StarPU a runtime system for Scheduling Tasks, *or* How to get portable performance on accelerator-based platforms without the agonizing pain

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Once upon a time in computer architecture ...

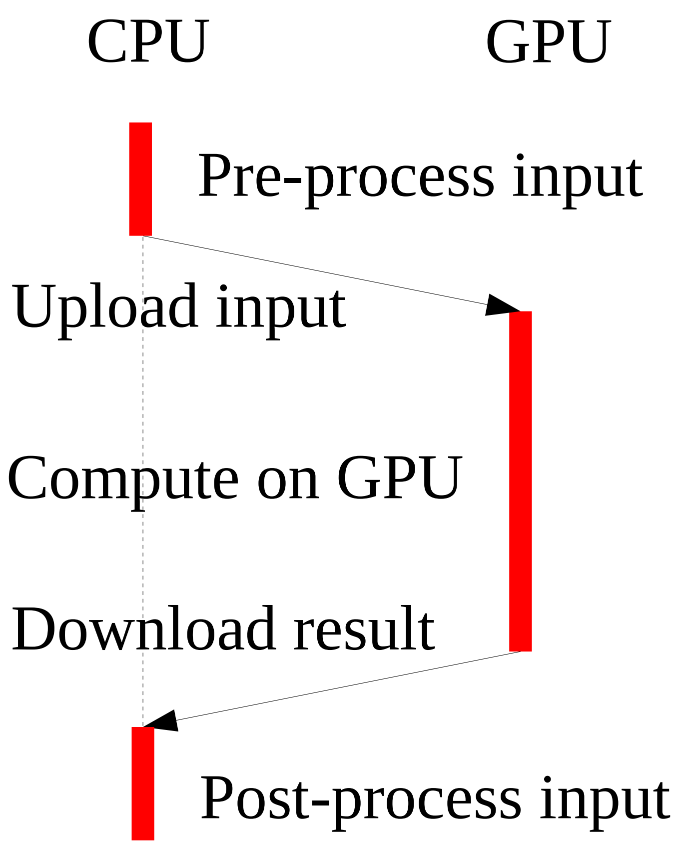
Introduction
Programming Accelerator-based machines

- Prehistory (<2007)
  - SMP machines (1960s !)
  - NUMA architectures (1970s)
  - Vector machines (1980s-90s)
  - Multicore chips (2000s)

- GPGPU for masses ? (from 2007)
  - CPUs are now deprecated ?
  - Rewrite all codes for accelerators
  - Pure offloading model

Introduction
Programming Accelerator-based machines

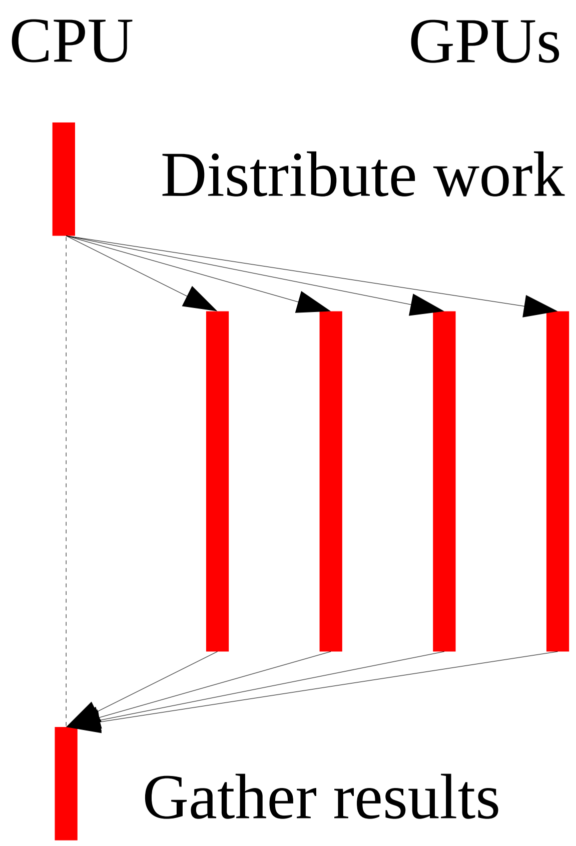
- Pure offloading model
    - CUDA 1.x (2007 – 2008)
        - Synchronous cards
    - Ignore CPUs
    - Concentrate on efficient kernels
        - Complex memory accesses
        - CUDA heros (eg. V.Volkov)
    - Port standard libraries to CUDA
        - CUBLAS
        - CUFFT
        - GPUCV...



Introduction

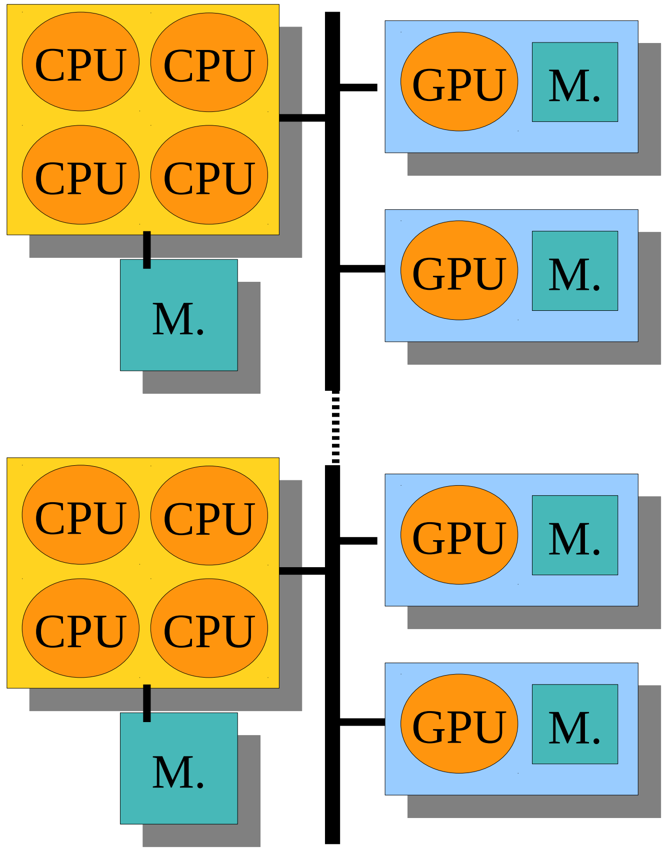
Programming Accelerator-based machines

- Multi-GPU era
  - CUDA 2.x (2008 – 2009)
    - Asynchronous transfers
    - S1070 servers
  - Still Ignore CPUs (in general)
  - Suitable for regular applications
    - Massively parallel problems
    - Use previously written kernels
  - New problems
    - Parallel programming for real
    - PCI bus = bottleneck
    - Pre/Post-processing is costly



Introduction
Programming Accelerator-based machines

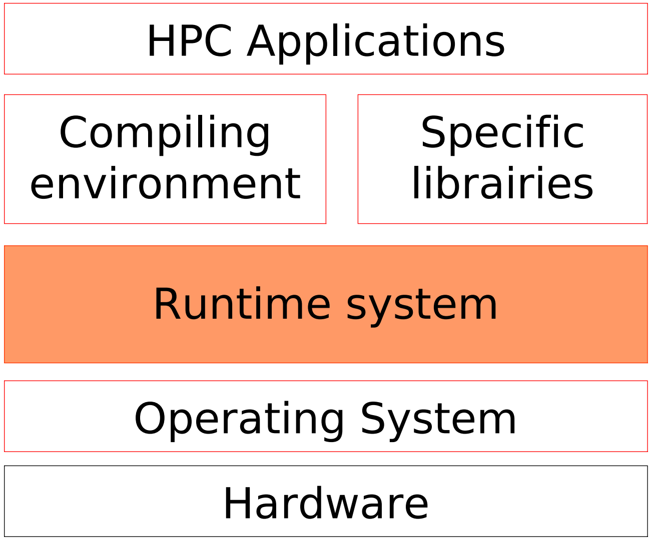
- GPU computing era
  - CUDA 3.x (2009 – ?)
    - End of GPGPU
    - Hybrid machines
  - Tightly coupled CPUs and GPUs
    - Take advantage of all ressources
    - MUCH more complicated
  - Load balancing
    - Who does what ?
    - Heterogeneous capabilities
  - Data management
    - Numerous data transfers
    - Fully asynchronous model



Introduction

Challenging issues at all stages

- Applications
  - Programming paradigm
  - BLAS kernels, FFT, …
- Compilers
  - Languages
  - Code generation/optimization
- Runtime systems
  - Resources management
  - Task scheduling
- Architecture
  - Memory interconnect



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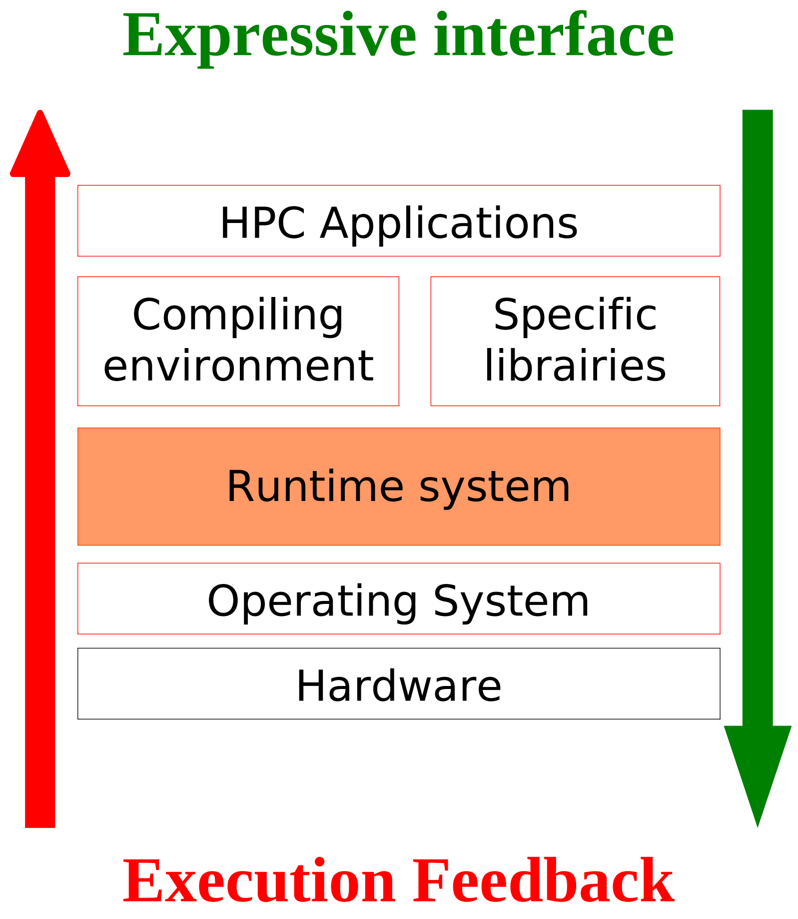


Outline

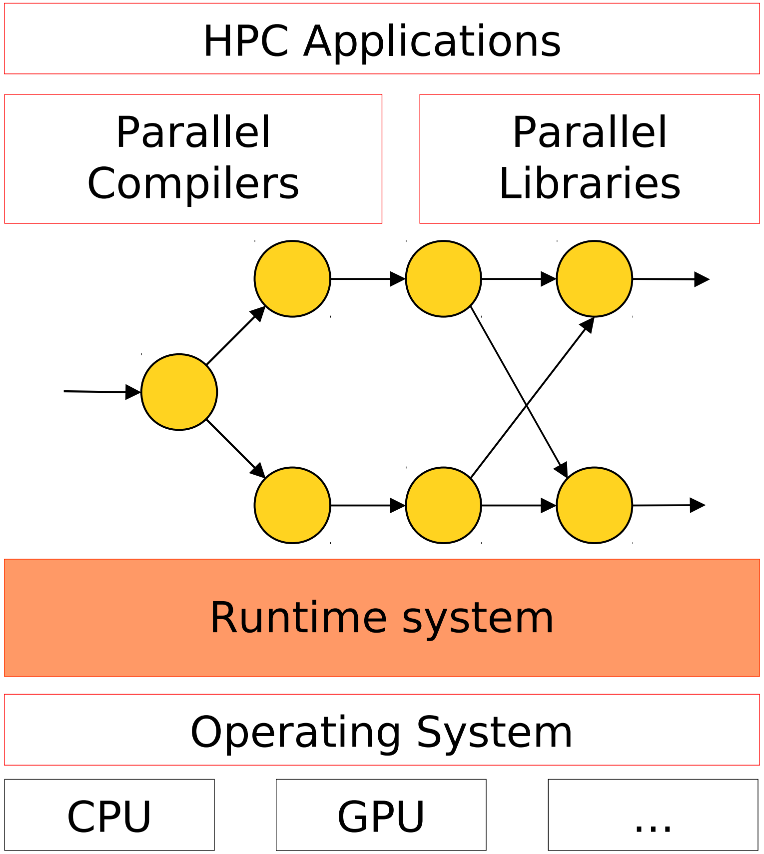
- The StarPU runtime system
- Task Scheduling
  - Load balancing
  - Improving data locality
- Evaluation on dense linear algebra algorithms
  - Synthetic “LU” decomposition
  - Mixing PLASMA and MAGMA (Cholesky & QR)
- Scheduling parallel tasks
- Adding support for MPI in StarPU

The StarPU runtime system

The StarPU runtime system

The need for runtime systems

- “do dynamically what can’t be done statically anymore”
- Library that provides
  - Task scheduling
  - Memory management
- Compilers and libraries generate (graphs of) parallel tasks
  - Additional information is welcome!

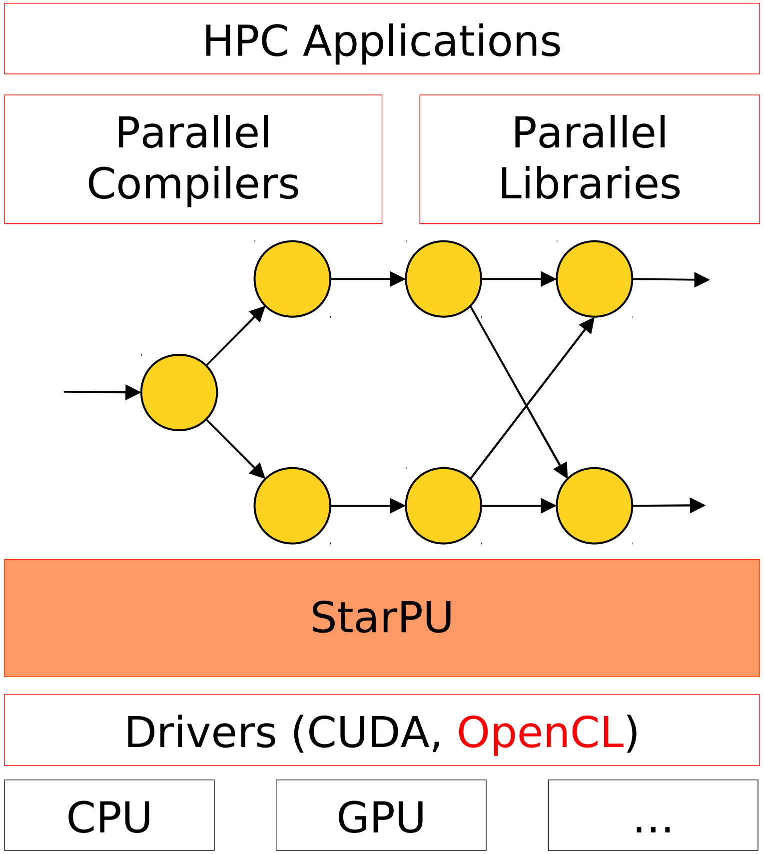


The StarPU runtime system

Data management library

- StarPU provides a Virtual Shared Memory subsystem
    - Weak consistency
    - Replication
    - Single writer
    - High level API
        - Partitioning filters

