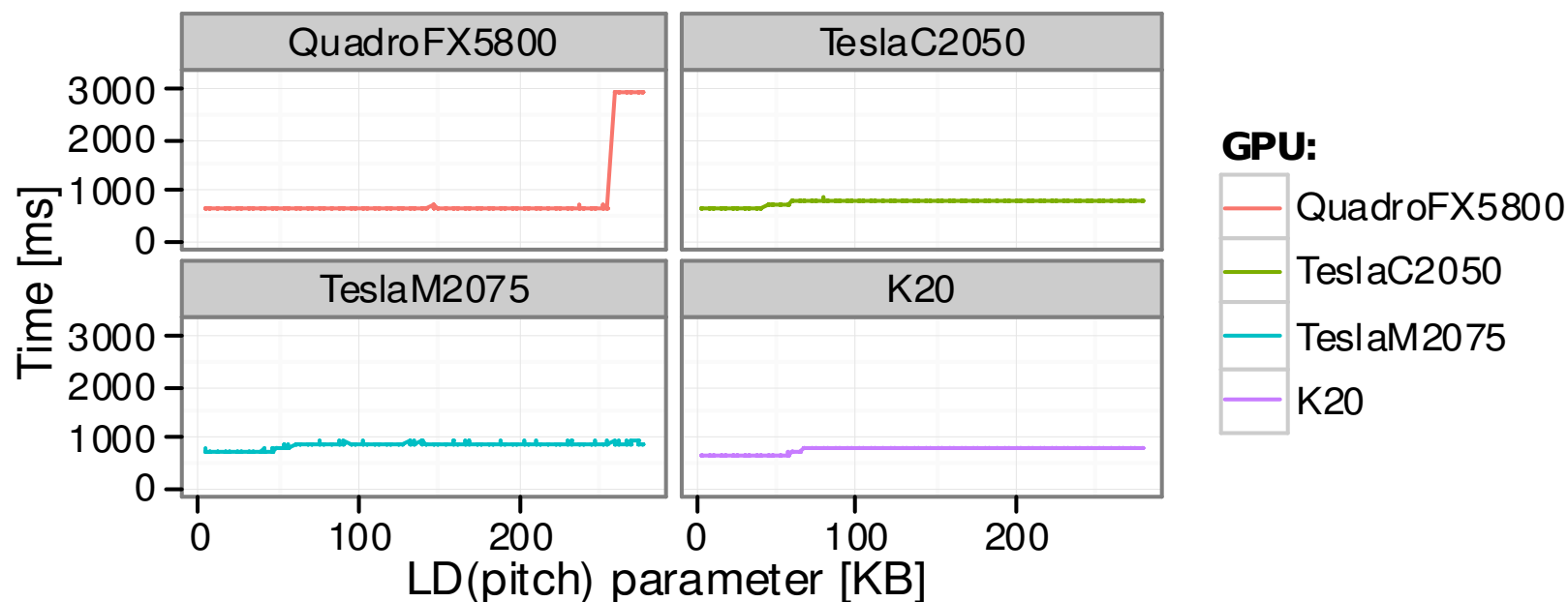


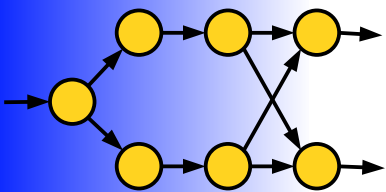


Pitch issue with Quadro FX5800

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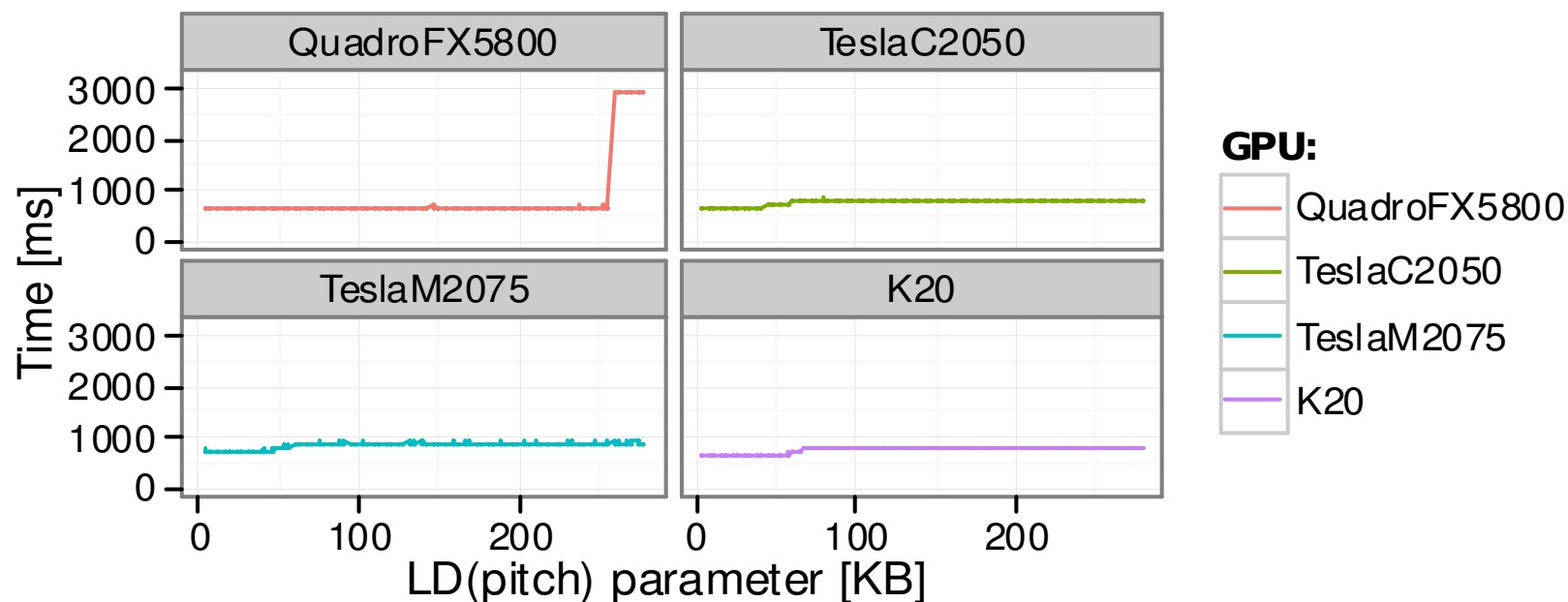




