Programming hierarchical multicore systems using hybrid approaches: a runtime's perspective

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- We also have a long standing activity in parallelism…

Background

- RUNTIME Team
  - High Performance Runtime Systems for Parallel Architectures

- 3 main research directions
  - Thread scheduling over shared memory machines
    - Application-guided, topology-aware thread scheduling
      - ForestGOMP/BubbleSched OpenMP, starPU
  - Communication over high speed networks
    - Fast, overlapped and reactive data transfers between machines
      - MPICH2/NEMESIS/NewMadeleine, Open-MX
  - Integration of multithreading and communication

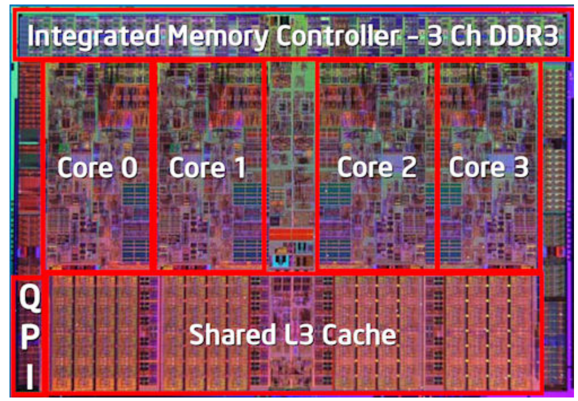
Outline

- Runtime systems for hybrid applications
  - How to program hierarchical clusters of multicore nodes?
- Runtime systems for heterogeneous machines
  - How to schedule tasks over a heterogeneous set of computing units?
- Challenges for the upcoming years

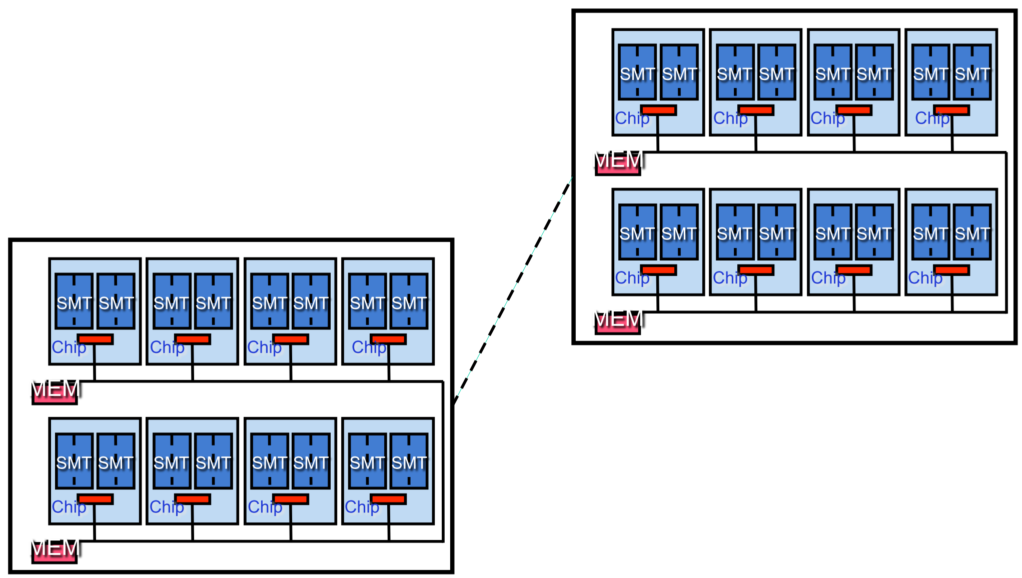
Runtime systems for hybrid applications

Multicore is a solid architecture trend

- Multicore chips
  - Different from SMPs
    - Hierarchical machines
    - Complex topology
  - Back to the CC-NUMA era?



- Clusters of multicore nodes
  - One more hierarchical level
  - Programmers are probably more confident with the “distributed” part…



Can we escape the pure MPI model?

- MPI is the most popular parallel programming interface
  - Its programming model has been widely accepted
  - Existing implementation are very efficient
  - Scalability is OK so far
- But the “pure, flat MPI” model raises several issues
  - Topology-aware applications
    - Concurrent point-to-point communications can generate bottlenecks
    - No convenient abstraction to develop portable, topology-aware applications
  - Load balancing
    - Each MPI process is usually bound to a single core
    - Load balancing policy can hardly be implemented independently

What programming model for clusters of multicore machines?