- Input & ouput of tasks = reference to VSM data

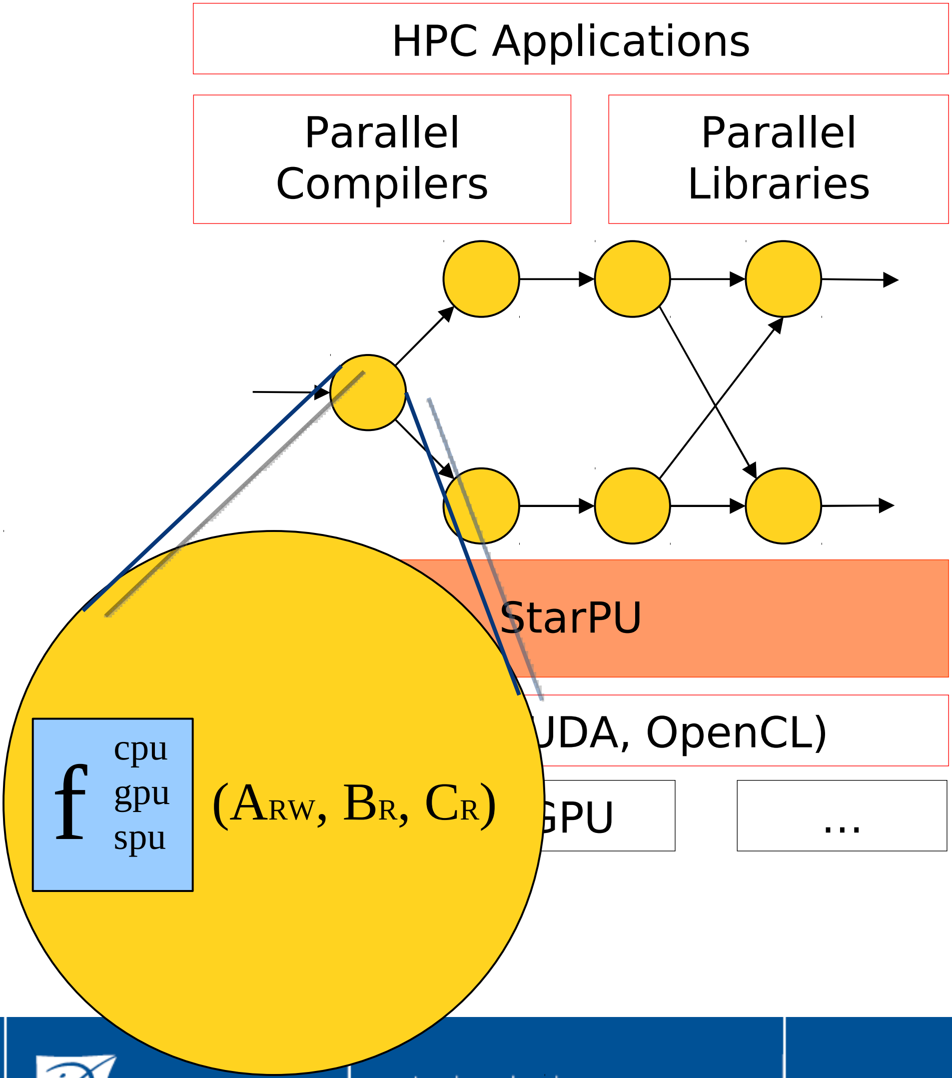


The StarPU runtime system

Task scheduling

- Tasks =
  - Data input & output
    - Reference to VSM data
  - Multiple implementations
    - E.g. CUDA + CPU implementation
  - Dependencies with other tasks
  - Scheduling hints

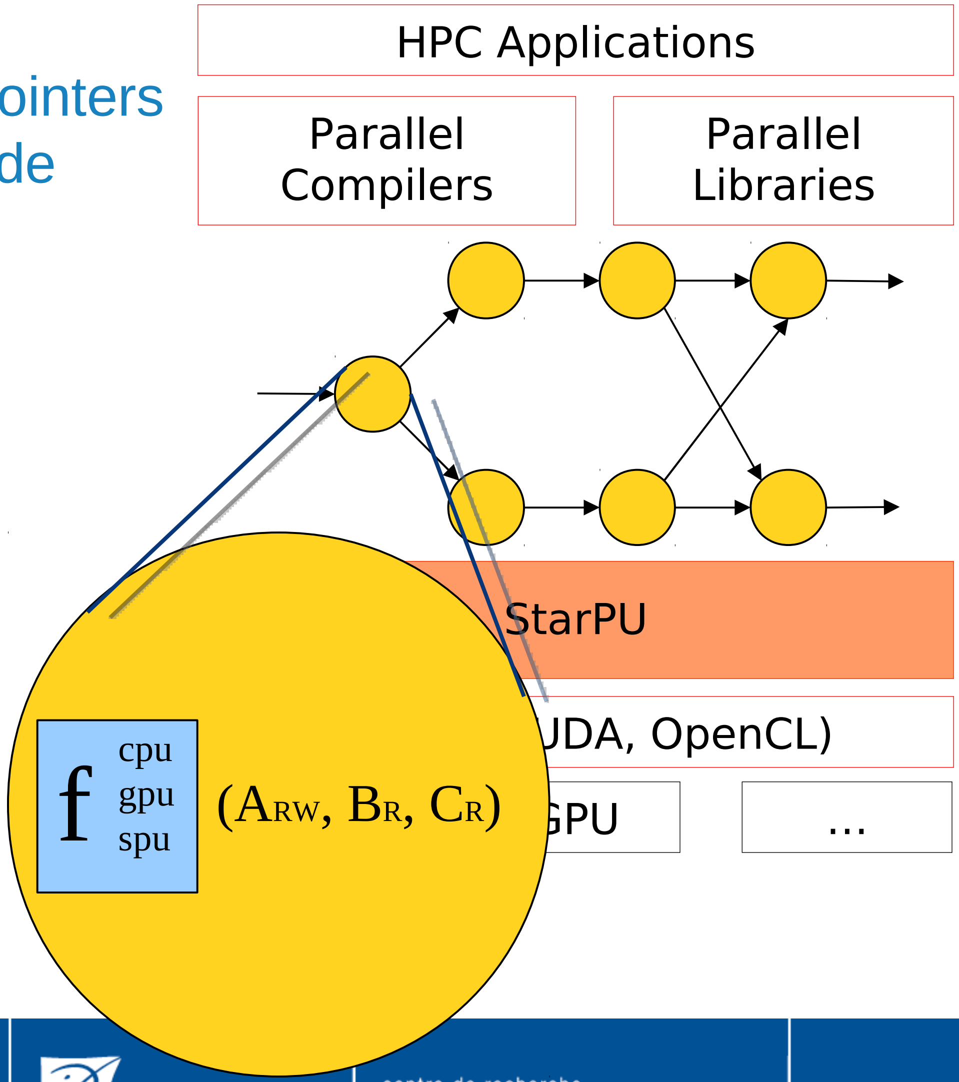
- StarPU provides an Open Scheduling platform
  - Scheduling algorithm = plug-ins



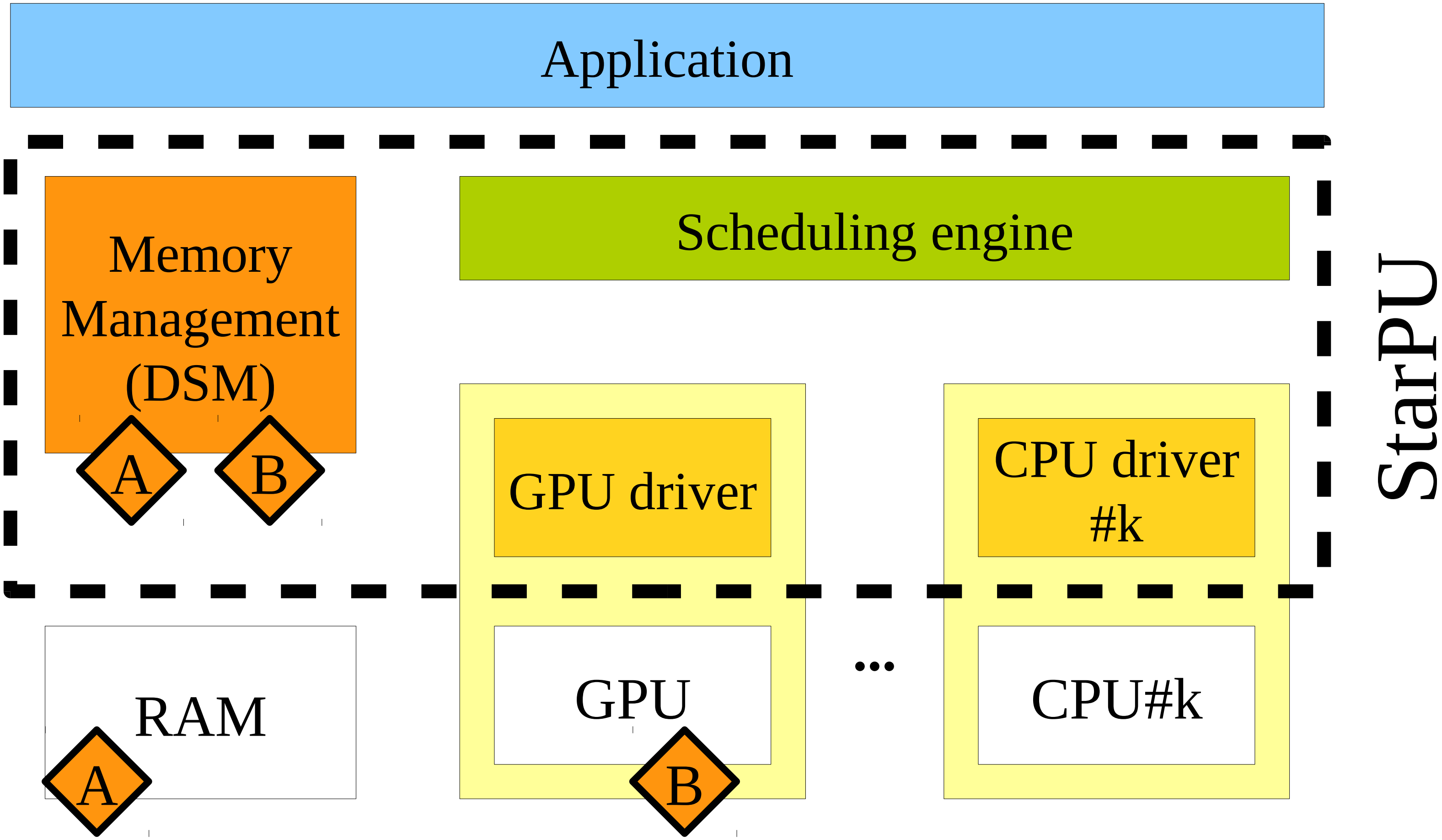
The StarPU runtime system

Task scheduling

- Who generates the code ?
  - StarPU Task = ~function pointers
  - StarPU don't generates code
- Programming heros ?
- Libraries era
  - PLASMA + MAGMA
  - FFTW + CUFFT...
- Rely on compilers
  - PGI accelerators
  - CAPS HMPP...



The StarPU runtime system
Execution model



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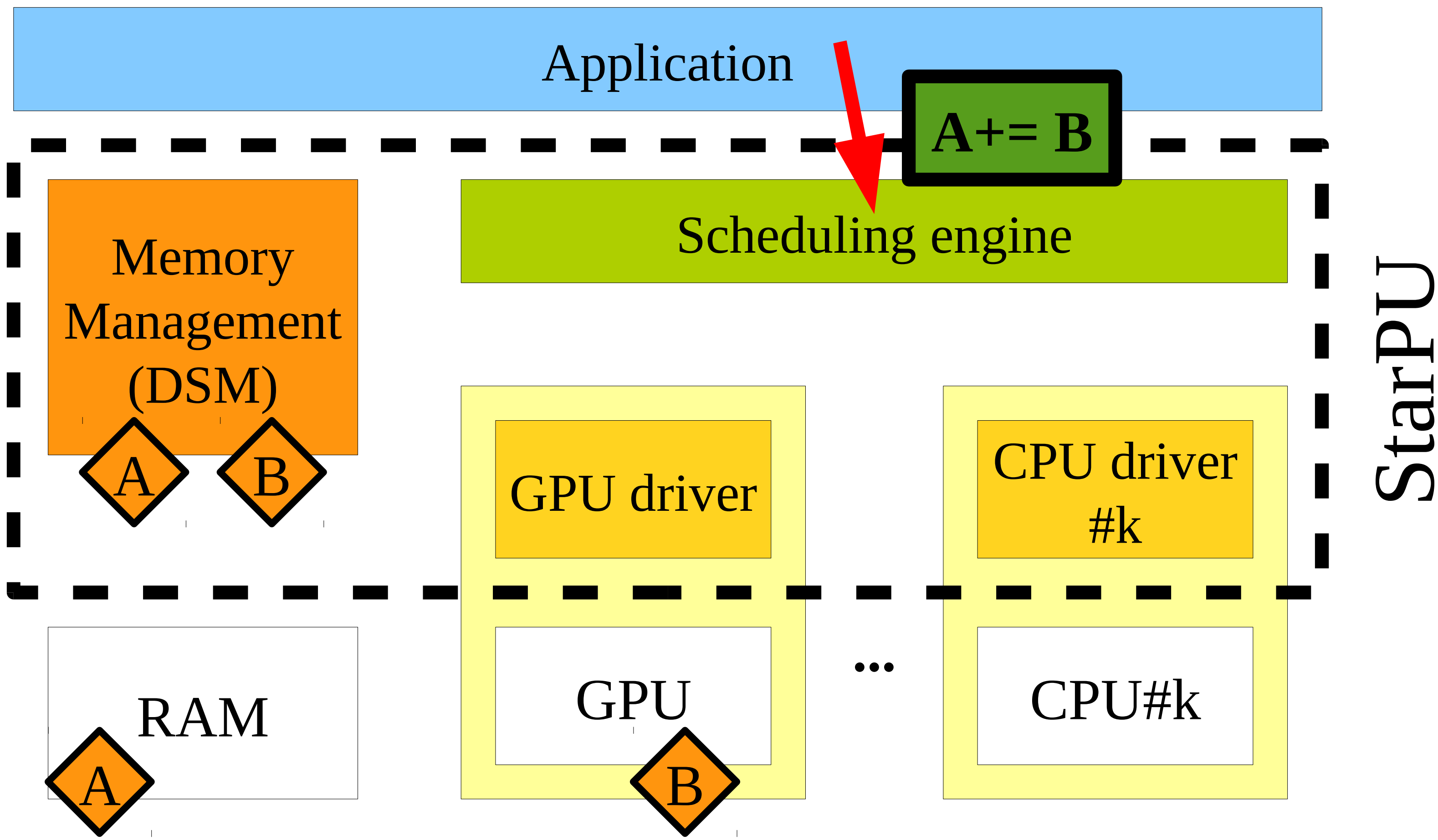
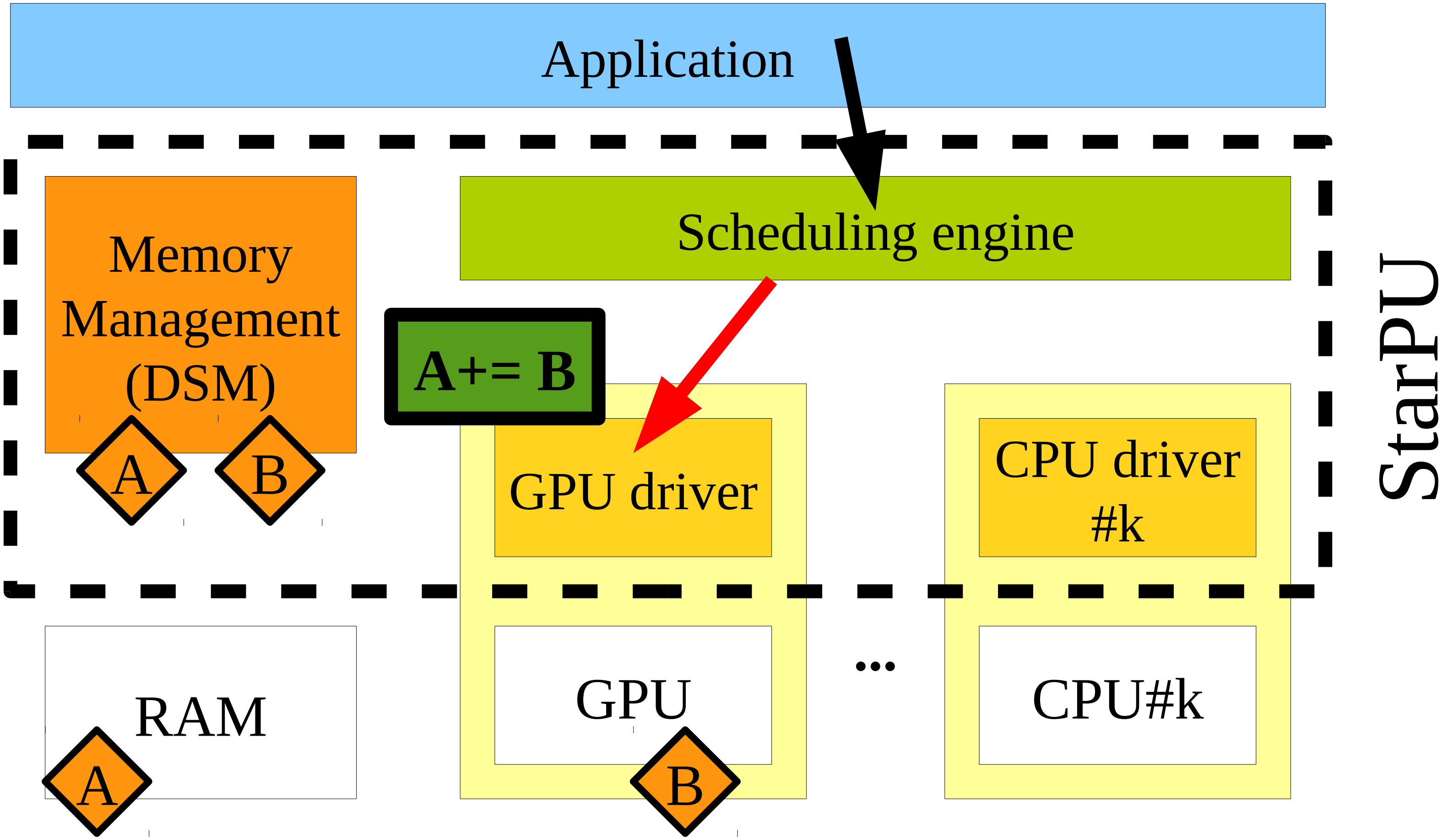