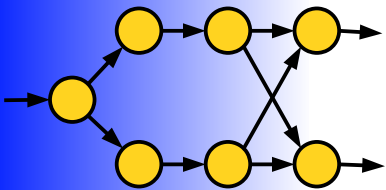
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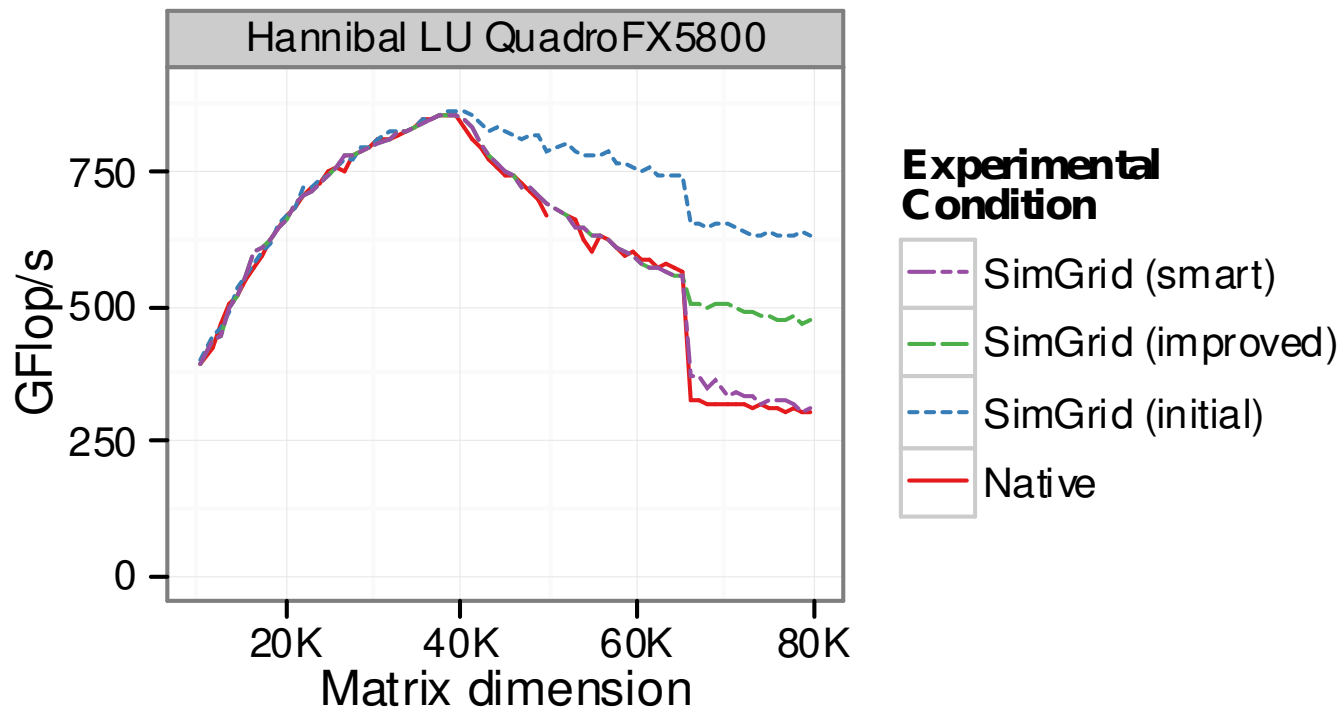