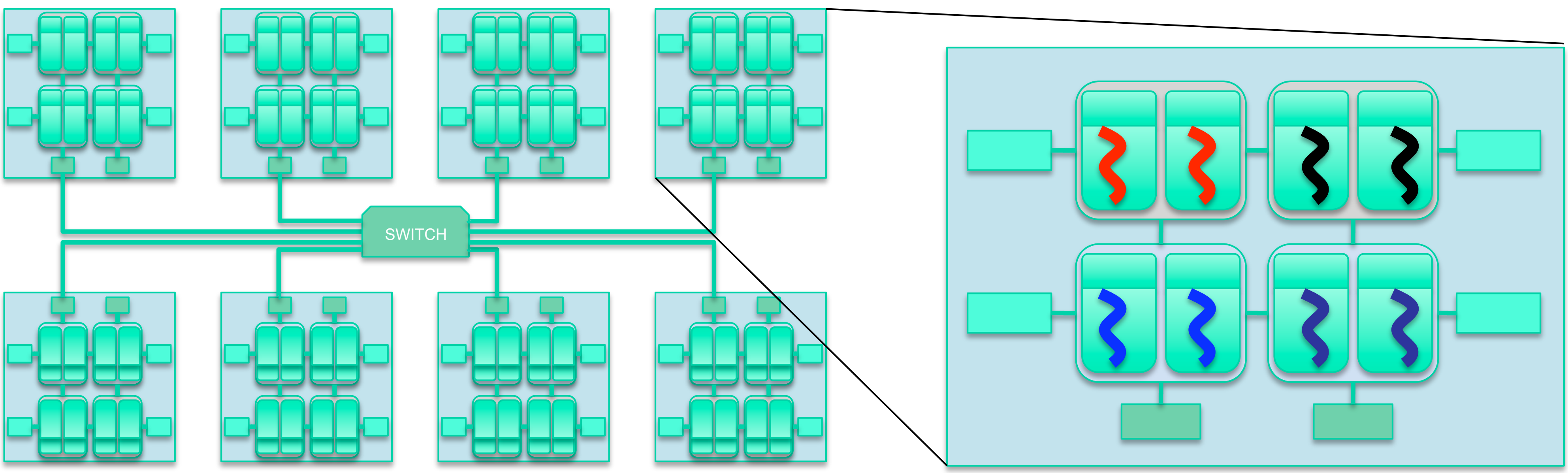
- I wish it would be XcalableMP 3.0, UPC 4.0 or Charm++ 8.0!
  - Uniform programming model
    - Scheduling / Load balancing
    - Communication
    - Synchronization
  - Fine-grain, structured parallelism!
- However
  - The world is actually full of natural born MPI programmers
  - MPI has proved to be very efficient on clusters
- The number of hybrid applications will probably increase in the future

Hybrid applications

- MPI + OpenMP is the most popular approach
  - OpenMP directives are typically inserted in existing MPI programs
- We believe that "indirect hybridization" is even more interesting
  - Parallel Libraries
    - MPI programs using MKL or PLASMA…
  - Big challenge = composability!
    - MPI + OpenMP + TBB + multicore BLAS…
- Mixing programming models raises a lot of issues
  - Semantics issues
    - MPI_recv inside parallel sections?
  - Technical issues
    - nested locks, user-space vs kernel space scheduling
  - Performance issues
    - thread/process distribution