Submit task « A += B »

The StarPU runtime system

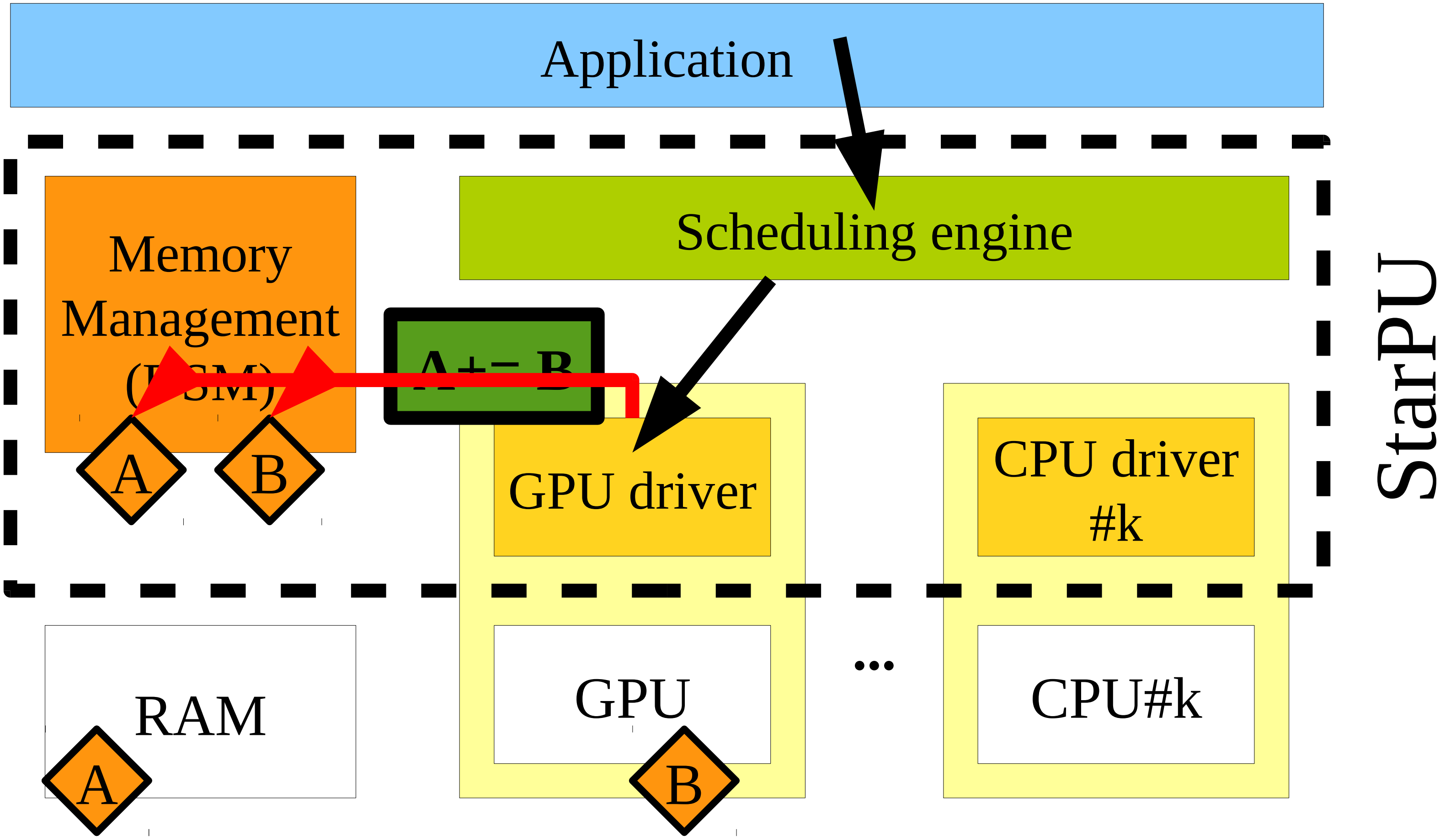
Execution model



Schedule task

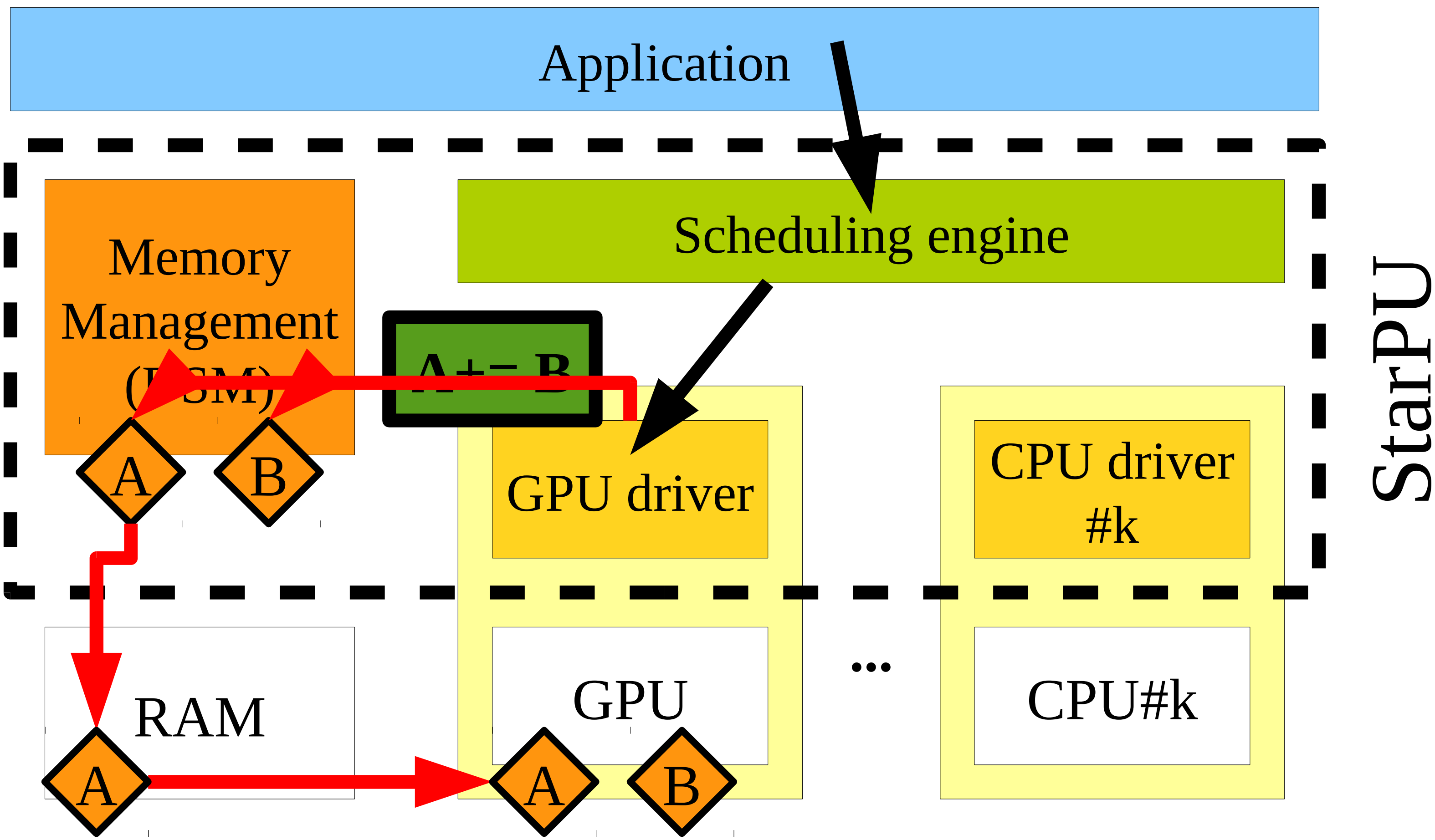
The StarPU runtime system

Execution model



Fetch data

The StarPU runtime system
Execution model



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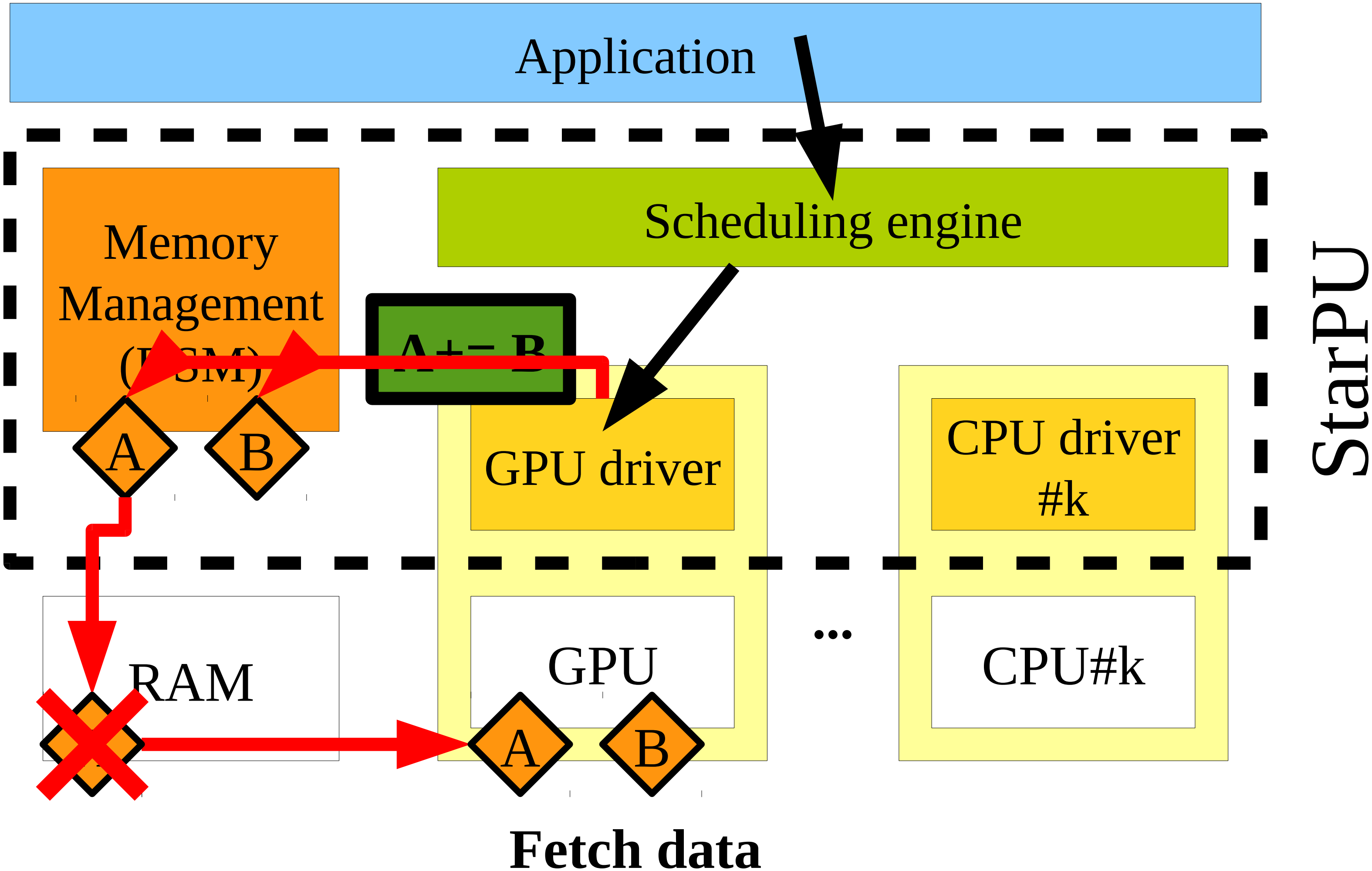