→ Update transfer performance model accordingly

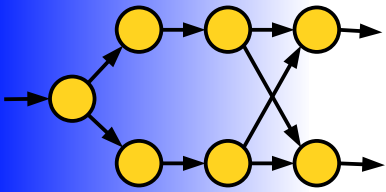


Refining data transfers

Result on LU factorization on Hannibal machine

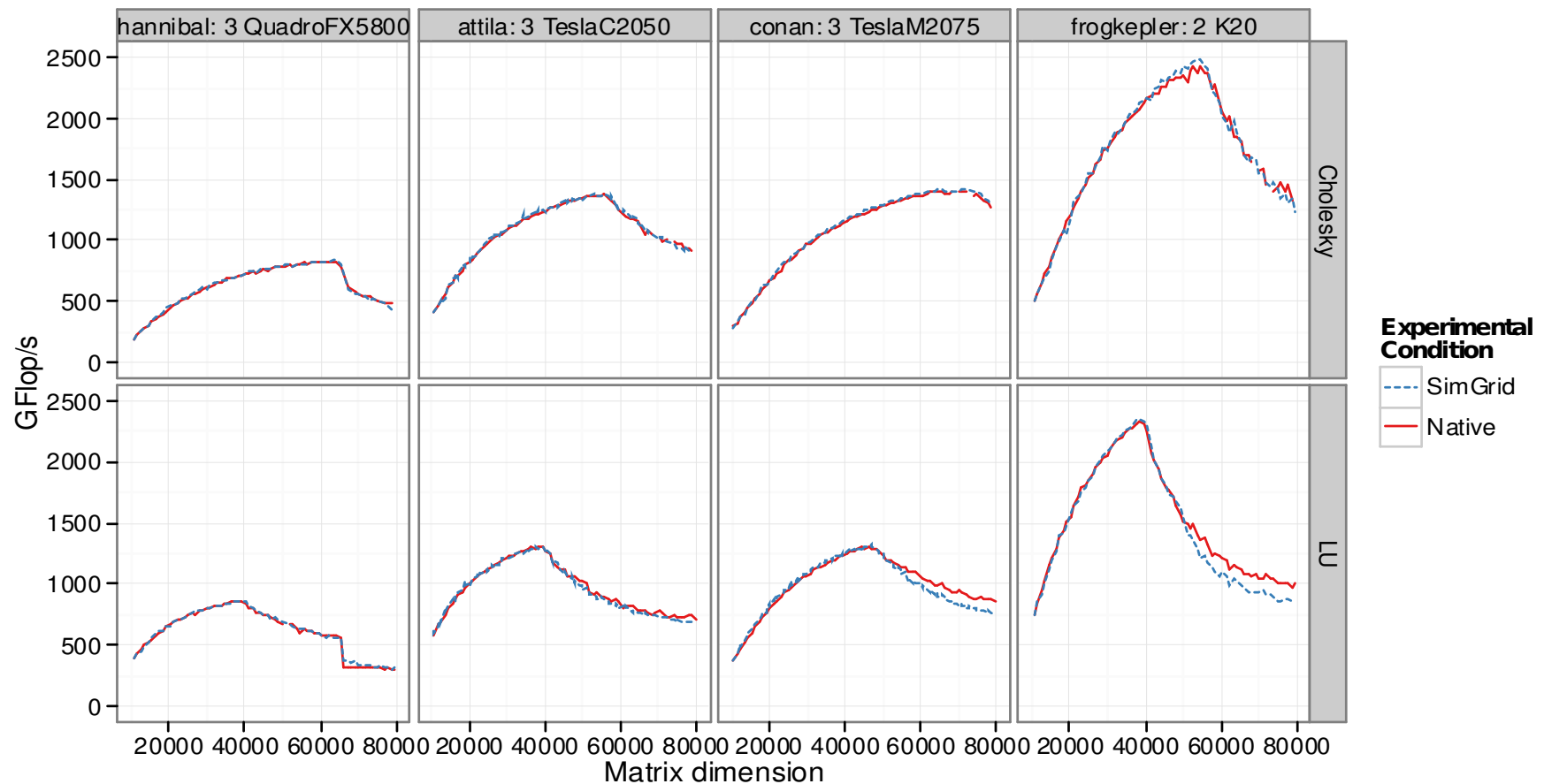


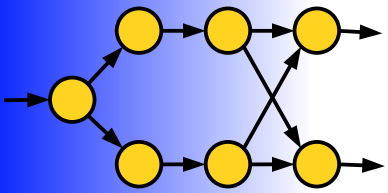
Simulation often reveals real bugs