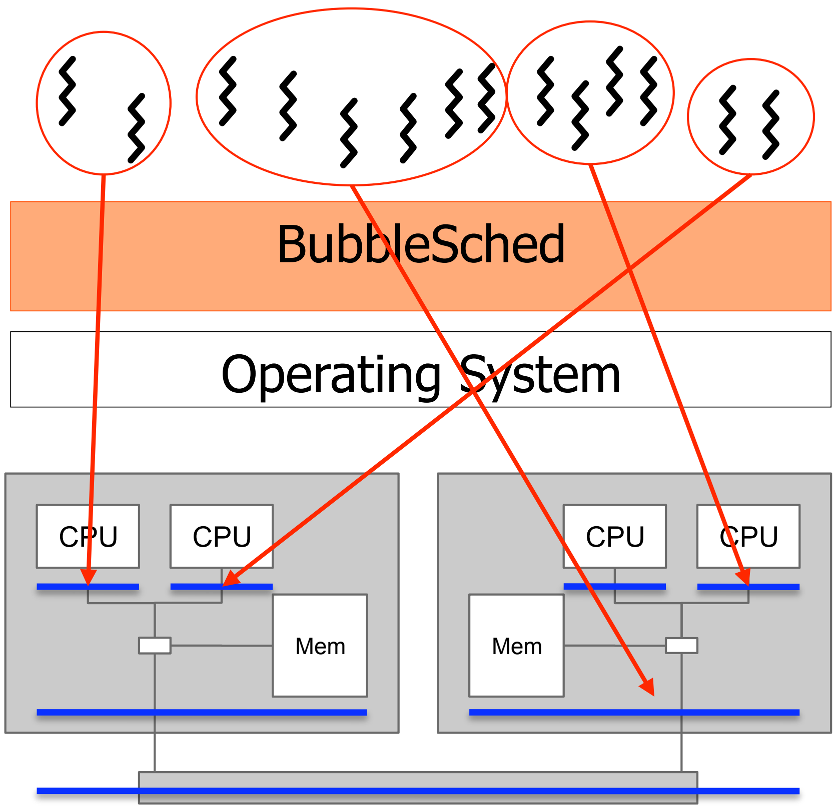
Designing a runtime system for hybrid programs

- Goals
  - Solve technical/performance issues
    - Ever tried to mix MKL and OpenMP?
  - Experiment and find the most adequate *core assignment* tradeoff
    - Process/thread/task ratio



Our background: Thread Scheduling over Multicore Machines

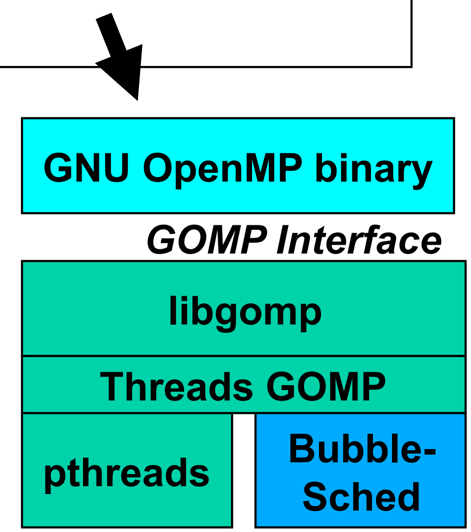
- The Bubble Scheduling concept
  - Capturing application’s structure with nested bubbles
  - Scheduling = dynamic mapping trees of threads onto a tree of cores
- The BubbleSched platform
  - Designing portable NUMA-aware scheduling policies
    - Focus on algorithmic issues
  - Debugging/tuning scheduling algorithms
    - FxT tracing toolkit + replay animation
    - [with Univ. New Hampshire, USA]



Our background: Thread Scheduling over Multicore Machines

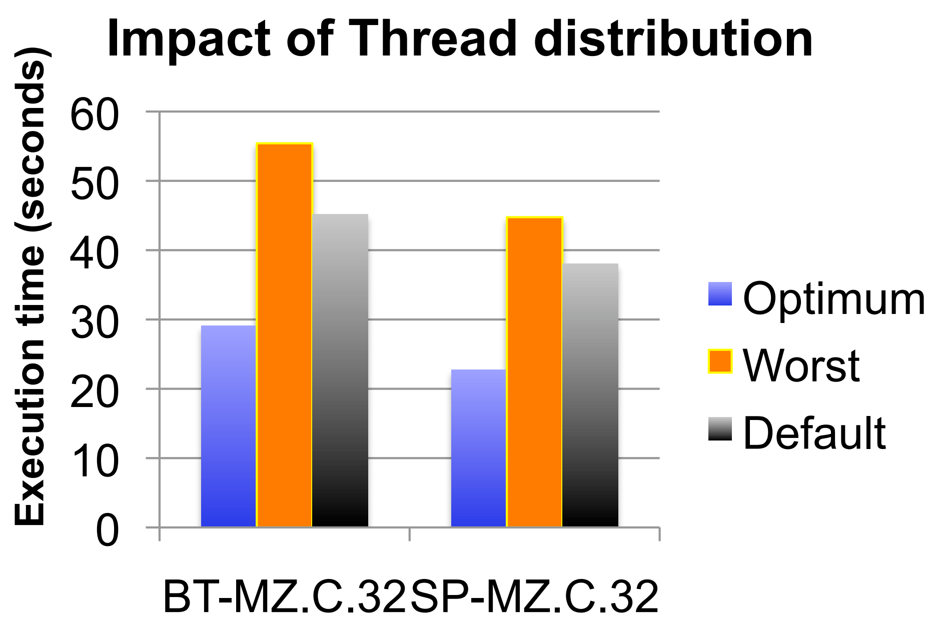
- Designing multicore-friendly programs with OpenMP
  - Parallel sections generate bubbles
  - Nested parallelism is welcome!
    - Lazy creation of threads
- The ForestGOMP platform
  - Extension of GNU OpenMP
    - Binary compliant with existing applications
  - Excellent speedups with irregular applications
    - Implicit 3D surface reconstruction [with iParla]
    - Tree depth > 15, more than 300,000 threads