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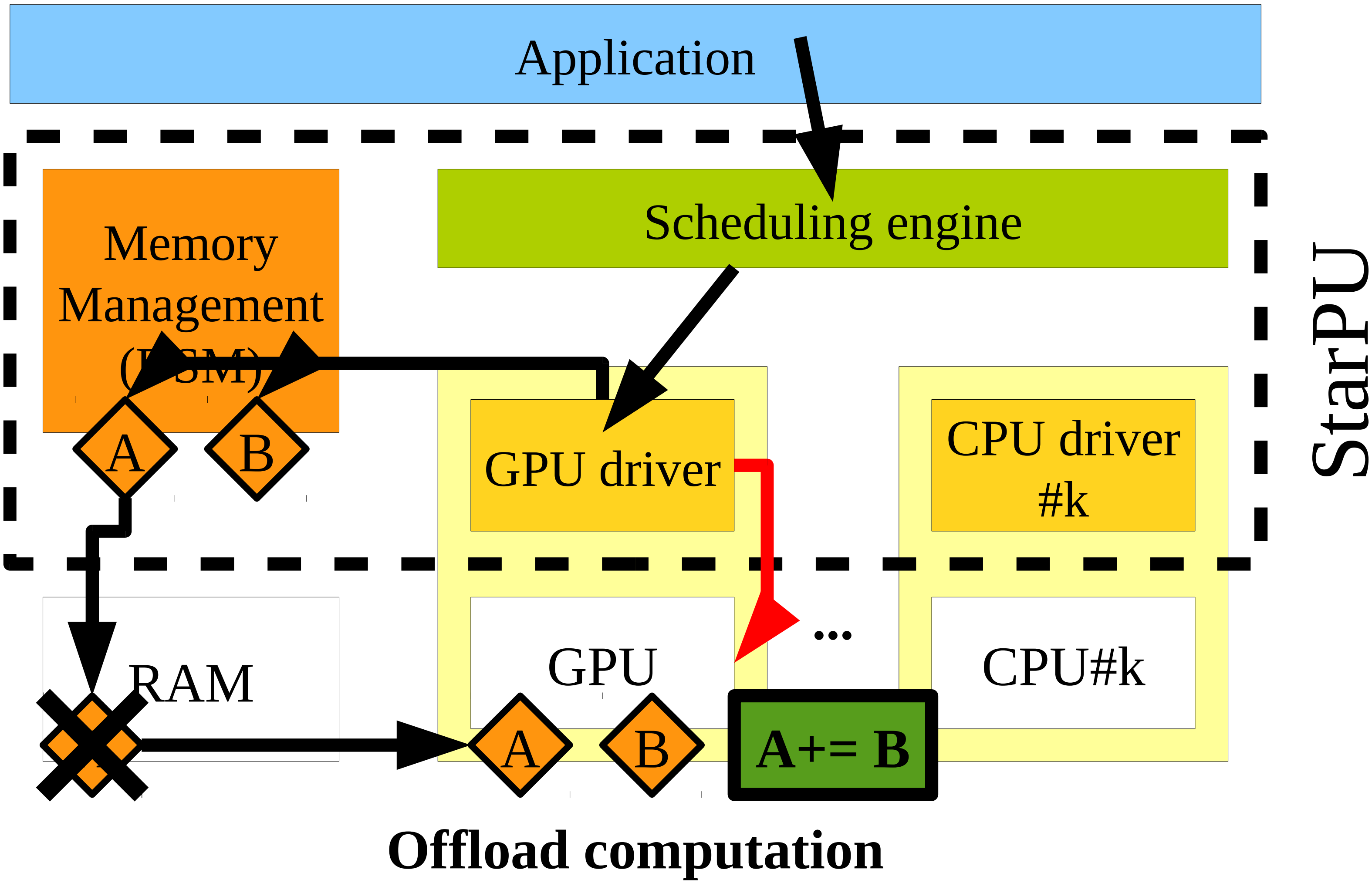

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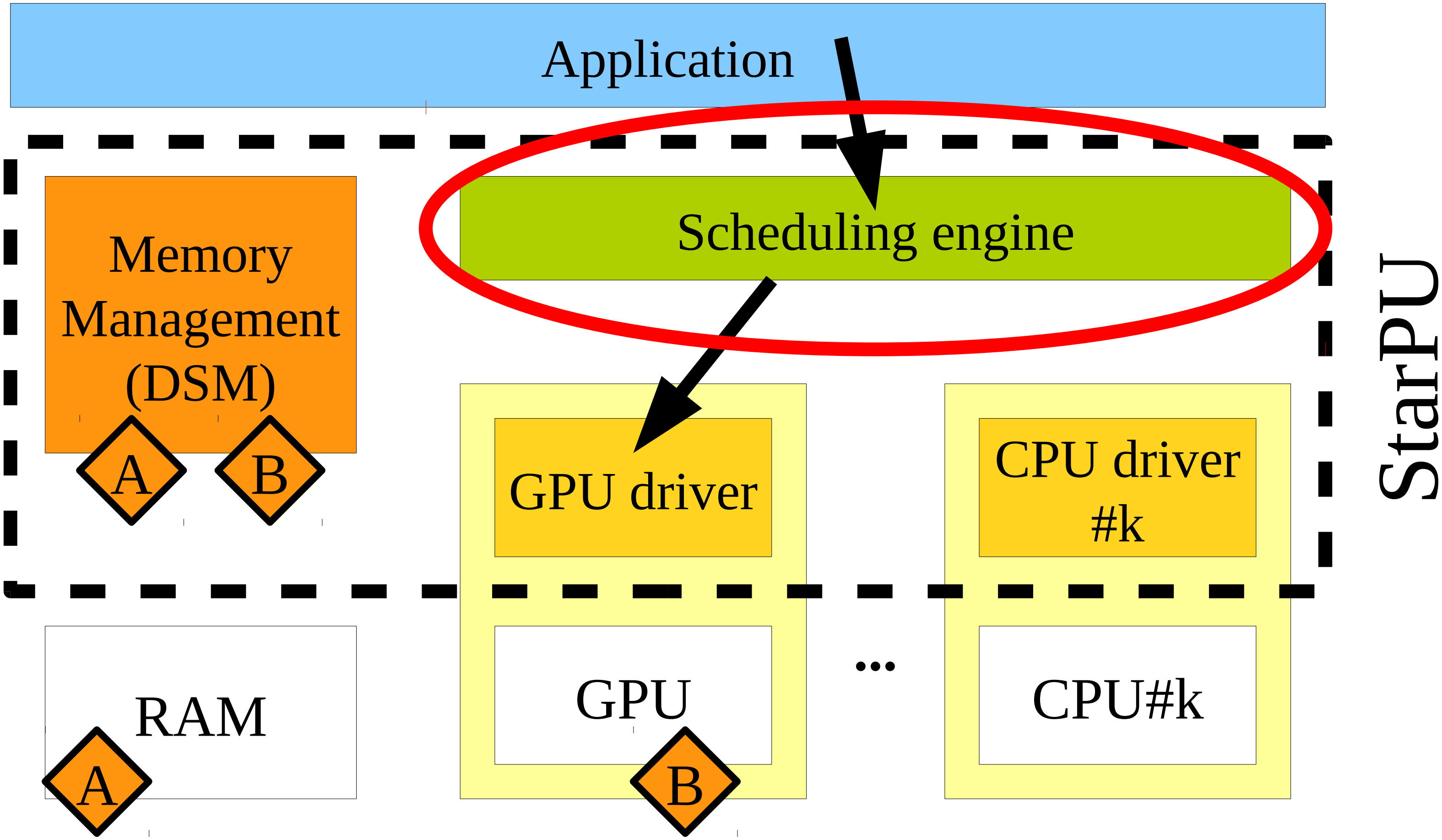


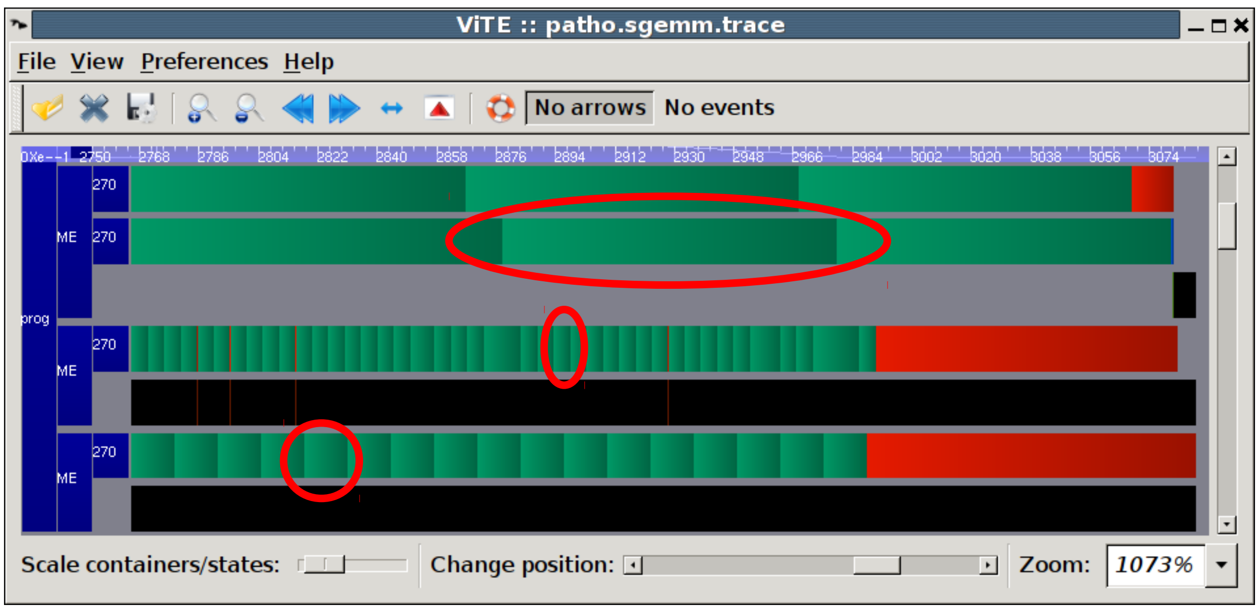
Task Scheduling

Why do we need task scheduling ?

Blocked Matrix multiplication

Things can go (really) wrong even on trivial problems !

- Static mapping ?
  - Not portable, too hard for real-life problems
- Need Dynamic Task Scheduling
  - Performance models



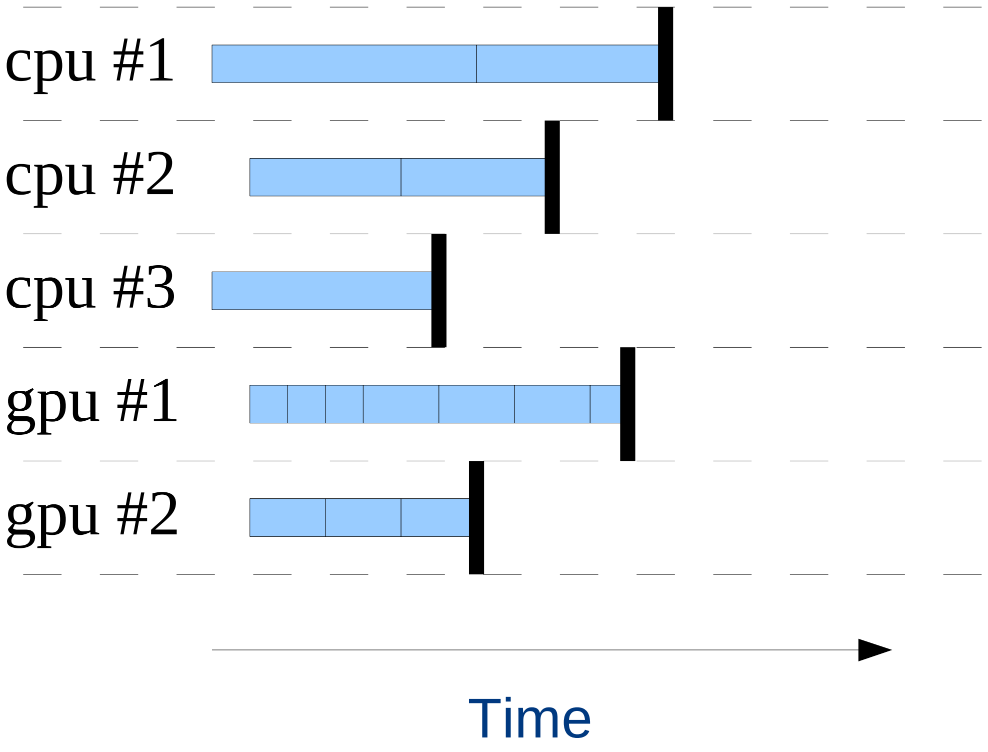
2 Xeon cores

Quadro FX5800

Quadro FX4600

Predicting task duration
Load balancing

- Task completion time estimation
  - History-based
  - User-defined cost function
  - Parametric cost model
- Can be used to improve scheduling
  - E.g. Heterogeneous Earliest Finish Time



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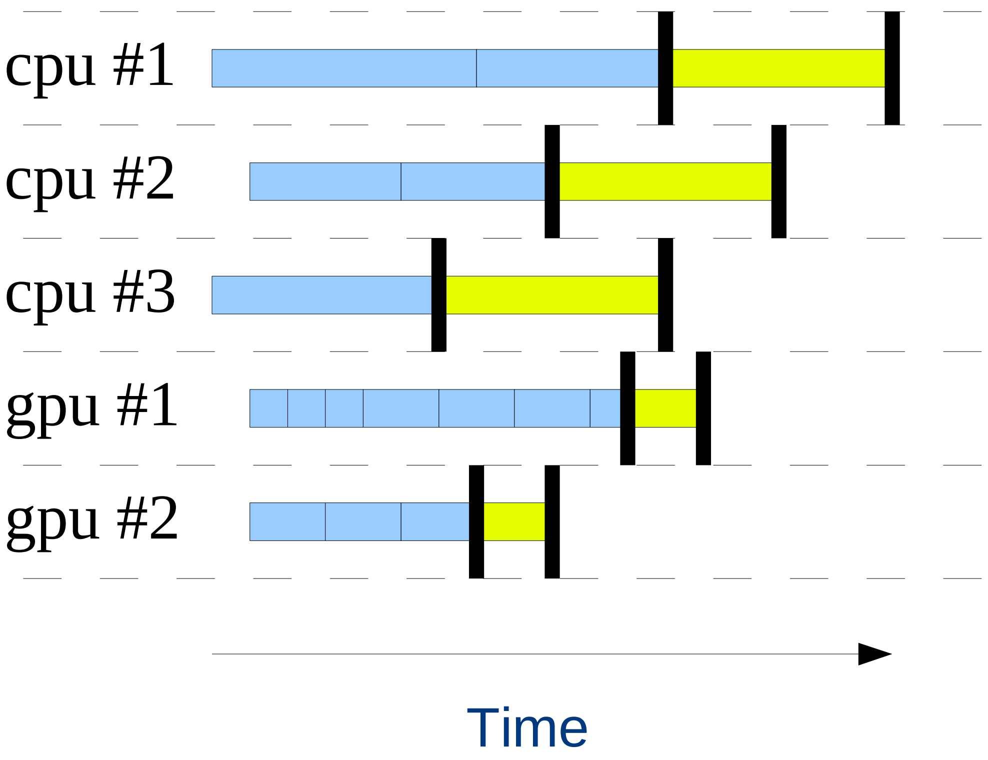

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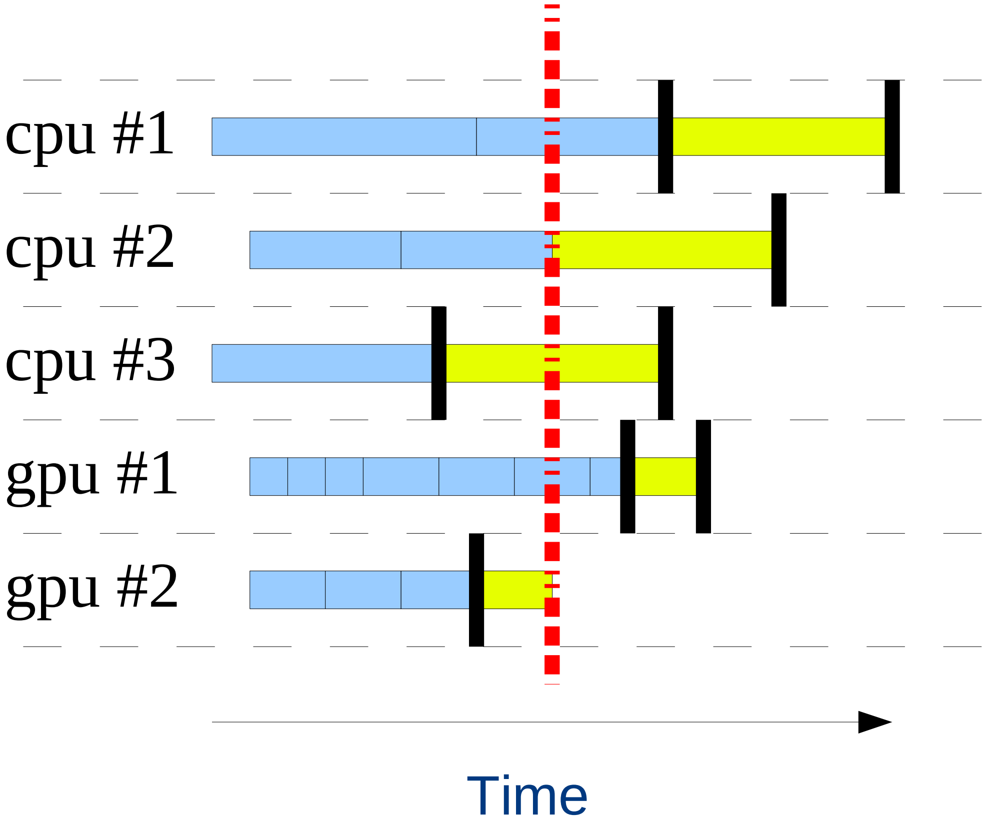