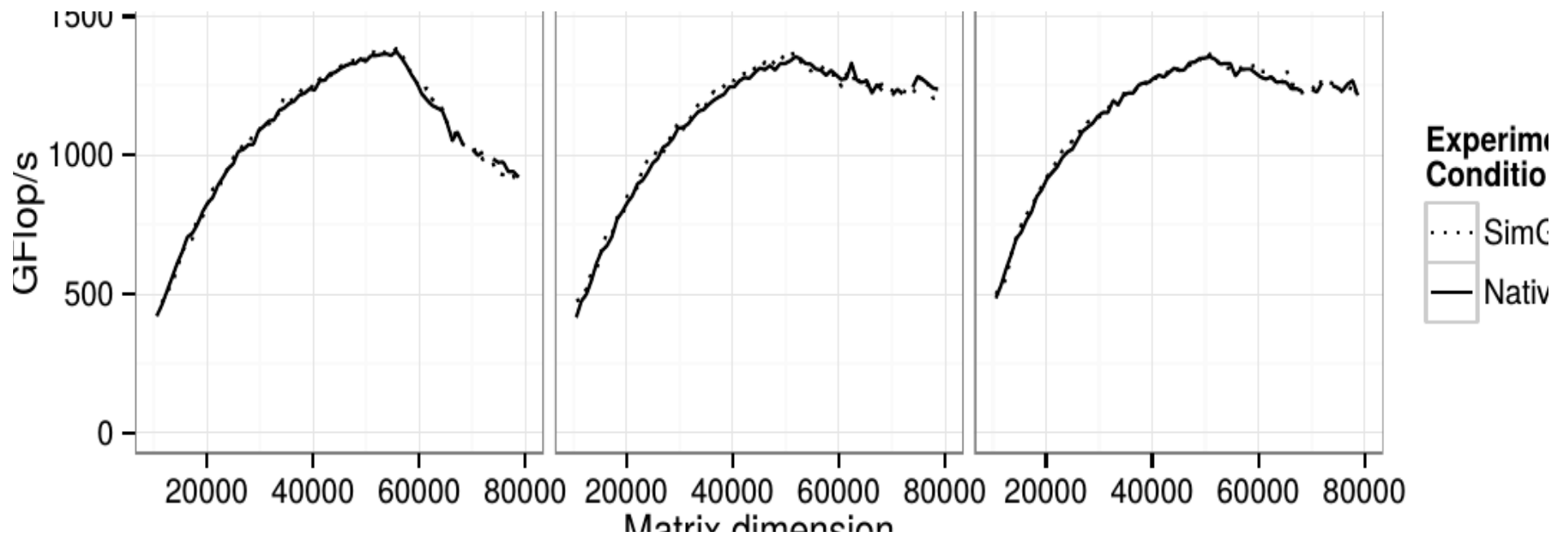
Results

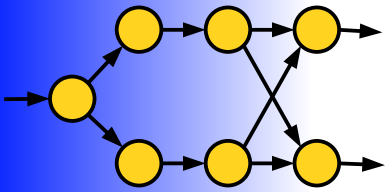
Various system, various applications



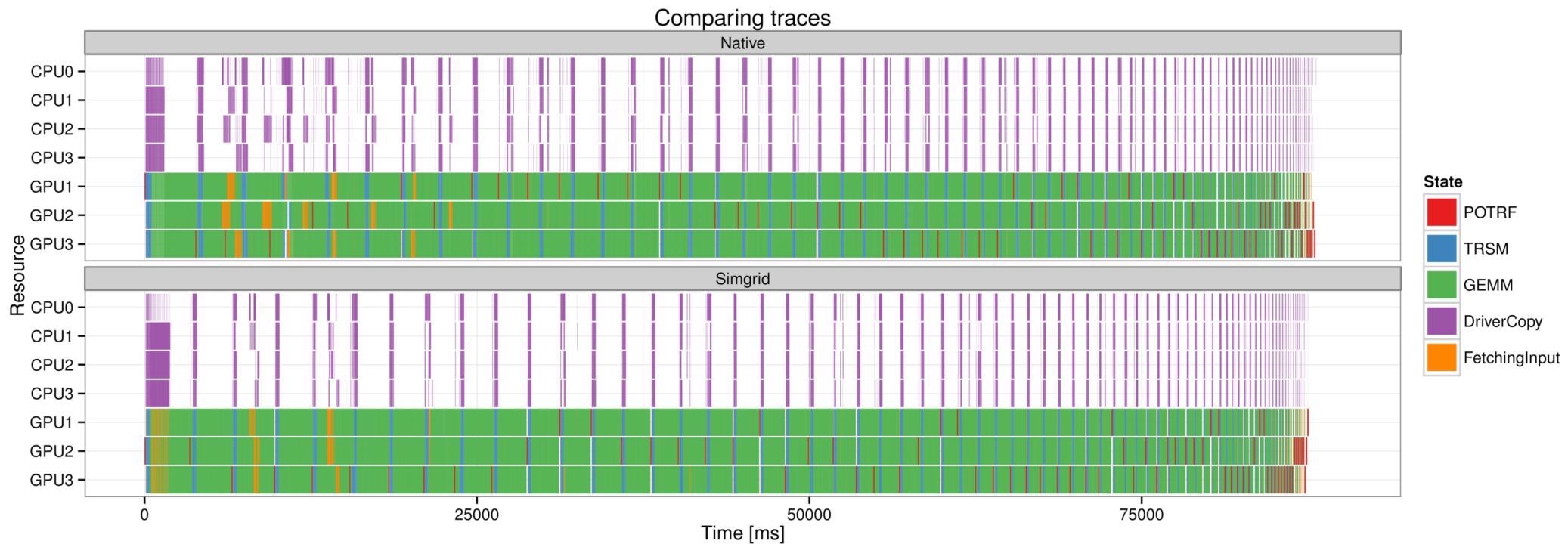


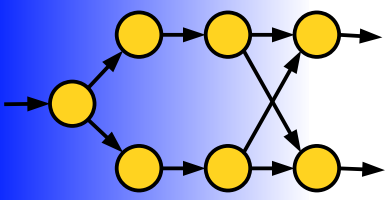
Various scheduling algorithms (Cholesky on attila)