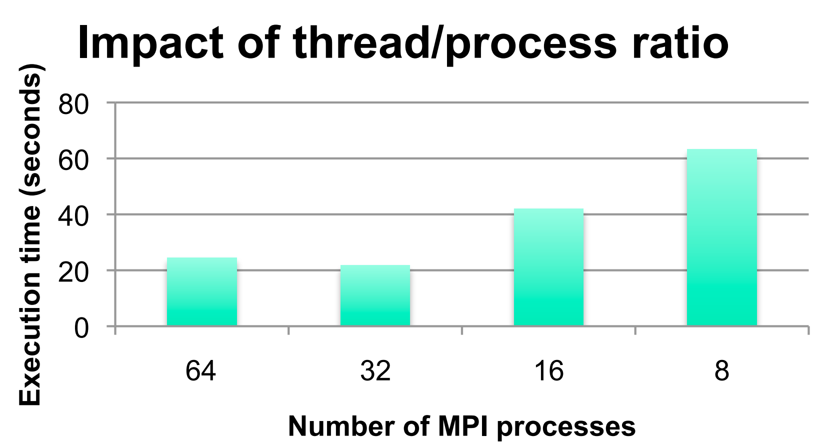
```
void Node::compute(){

  // approximate surface
  computeApprox();

  if(_error > _max_error) {
    // precision not sufficient
    // so divide and conquer
    splitCell();

    #pragma omp parallel for
    for(int i=0; i<8; i++)
      _children[i]->compute();
  }
}
```



Our ForestGOMP/MPICH Runtime

- Experimental platform for hybrid applications
  - Topology-aware process allocation
  - Customizable core/process ratio
  - # of OpenMP tasks independent from # of cores
    - OMP_NUM_THREADS ignored
  - Traces can be generated and analyzed offline