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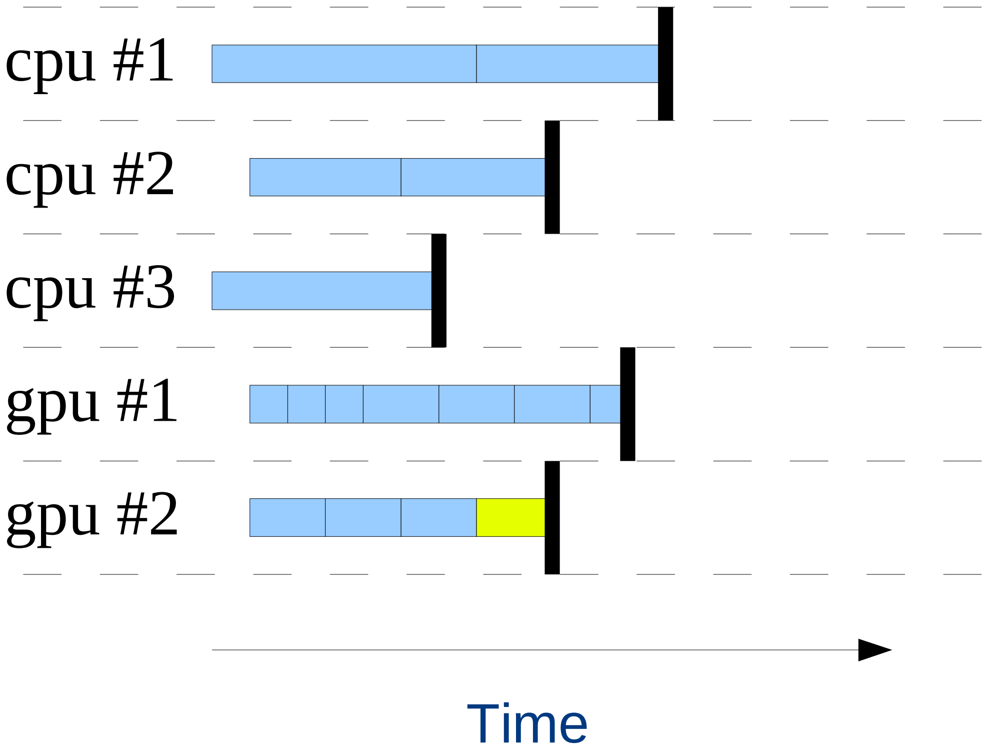
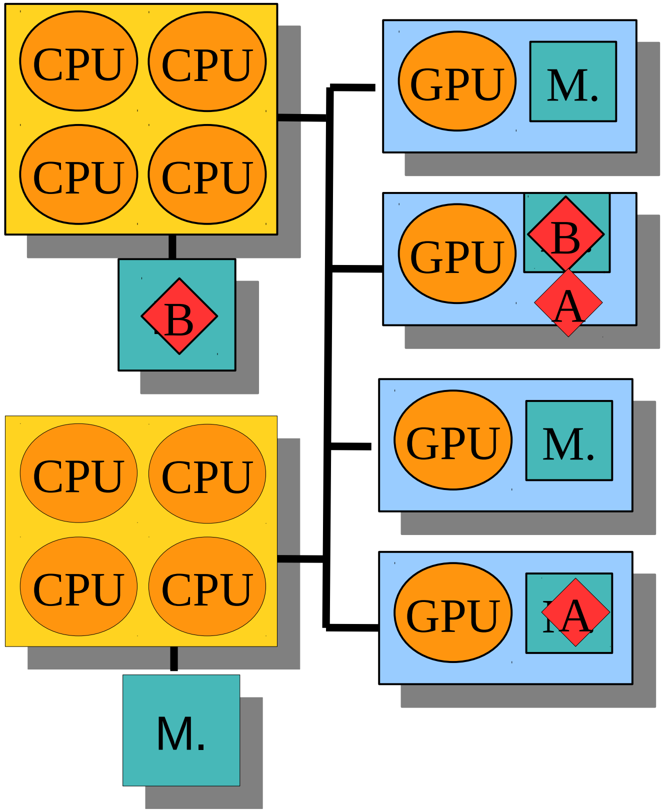


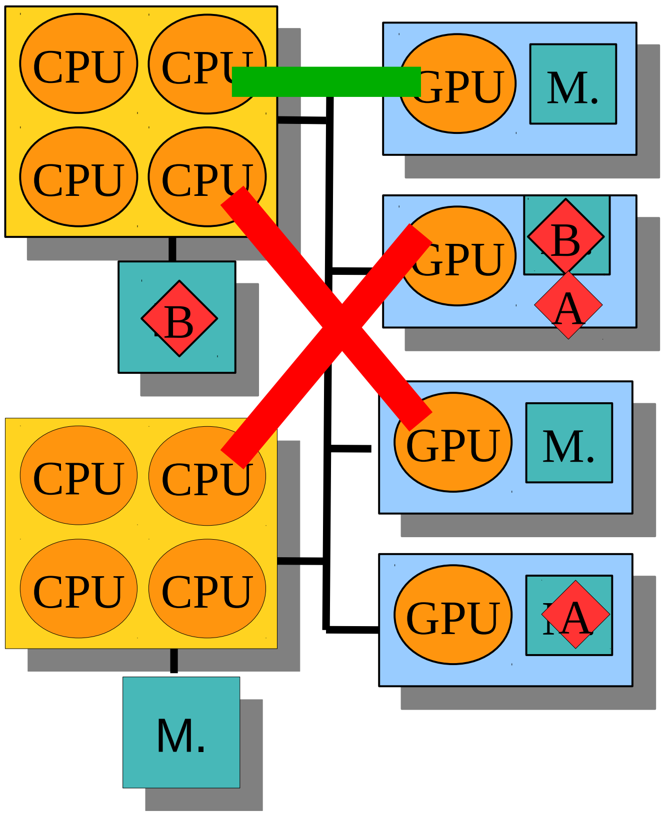
Predicting data transfer overhead
Motivations

- Hybrid platforms
  - Multicore CPUs and GPUs
  - PCI-e bus is a precious ressource
- Data locality vs. Load balancing
  - Cannot avoid all data transfers
  - Minimize them
- StarPU keeps track of
  - data replicates
  - on-goig data movements



Predicting data transfer overhead
Offline bus benchmarking

- Offline bus benchmarking
  - When StarPU is launched for the first time
  - Measure bandwidth and latency
    - Stored as files
  - Loaded when StarPU is initialized



- Detect CPU/GPU affinity
  - Control a GPU from the closest CPU
  - Significant impact on bus usage

- Straightforward cost prediction
  - Latency + size * bandwidth
  - Could be improved in many ways

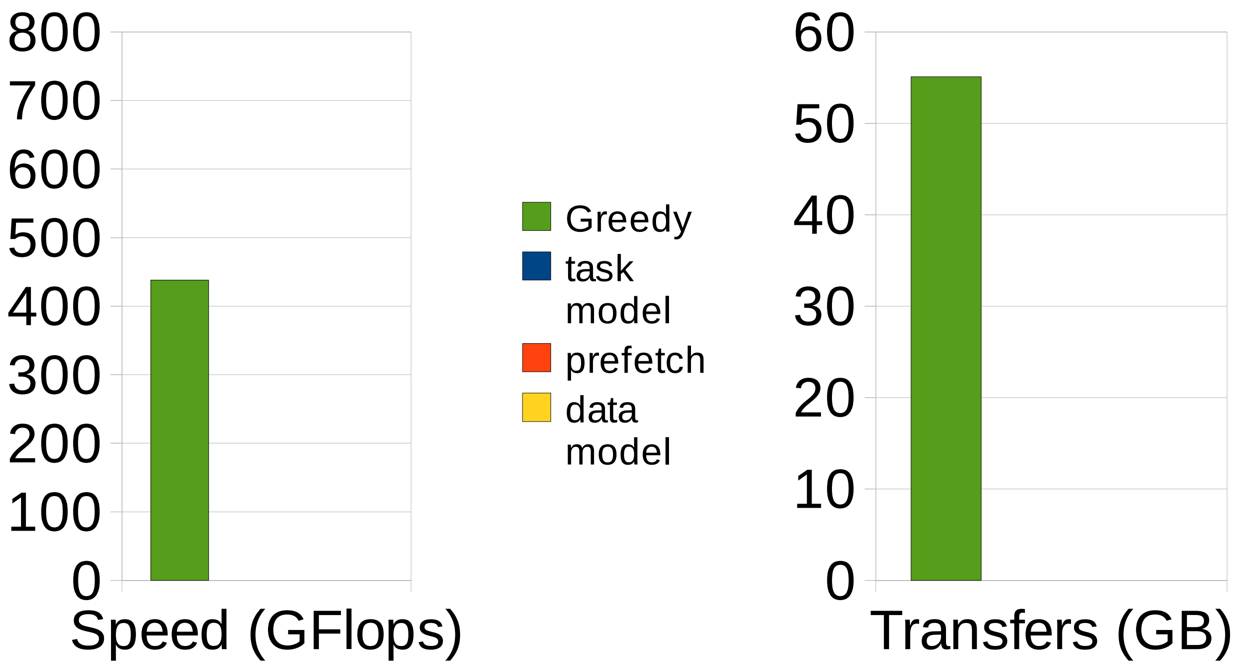
Impact of scheduling policy on a synthetic LU decomposition

(without pivoting !)

Scheduling in a hybrid environment

Performance models

- LU without pivoting (16GB input matrix)
  - 8 CPUs (nehalem) + 3 GPUs (FX5800)



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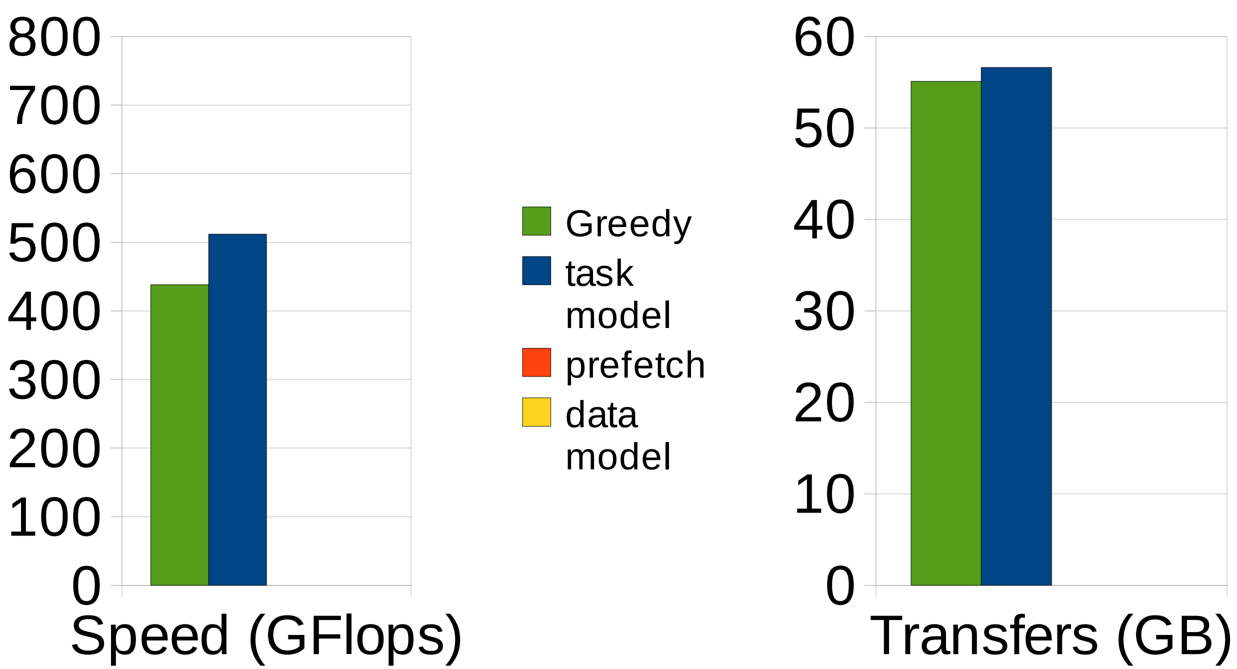

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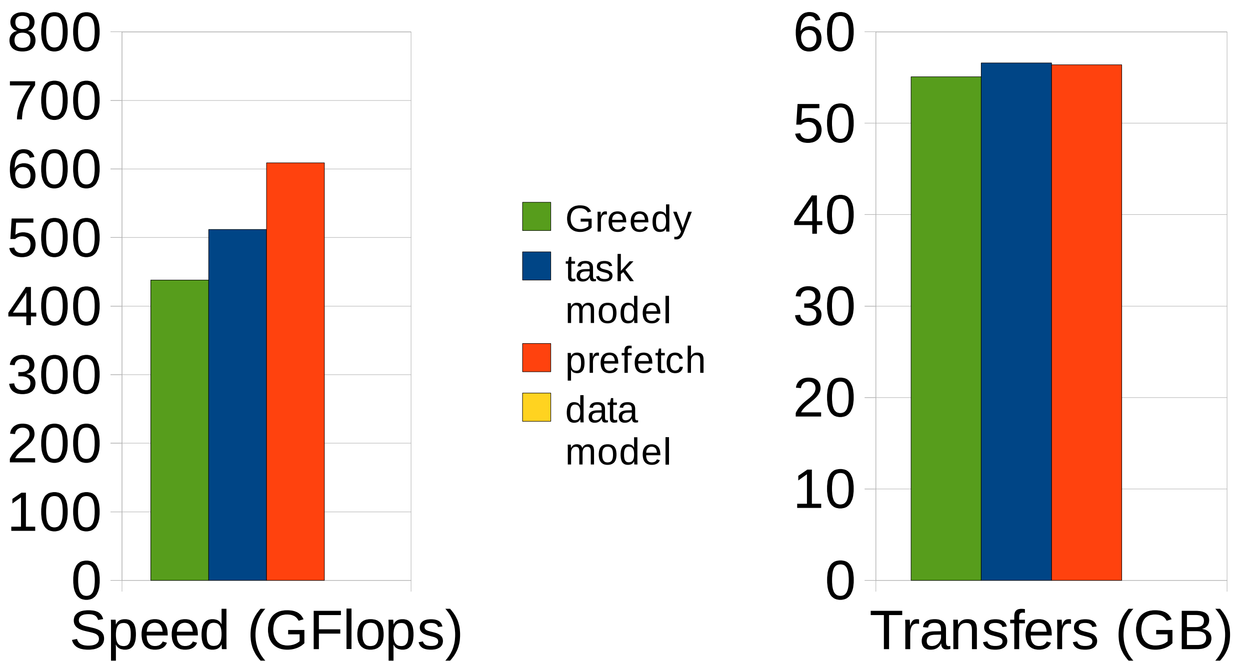