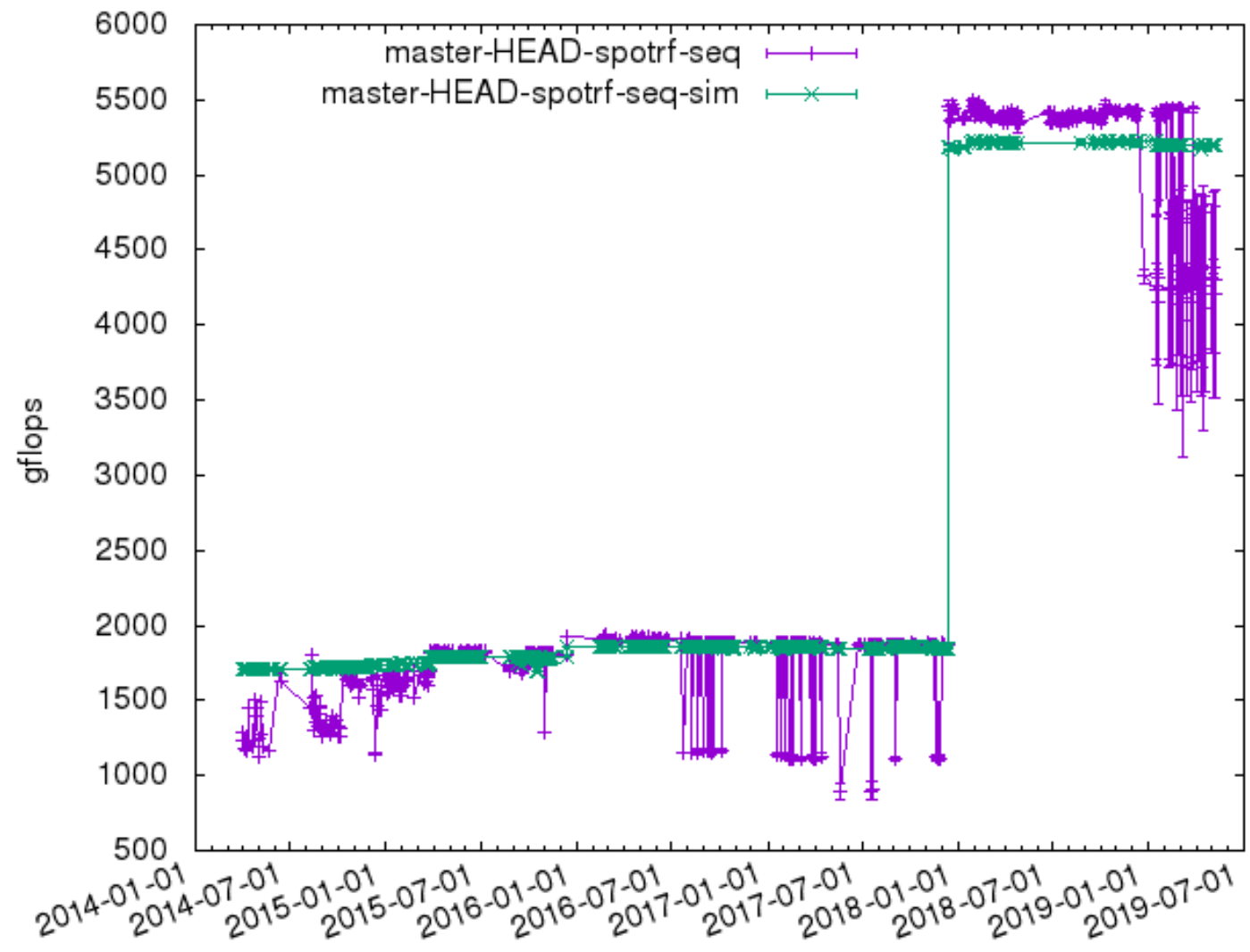
Execution behavior is representative

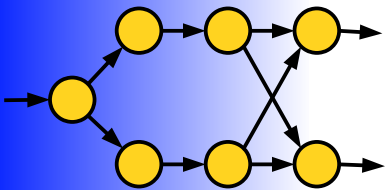




Results

More trustworthy Continuous Integration regression testing

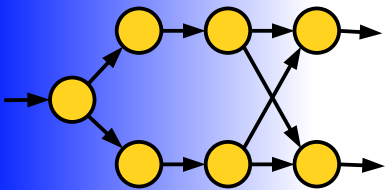




Research opportunities

Experimenting scheduling heuristics

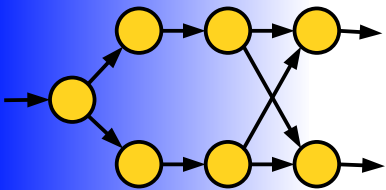
- With representative & reproducible simulated results
 - Confidence
- On various target platforms
 - Different GPU models
 - Different PCI topologies
 - ...
 - Without any platform account or CPU.hour allocation



Research opportunities

Experimenting scheduling heuristics

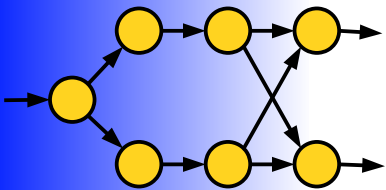
- **With tuned platform**
 - Change GPU memory size
 - Change PCI bus speed
 - Change topology (e.g. NVLink)
- **With invented platforms**
 - Assemble existing performance models
 - Different kinds of GPUs in same system
 - Or even write some
- **Could also be used for provisioning**
 - “Does this application, with 8 V100 GPUs, needs NVLink?”