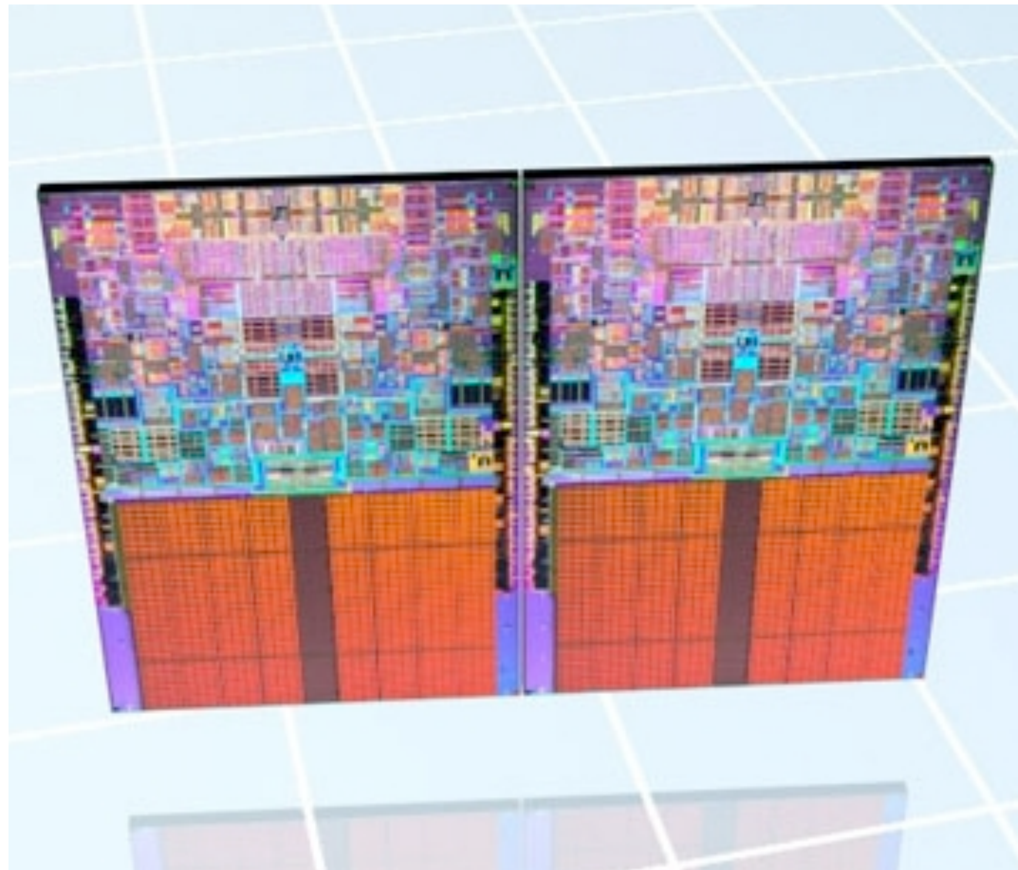
Ongoing work

- Extending the platform to other programming environments
  - Intel TBB
  - StarPU
- Providing performance feedback to the programmer
  - Can we still understand performance?
- Allowing the user to give scheduling hints
  - Composability of hints? ☺

Designing Runtime Systems for Heterogenenous Architectures

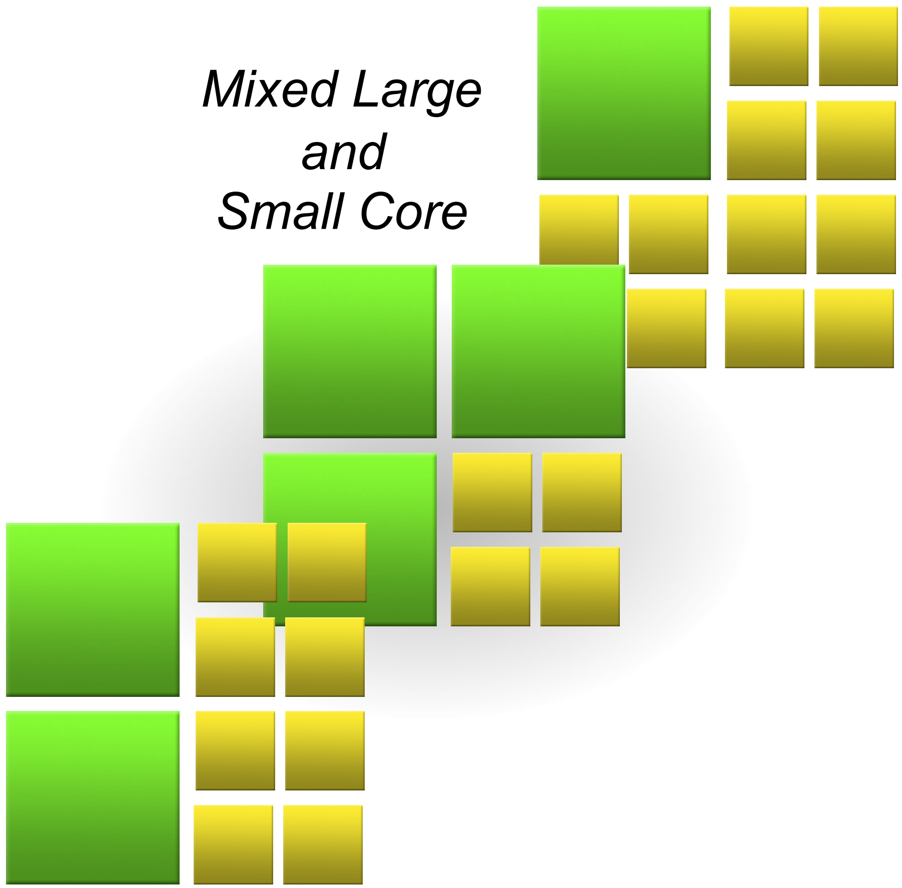
Parallel machines are going heterogeneous

- GPGPU are the *new kids on the block*
  - Very powerful SIMD accelerators
  - Successfully used for offloading data-parallel kernels
- Some chips already feature specialized hardware
  - IBM Cell/BE
    - 1 PPU + 8 SPUs
  - Intel Larrabee
    - 48-core with SIMD units