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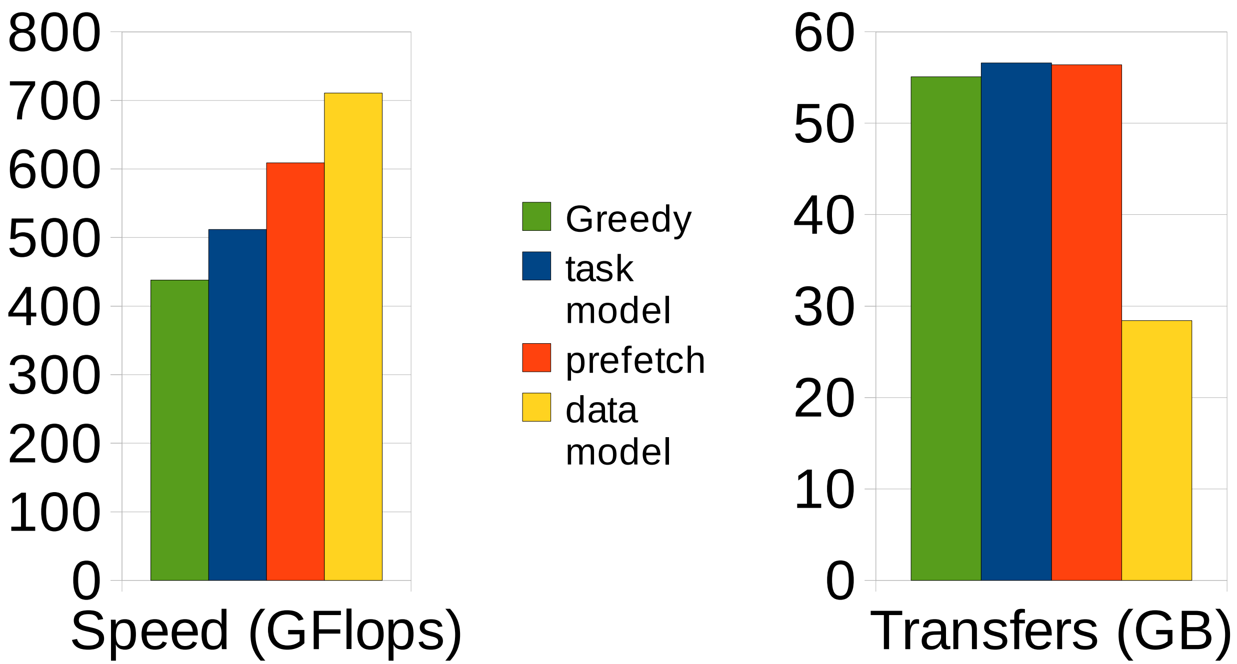


Mixing PLASMA and MAGMA with StarPU

(in collaboration with UTK)

Cholesky & QR decompositions

Mixing PLASMA and MAGMA with StarPU

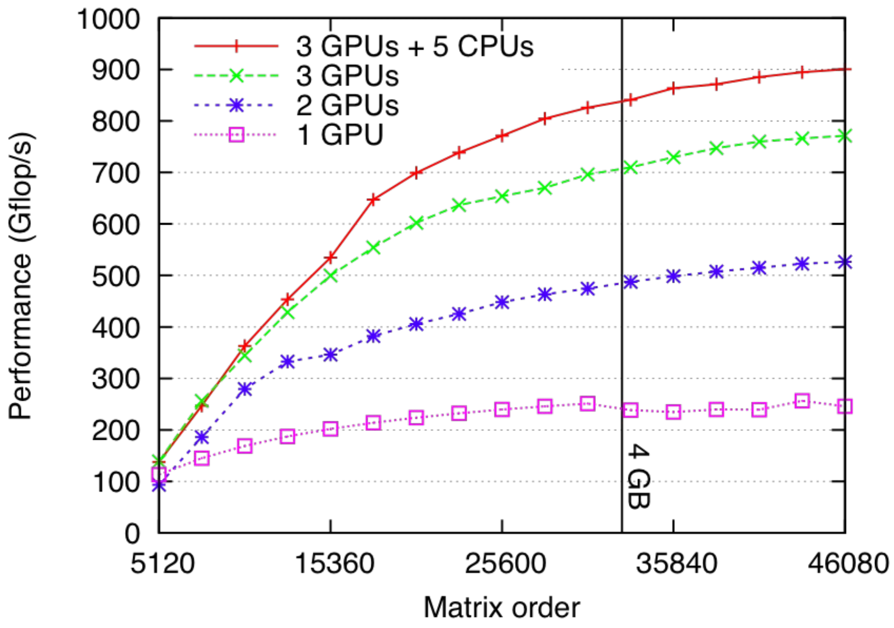
- State of the art algorithms
  - PLASMA (Multicore CPUs)
    - Dynamically scheduled with Quark
  - MAGMA (Multiple GPUs)
    - Hand-coded data transfers
    - Static task mapping

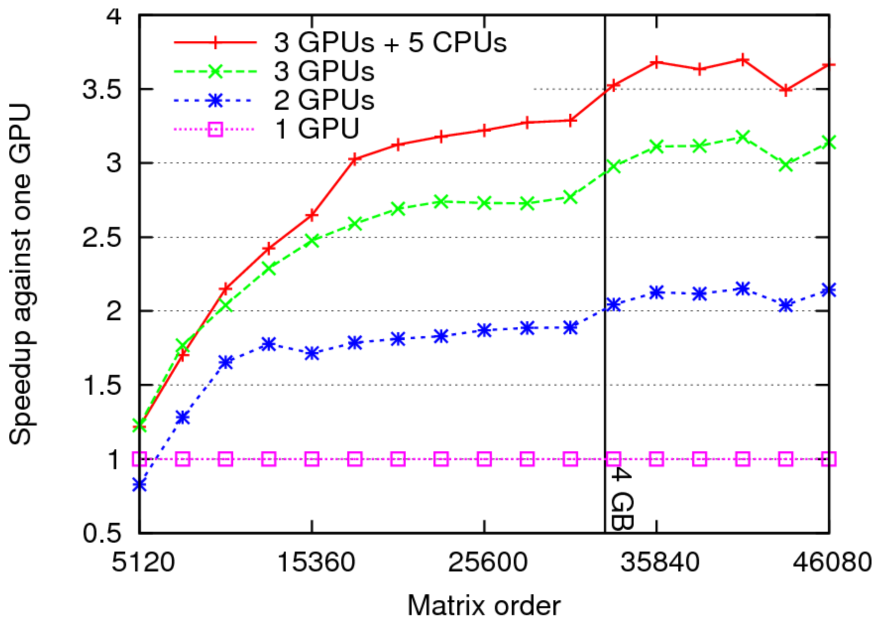
- General SPLAGMA design
  - Use PLASMA algorithm with « magnum tiles »
  - PLASMA kernels on CPUs, MAGMA kernels on GPUs
  - Bypass the QUARK scheduler

- Programmability
  - Cholesky: ~half a week
  - QR : ~2 days of works
  - Quick algorithmic prototyping

Mixing PLASMA and MAGMA with StarPU

- Cholesky decomposition
  - 5 CPUs (Nehalem) + 3 GPUs (FX5800)
  - Efficiency > 100%





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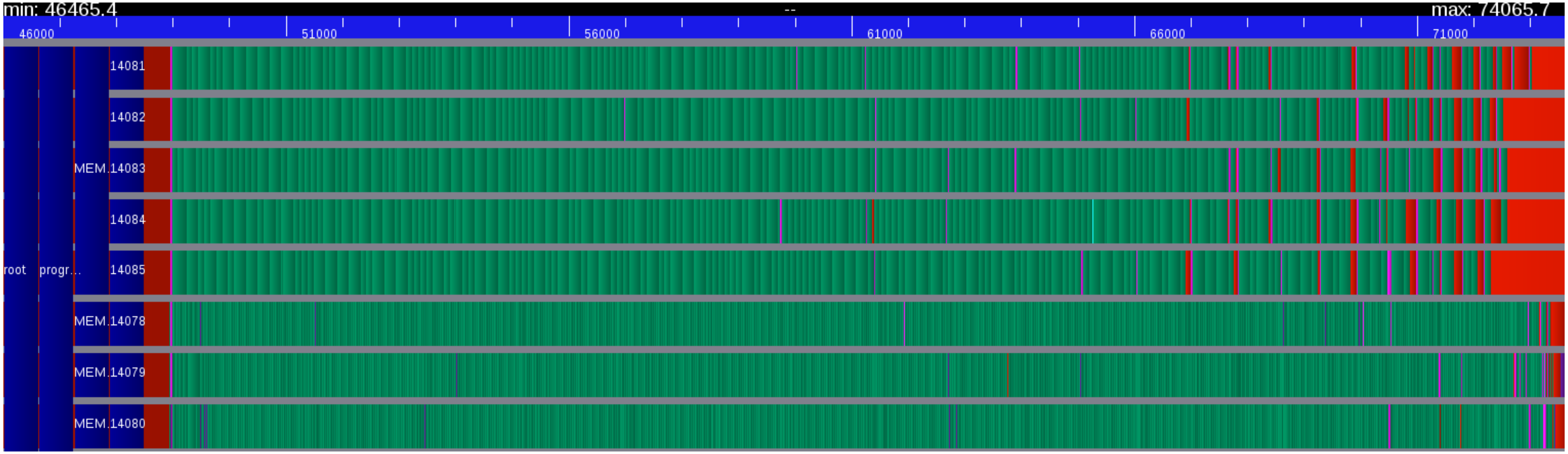
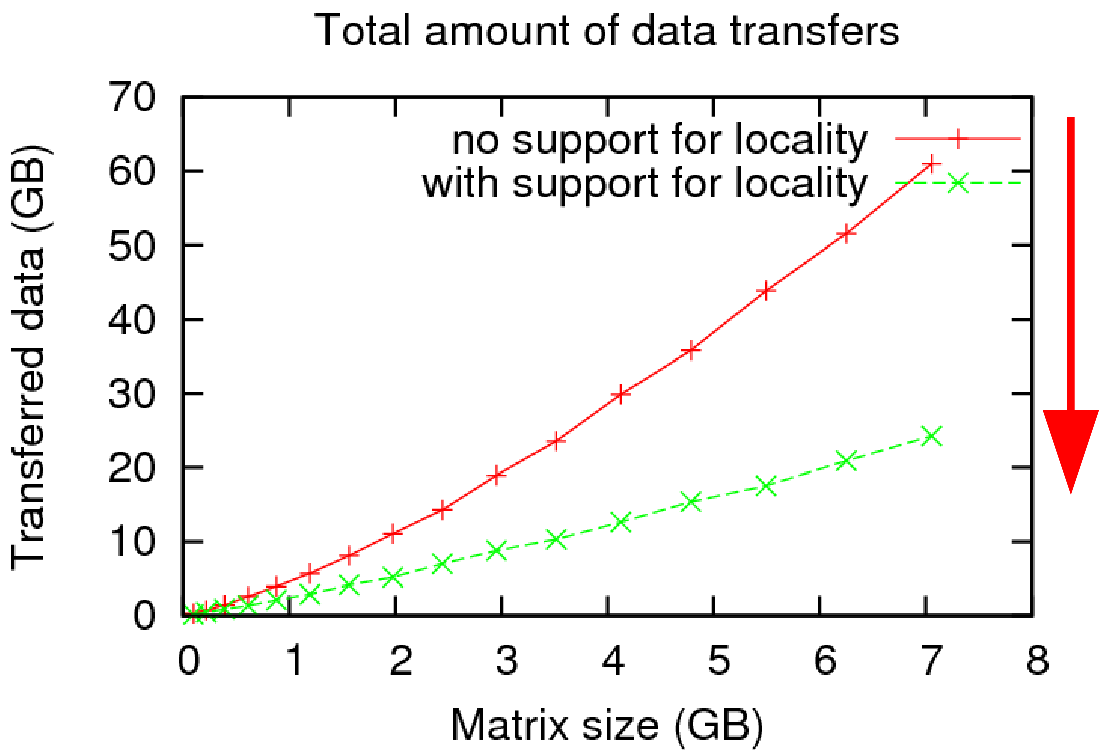


Mixing PLASMA and MAGMA with StarPU

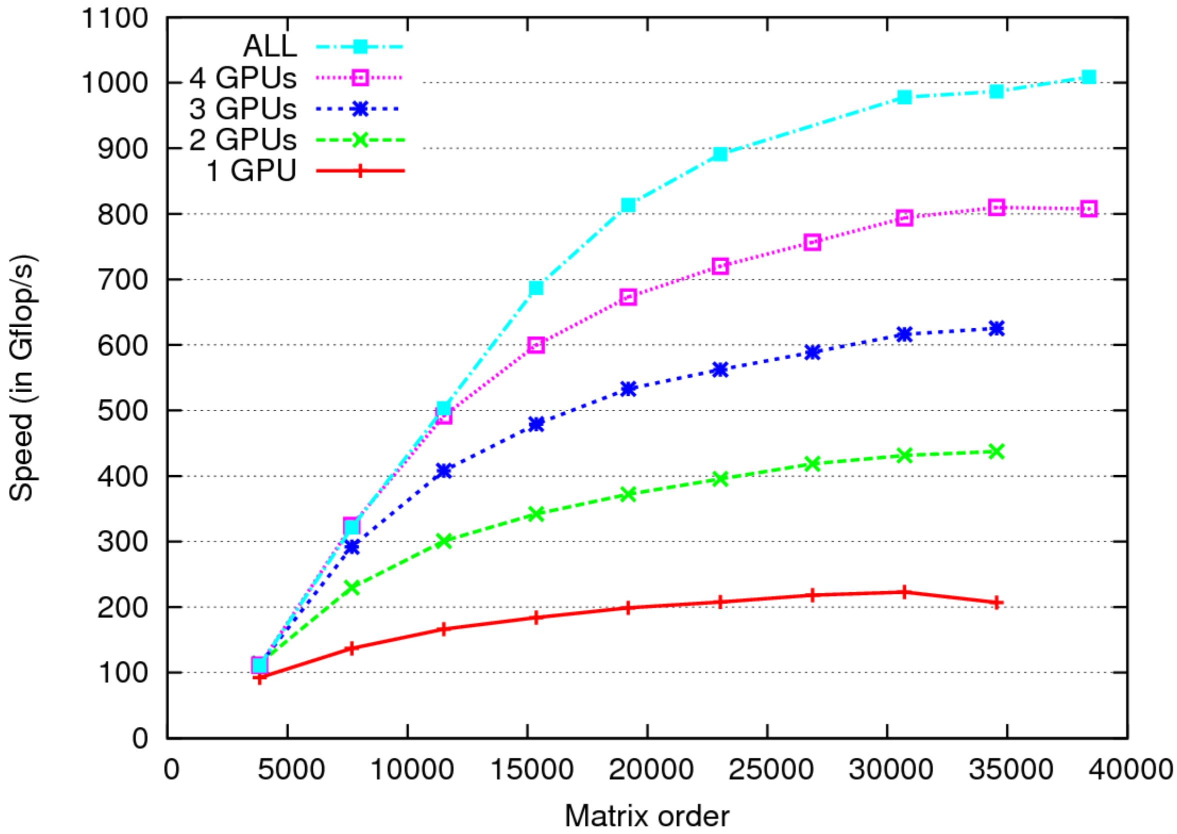
- Memory transfers during Cholesky decomposition



~2.5x less transfers

Mixing PLASMA and MAGMA with StarPU

- QR decomposition
  - Mordor8 (UTK) : 16 CPUs (AMD) + 4 GPUs (C1060)