Research opportunities

Experimenting scheduling heuristics

- Ignoring data transfer costs
 - Set PCI bandwidth to infinity
 - Scheduling tasks without caring about locality, as first step
- Ignoring scheduler cost
 - No need to care about efficient implementation, as first step
- Suraj Kumar's PhD thesis mostly in simulation
 - Scheduling improvements then confirmed with measurements



Research opportunities

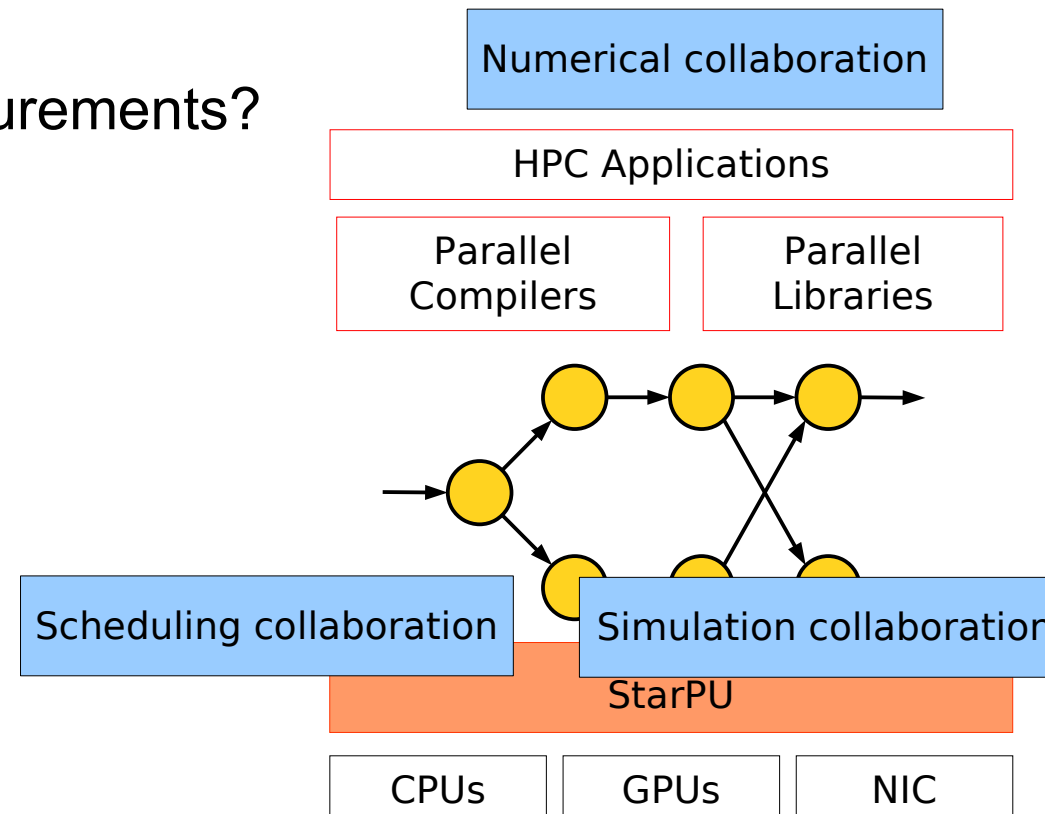
Debugging scheduling heuristics

- **Deterministic bugs**
 - Can reproduce them at will
 - Adding printf's do not change behavior
- **Breakpoint on timestamp**
 - Inspect runtime system state etc.
 - Direct link between artifact in trace and scheduling decision

Conclusion

Simulation of a runtime system

- **Trustworthy results**
 - Even more than actual measurements?
- **Playground for scheduling research**
 - Reproducibility
 - Various testcases
 - Progressive exposition of theory to practice
- **Not discussed today**
 - MPI support
 - Irregular kernel modeling