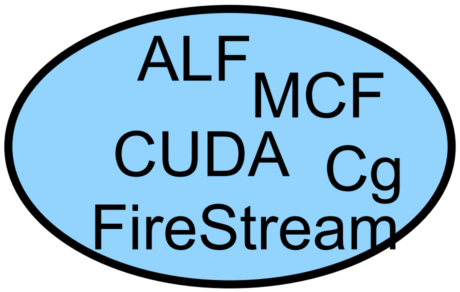
Parallel machines are going heterogeneous

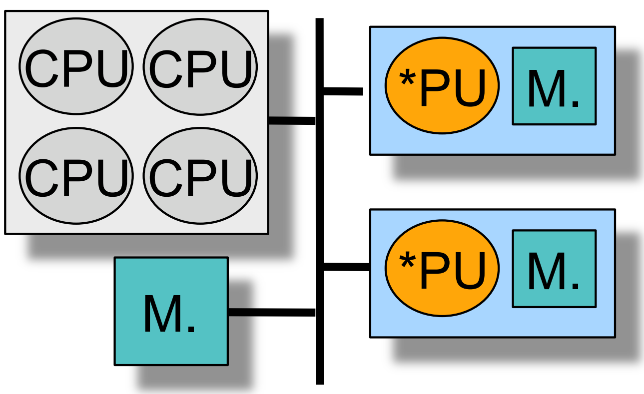
- Programming model
  - Specialized instruction set
  - SIMD execution model
- Memory
  - Size limitations
  - No hardware consistency
    - Explicit data transfers
- Are we happy with that?
  - No, but it's a clear trend!



Dealing with heterogenenous accelerators

Accelerators

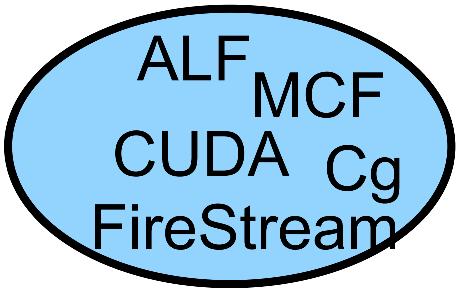


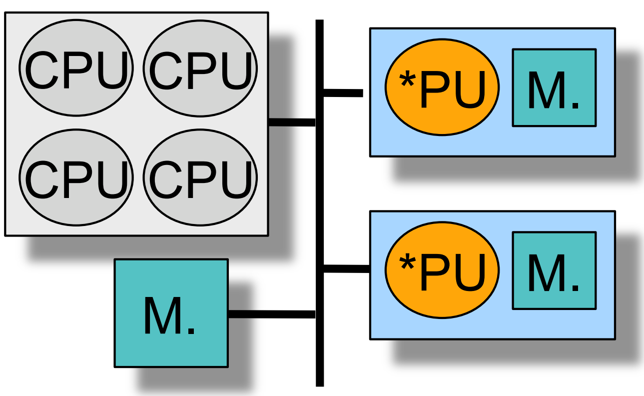


- Specific APIs
  - CUDA, IBM SDK, …
  - No consensus
    - Specialized languages/ compilers
  - OpenCL?
- Communication libraries
  - MCAPI, MPI