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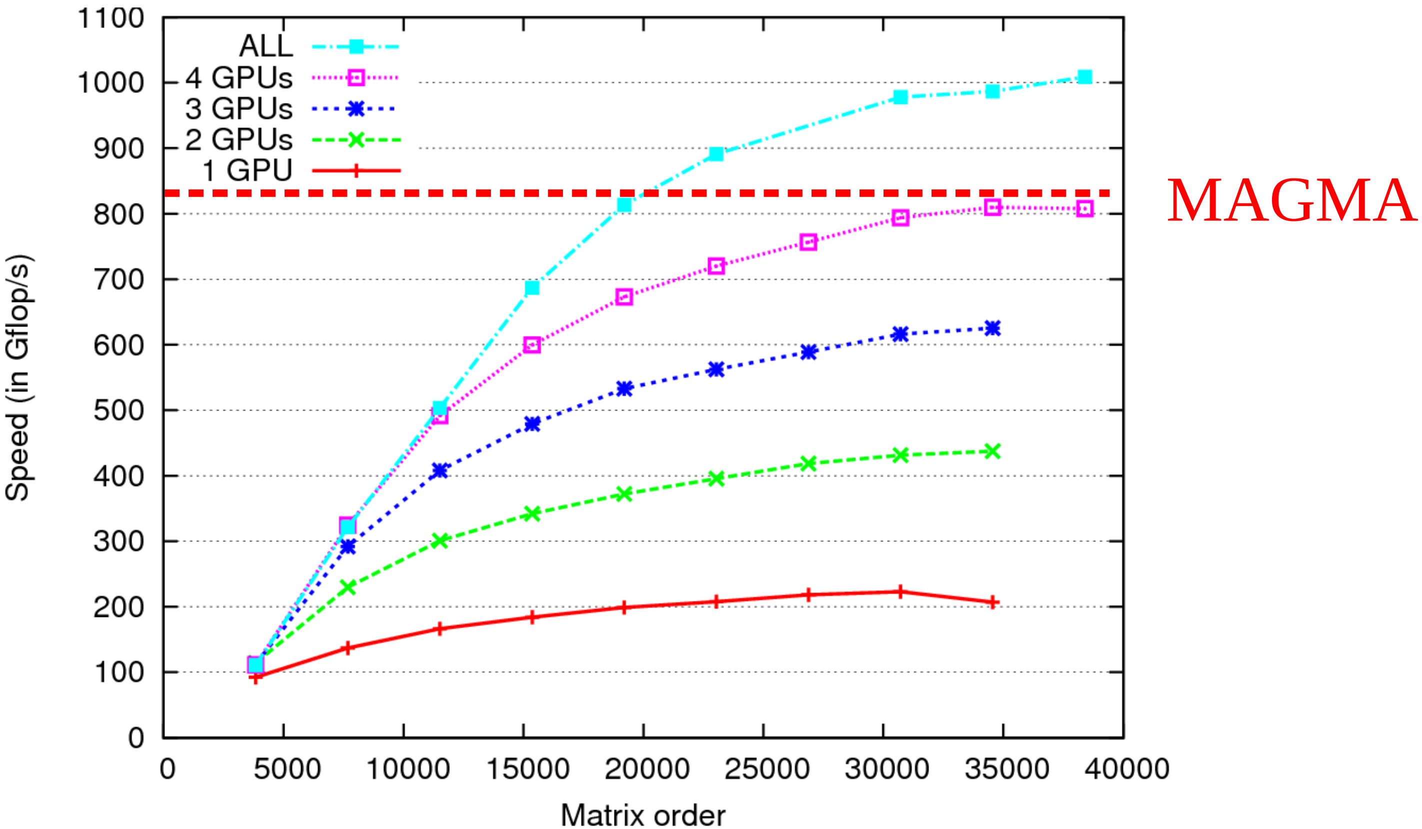

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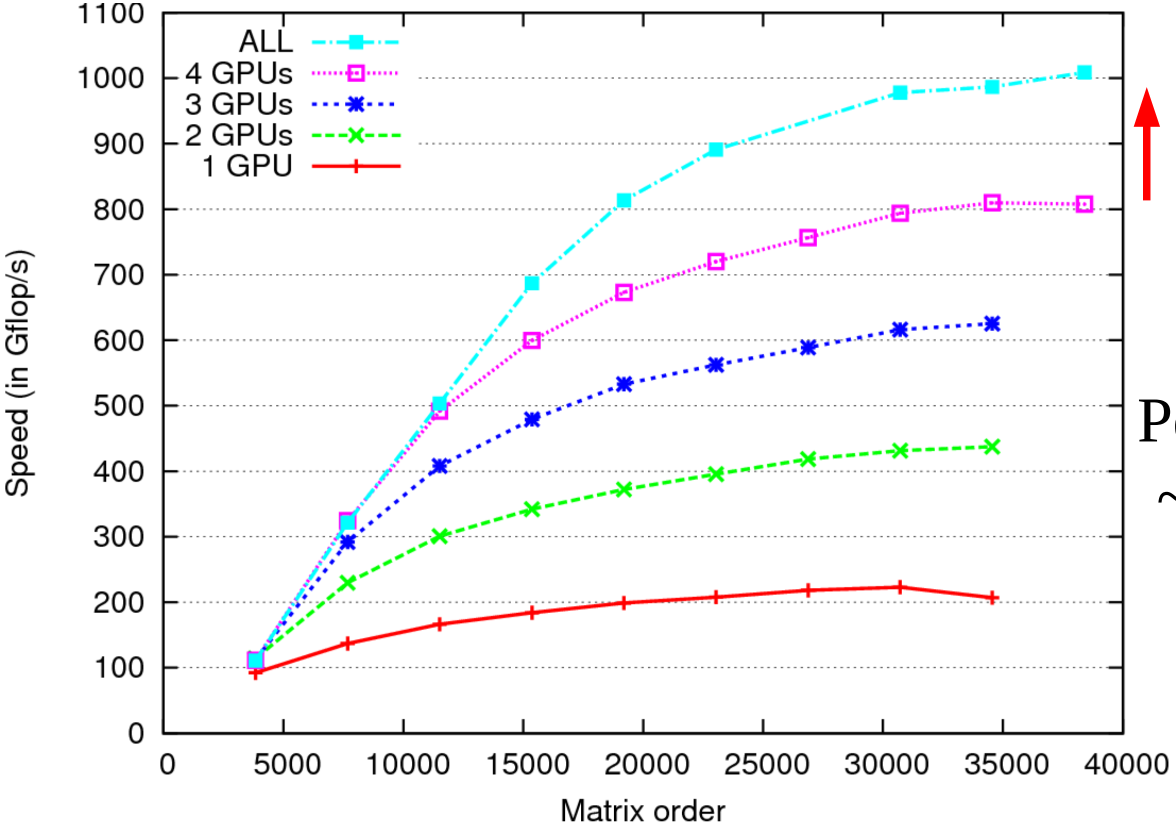


+12 CPUs
~200GFlops

Peak : 12 cores
~150 GFlops

Mixing PLASMA and MAGMA with StarPU

- « Super-Linear » efficiency in QR?
  - Kernel efficiency
    - sgeqrt
      - CPU: 9 Gflops GPU: 30 Gflops (Speedup : ~3)
    - stsqrt
      - CPU: 12Gflops GPU: 37 Gflops (Speedup: ~3)
    - somqr
      - CPU: 8.5 Gflops GPU: 227 Gflops (Speedup: ~27)
    - Sssmqr
      - CPU: 10Gflops GPU: 285Gflops (Speedup: ~28)
  - Task distribution observed on StarPU
    - sgeqrt: 20% of tasks on GPUs
    - Sssmqr: 92.5% of tasks on GPUs
  - Taking advantage of heterogeneity !
    - Only do what you are good for
    - Don't do what you are not good for

Scheduling parallel tasks

Parallel tasks

Why do we need parallel tasks ?

- Take advantage of multicore architectures

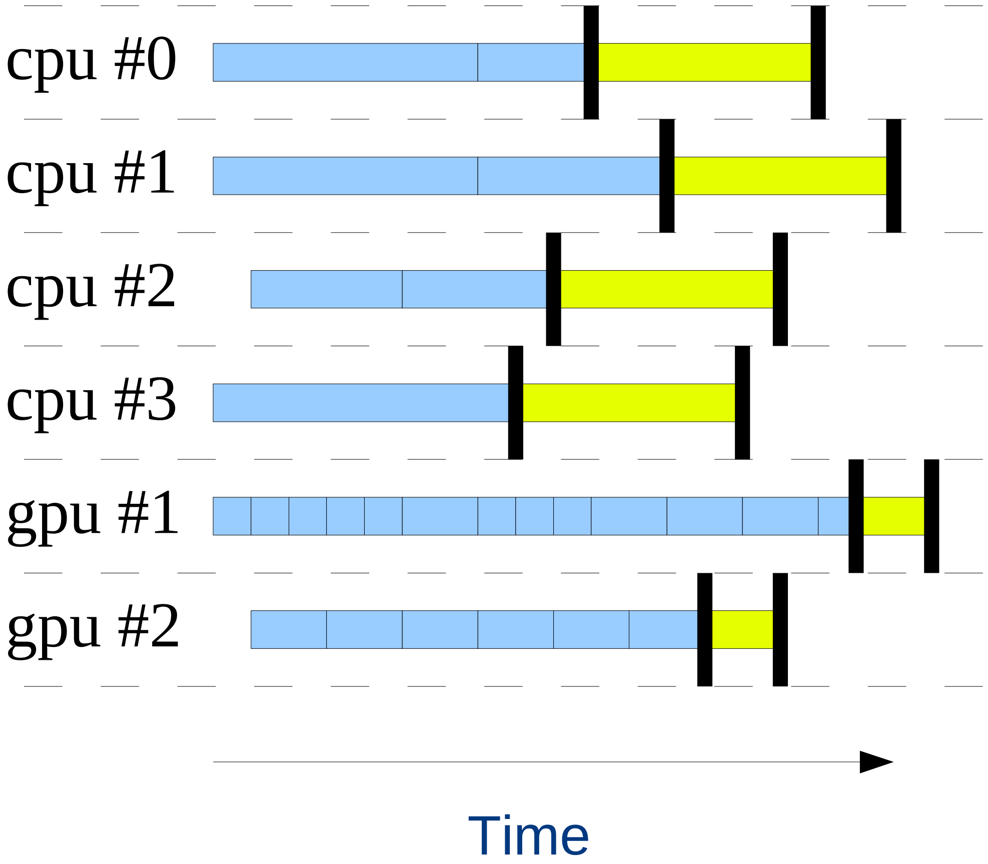
- Task parallelism may not be suited at a fine grain
  - Use other parallel paradigms
    - eg. OpenMP
  - Use existing parallel libraries
    - eg. do not reimplement parallel BLAS …

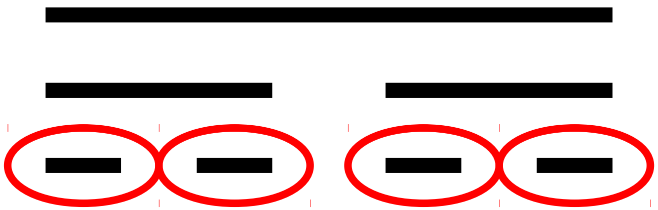
- Alleviate granularity concerns
  - Less tasks
  - Large enough tasks (suited for the GPU)

Parallel tasks

Scheduling parallel tasks

- StarPU allocates processing units





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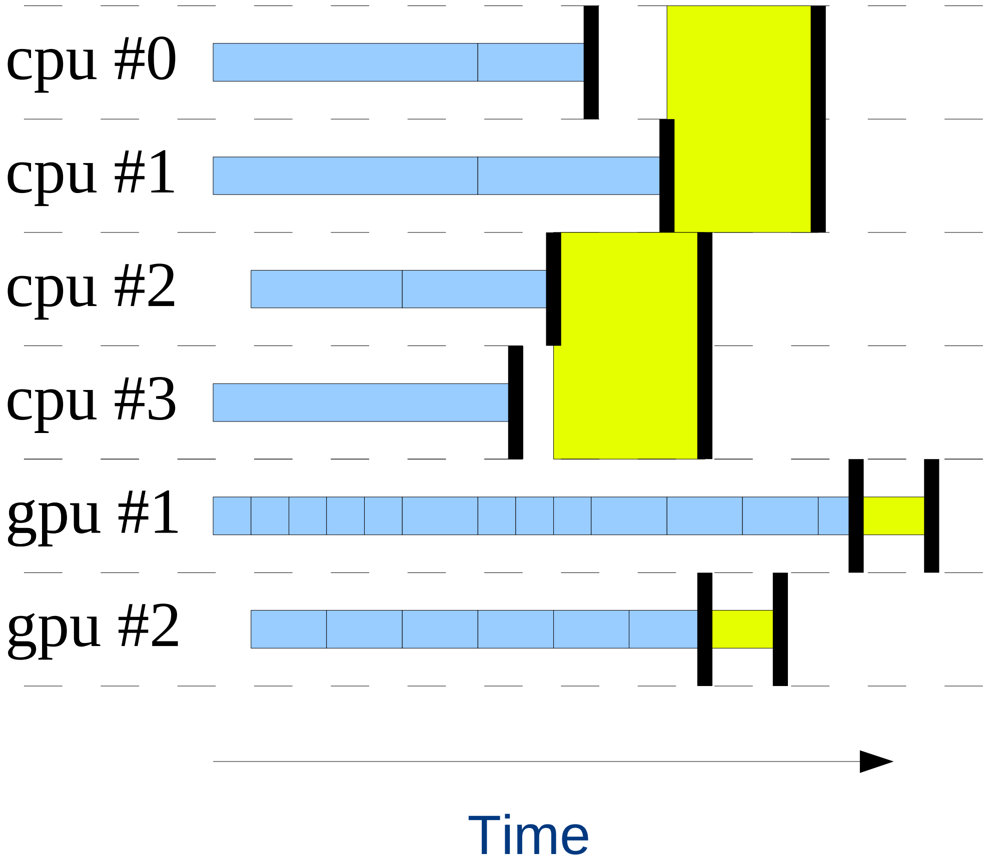

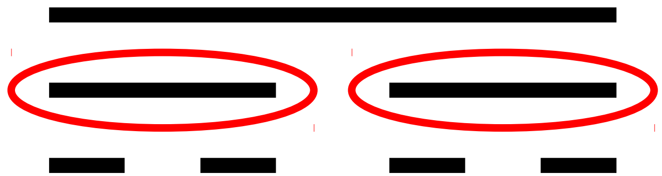

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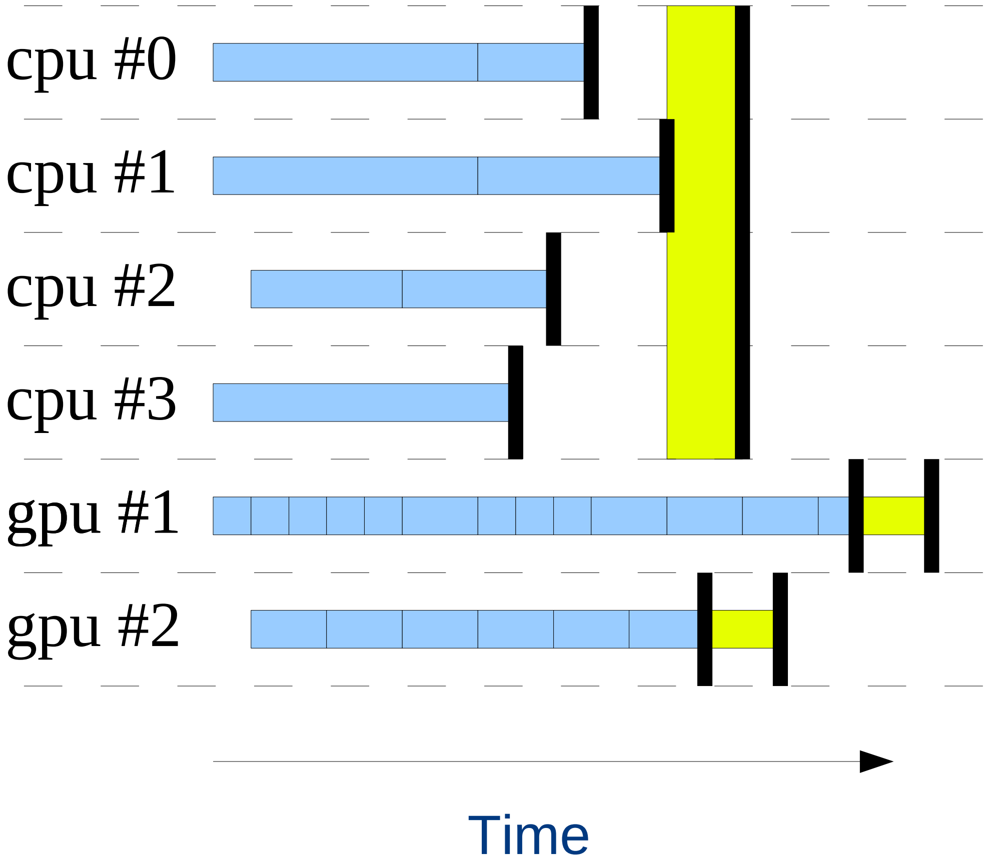