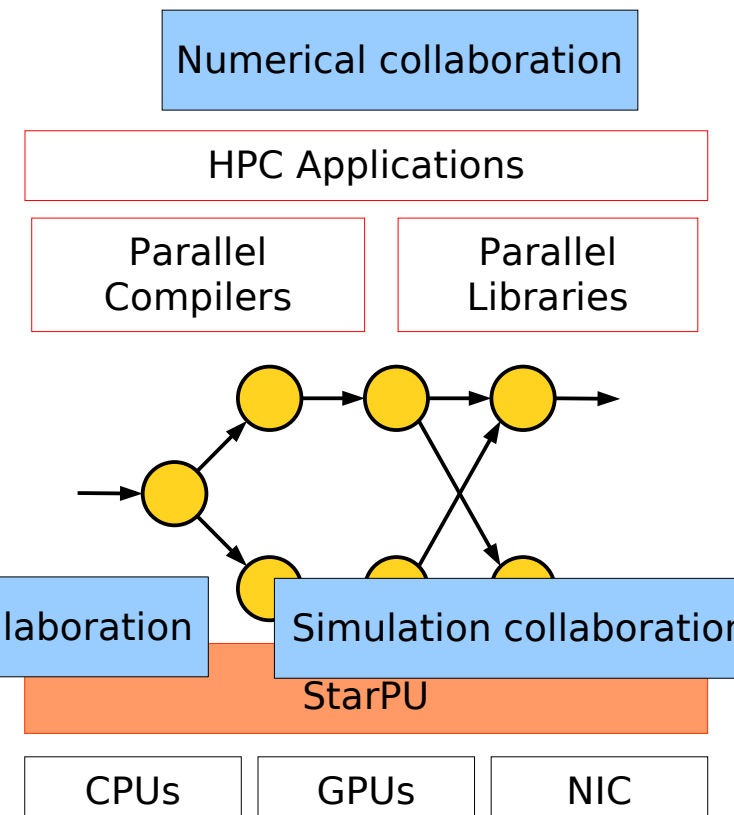
Perspectives

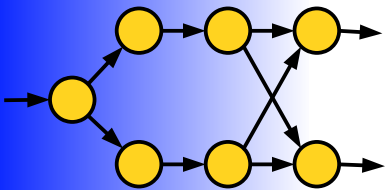
Task graph market

- Collecting application cases
- Tools to assemble synthetic systems

Refined CPU kernel modeling

- Cache effects between tasks
 - Scheduling decision thus has impact
 - Germán Ceballos PhD
- NUMA systems
 - Isolation of cache / PCI bus effect
 - Idriss Daoudi PhD

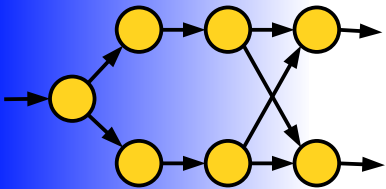


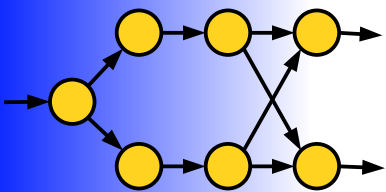


Thanks!

[AugonnetPhD11] [ArrasPhD15] [RossignonPhD15]
[SergentPhD16] [KumarPhD17] [LionPhD]

- ANR ProHMPT'09, MEDIAGPU'10, FP3C'10, SONGS'12, SOLHAR'13
- IPL HAC-SPECIS'16, HPC-BigData'18
- EU PEPPER'10, EXA2PRO'18
- Rapid Hi-BOX'13
- MORSE associate-team
- Used by AL4SAN, Chameleon, ExaGeoStat, FLUSEPA, HiCMA, hmat, KSVD, MAGMA, MaPHyS, MOAO, PaStiX, QDWH, qr_mumps, ScalFMM, SCHNAPS, SignalPU, SkePU, STARS-H





Performance models - MultiLinear

- Theoretical complexity of BLAS GEQRT

$$T_{\text{GEQRT}} = a + 2b(NB^2 \times MB) - 2c(NB^3 \times BK) + \frac{4d}{3}NB^3$$

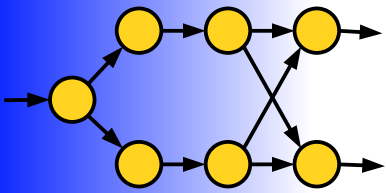
- Can tune a, b, c, d with linear regression
- Why these $NB^2 \times MB$, $NB^3 \times BK$ and NB^3 parameters ?

	GEQRT Duration		
Constant	-2.49×10^1	$(-2.83 \times 10^1, -2.14 \times 10^1)$	***
$NB^2 \times MB$	5.49×10^{-7}	$(5.46 \times 10^{-7}, 5.51 \times 10^{-7})$	***
$NB^3 \times BK$	-5.52×10^{-7}	$(-5.57 \times 10^{-7}, -5.48 \times 10^{-7})$	***
NB^3	1.50×10^{-5}	$(1.30 \times 10^{-5}, 1.70 \times 10^{-5})$	***
Observations			493
R^2			0.999

Note:

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

- Works well with regular kernels



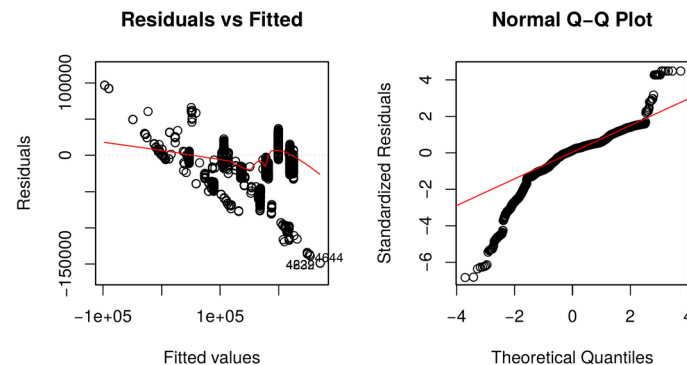
Performance models - ScalFMM

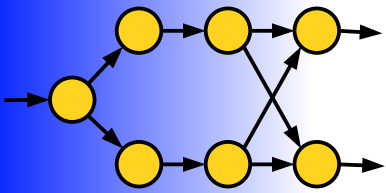
- Initial attempt with direct parameters

<i>TreeLevel</i>	7.73×10^1 (7.32×10^1 , 8.14×10^1)	***
<i>NbCells</i>	1.52×10^2 (1.46×10^2 , 1.59×10^2)	***
<i>IntervalSize</i>	-5.55×10^{-1} (-6.65×10^{-1} , -4.45×10^{-1})	***
<i>TreeLevel</i> ²	-6.73 (-7.10 , -6.37)	***
<i>NbCells</i> ²	-6.08×10^{-3} (-7.94×10^{-3} , -4.21×10^{-3})	***
<i>IntervalSize</i> ²	-3.63×10^{-12} (-6.36×10^{-12} , -9.04×10^{-13})	***
<i>TreeLevel</i> × <i>NbCells</i>	-4.68 (-5.88 , -3.48)	***
<i>TreeLevel</i> × <i>IntervalSize</i>	6.24×10^{-2} (5.02×10^{-2} , 7.46×10^{-2})	***
<i>NbCells</i> × <i>IntervalSize</i>	1.81×10^{-4} (1.39×10^{-4} , 2.24×10^{-4})	***
<i>TreeLevel</i> × <i>NbCells</i> × <i>IntervalSize</i>	-2.08×10^{-5} (-2.55×10^{-5} , -1.61×10^{-5})	***
Constant	-2.27×10^2 (-2.40×10^2 , -2.14×10^2)	***
Observations		4,987
<i>R</i> ²		0.906