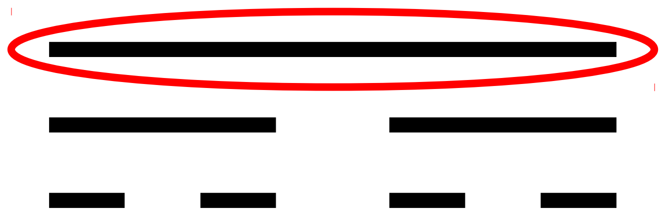

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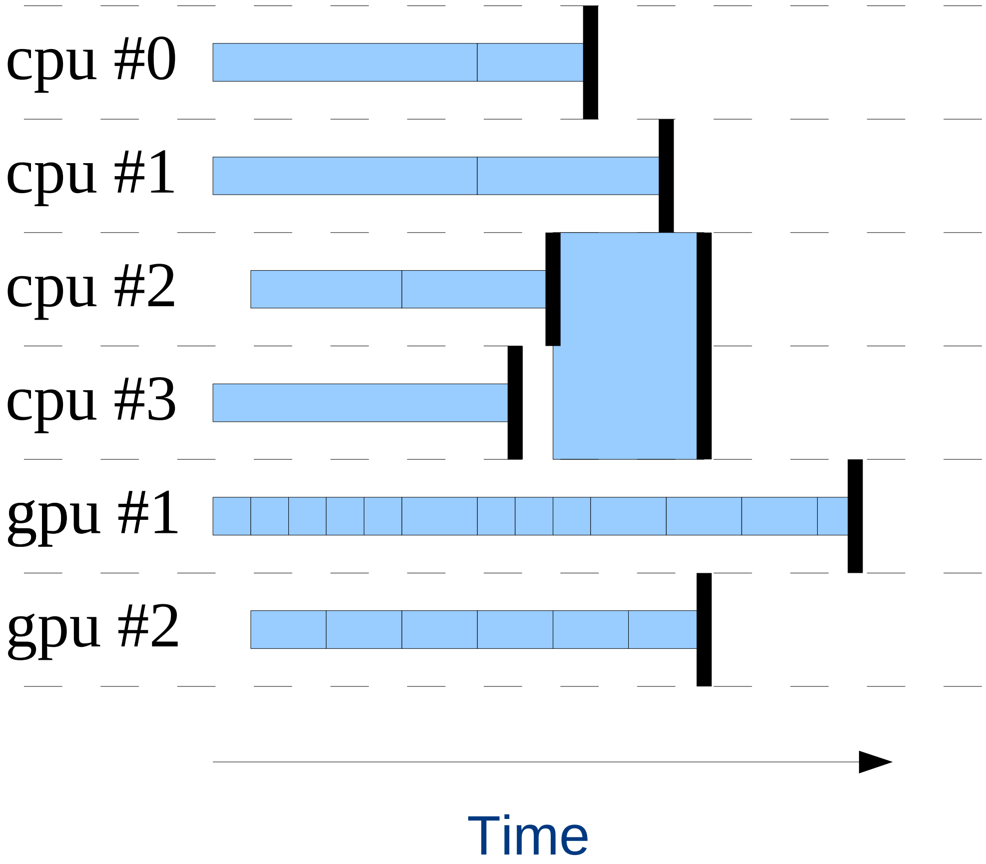


Adding support for MPI in StarPU

Accelerating MPI applications with StarPU

- Keep MPI SPMD style
  - Static distribution of data
  - Scheduling within the node only
    - No load balancing between MPI processes
- Inter-process data dependencies
  - MPI communications triggered by StarPU data availability
  - Support from StarPU's memory management
    - Automaticallly construct MPI datatype

Accelerating MPI applications with StarPU

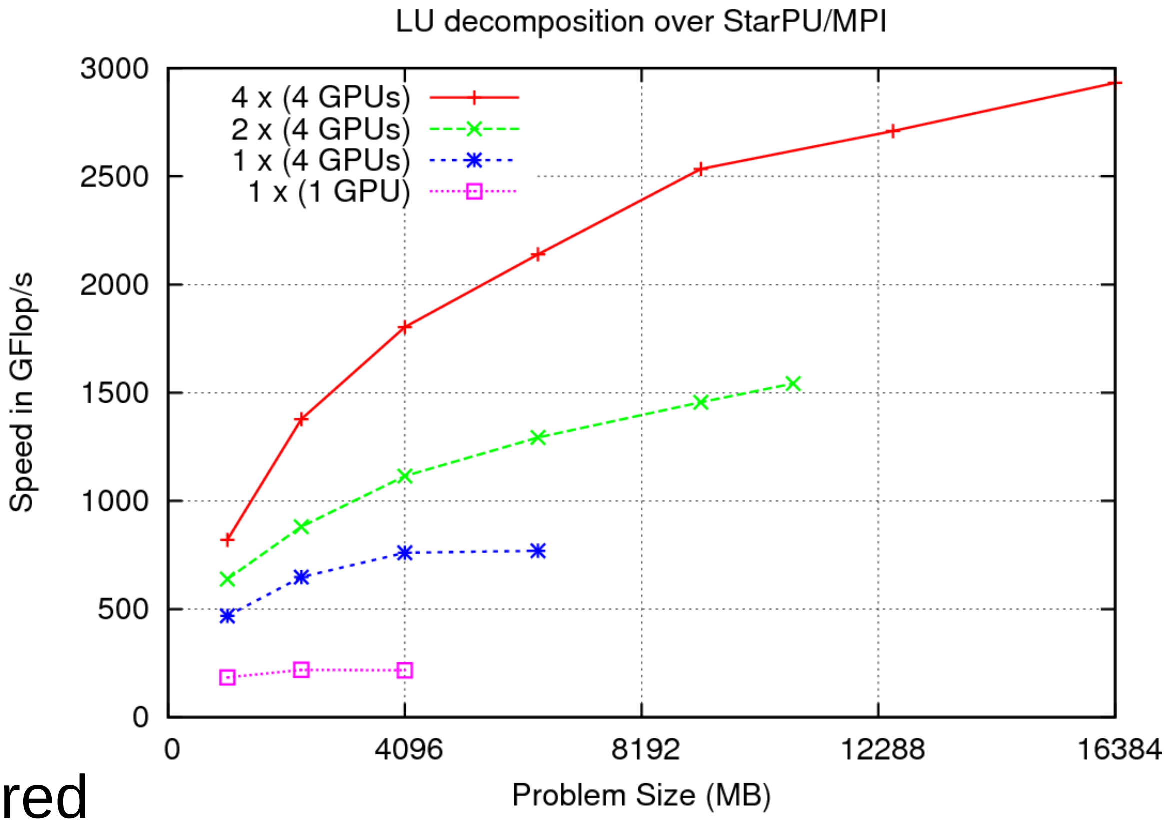
- Provided API
  - starpu_mpi_{send,recv}
  - starpu_mpi_{isend,irecv}
  - starpu_mpi_{test,wait}
  - starpu_mpi_{send,recv}_detached
  - starpu_mpi_*_array

- Detached calls
  - No need to explicitly test/wait for the request
  - Automatic progression

- Automatic data dependencies
  - MPI transfers ~ StarPU tasks
  - Accelerating legacy codes

Accelerating LU/MPI with StarPU

- LU decomposition
  - MPI+multiGPU
- Static MPI distribution
  - 2D block cyclic
  - ~SCALAPACK
  - No pivoting !
- Algorithmic work required
  - Collaboration with UTK

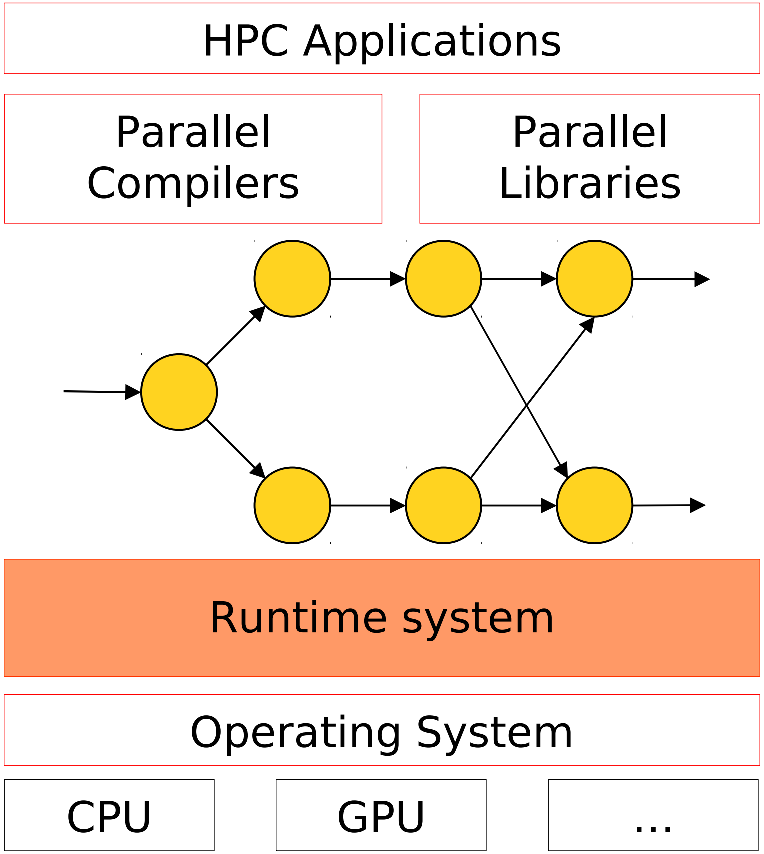


Conclusion

Conclusion

Summary

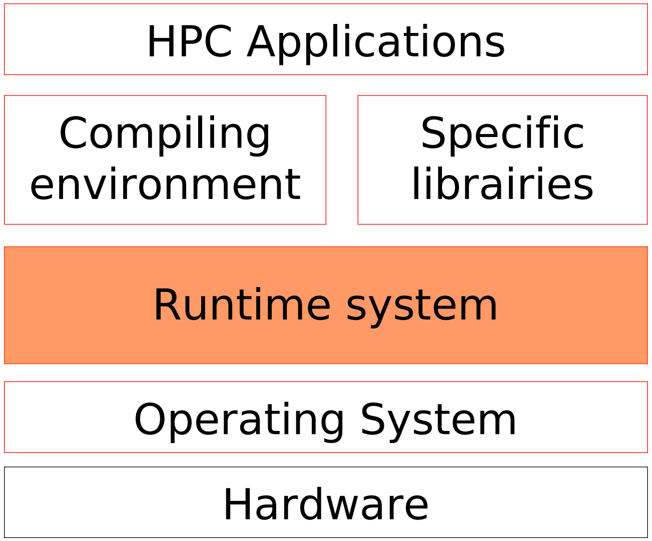
- StarPU
  - Freely available under LGPL
  - Available on Linux, OS/X, Windows
  - Open to external contributors!
- Task Scheduling
  - Required on hybrid platforms
  - Auto-tuned performance models
- Combined PLASMA and MAGMA
- Parallel tasks
- MPI extensions



Conclusion

Future work

- Implement more algorithms
  - LU, Hessenberg
  - Communication Avoiding algorithms
  - Hybrid Scalapack
  - Provide higher level constructs (eg. reductions)
- Provide a back-end for compilers
  - StarSs, XscalableMP, HMPP
- Support new architectures
  - Intel SCC, Fermi cards, …
- Dynamically adapt granularity
  - Divisible tasks



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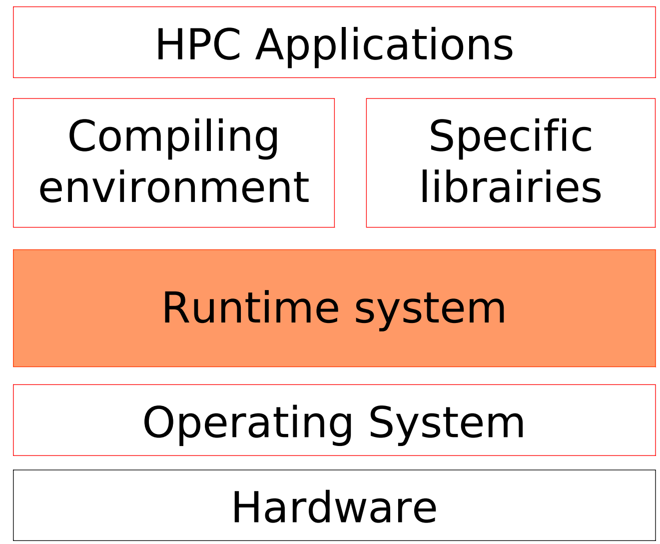
  - Hybrid Scalapack
  - Provide higher level constructs (eg. reductions)
- Provide a back-end for compilers
  - StarSs, XscalableMP, HMPP
- Support new architectures
  - Intel SCC, Fermi cards, …
- Dynamically adapt granularity
  - Divisible tasks

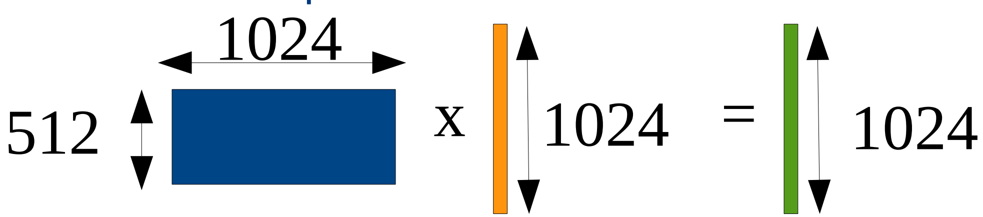


Thanks for your attention !

Any question ?

Performance Models
Our History-based proposition

- Hypothesis
  - Regular applications
  - Execution time independent from data content
    - Static Flow Control
- Consequence
  - Data description fully characterizes tasks
  - Example: matrix-vector product



  - **Unique** Signature : ((1024, 512), 1024, 1024)
  - Per-data signature
    - CRC(1024, 512) = 0x951ef83b
  - Task signature
    - CRC(CRC(1024, 512), CRC(1024), CRC(1024)) = 0x79df36e2

Performance Models
Our History-based proposition

- Generalization is easy
  - Task f(D1, … , Dn)

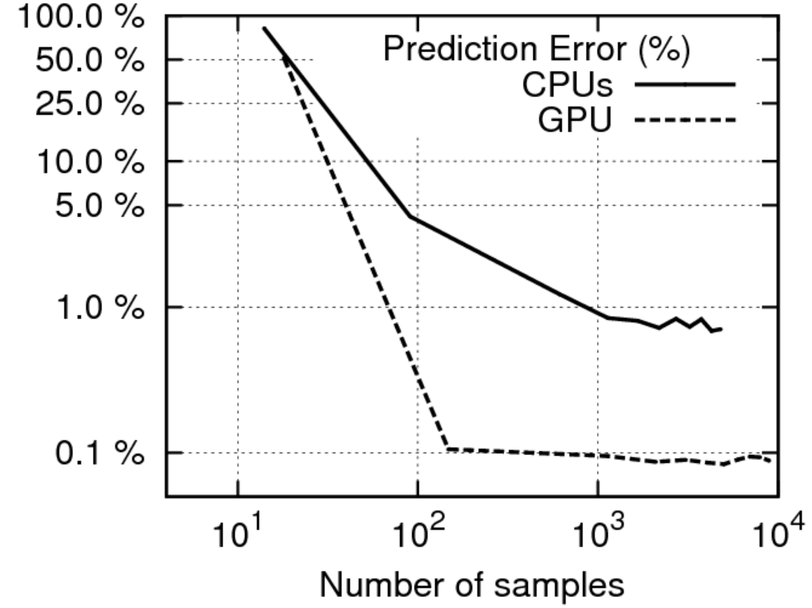
  - Data
    - Signature(Di) = CRC(p1, p2, … , pk)
  - Task ~ Series of data
    - Signature(D1, ..., Dn) = CRC(sign(D1), ..., sign(Dn))

- Systematic method
  - Problem independent
  - Transparent for the programmer
  - Efficient

Evaluation
Example: LU decomposition

	Speed (GFlop/s)	
	(16k x 16k)	(30k x 30k)
ref.	89.98 ±2.97	130.64 ±1.66
1st iter	48.31	96.63
2nd iter	103.62	130.23
3rd iter	103.11	133.50
≥ 4 iter	**103.92 ±0.46**	**135.90 ±□.□□**

- Faster
- No code change !
- More stable



- Dynamic calibration
- Simple, but accurate