Note:

*p<0.1; **p<0.05; ***p<0.01





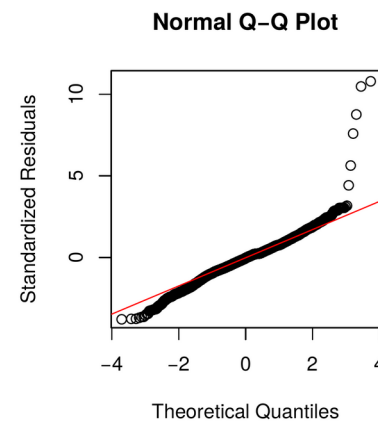
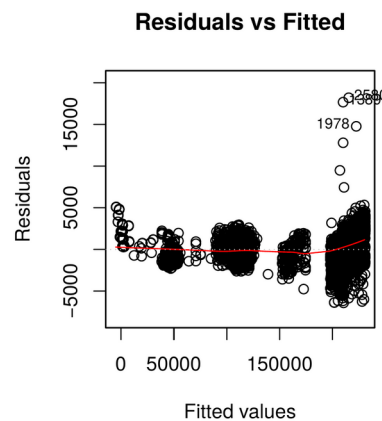
Performance models - ScalFMM

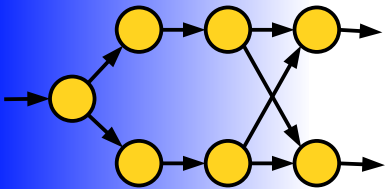
- Introduce NbInteraction parameter

<i>TreeLevel</i>	9.10×10^2	$(8.46 \times 10^2, 9.74 \times 10^2)$	***
<i>NbCells</i>		5.34 (5.17, 5.50)	***
<i>NbInteractions</i>	8.59×10^{-1}	$(8.58 \times 10^{-1}, 8.60 \times 10^{-1})$	***
Constant		-7.09 (-7.50, -6.67)	***
Observations			4,987
R^2			0.999

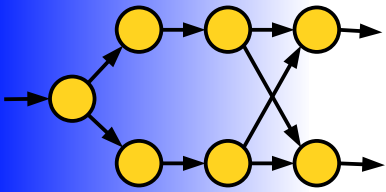
Note:

*p<0.1; **p<0.05; ***p<0.01

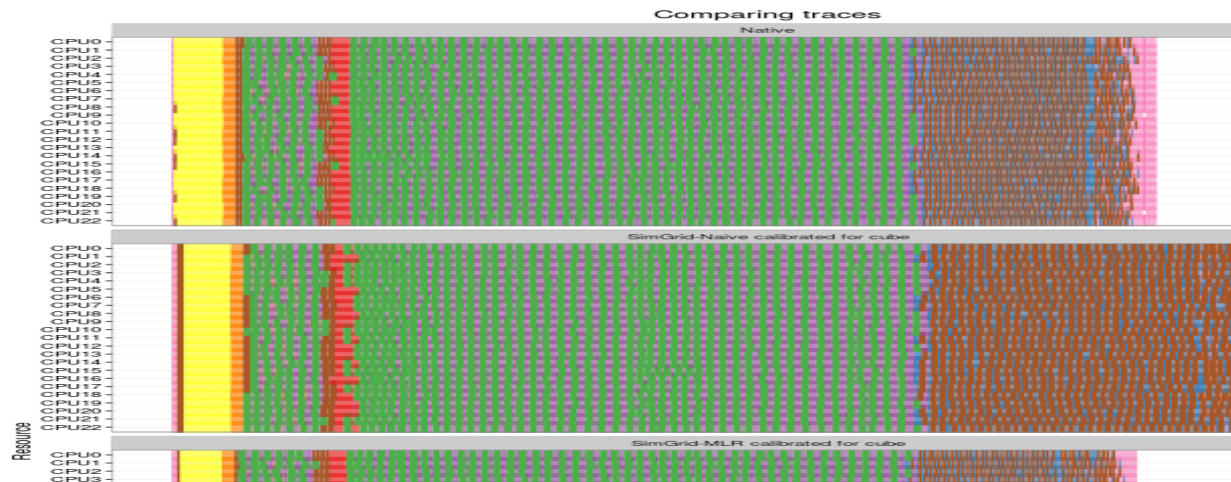


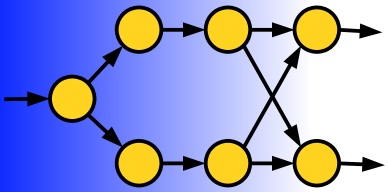


Performance models - ScalFMM



Performance models - ScalFMM





Performance models - ScalFMM