Dealing with heterogenenous accelerators

Accelerators



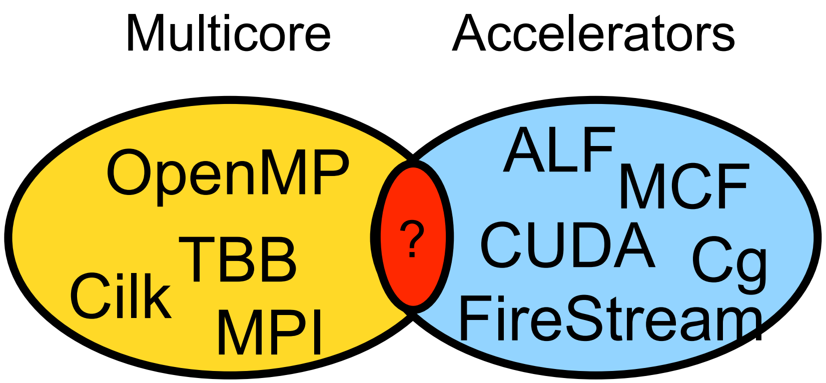


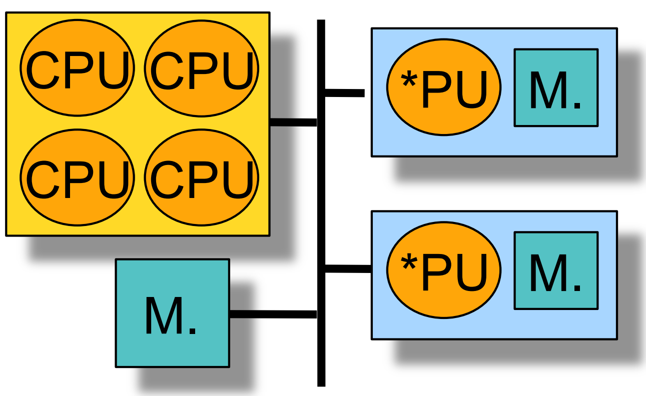
- Language extensions
  - RapidMind, Sieve C++
  - HMPP

    #pragma hmpp target=cuda
  - Cell Superscalar

    #pragma css input(..) output(…)
- Most approaches focus on *offloading*
  - As opposed to *scheduling*

Programming Hybrid Architectures



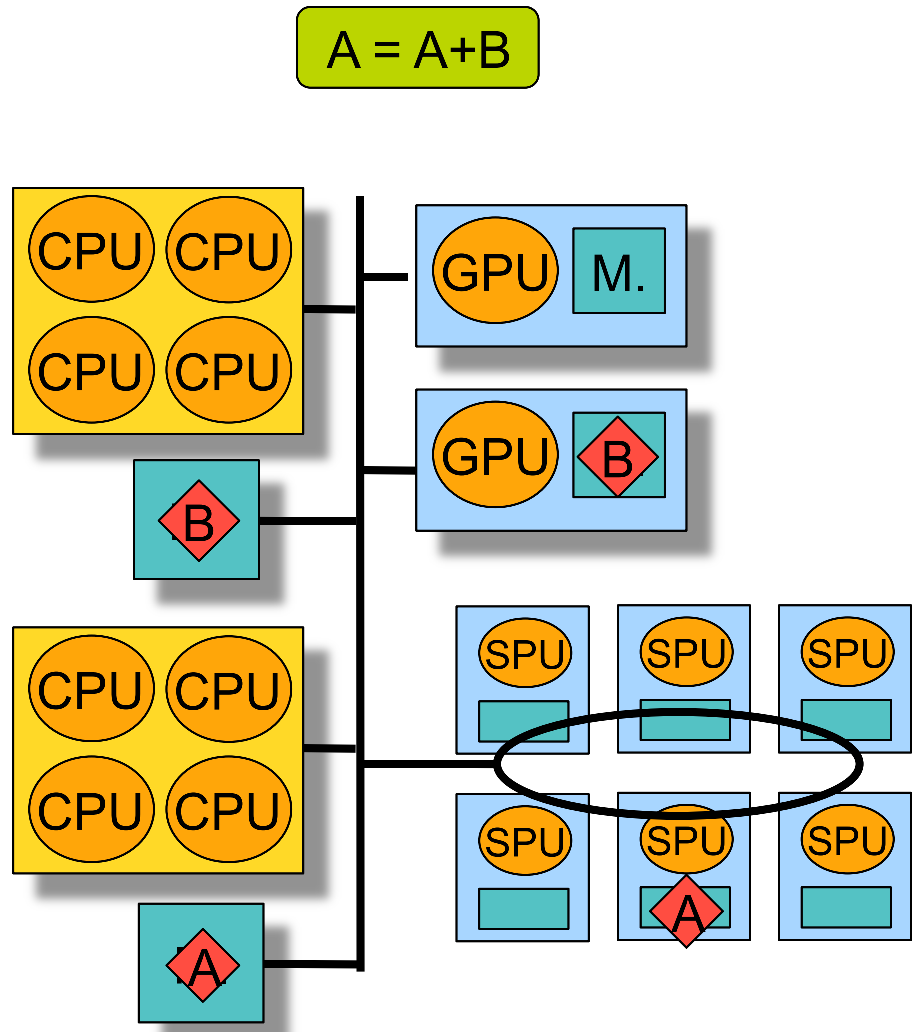


- Challenge = exploiting all computing units simultaneously
- Either use a hybrid programming model
  - E.g. OpenMP + HMPP + Intel TBB + CUBLAS + MKL + …
- Or use a uniform programming model
  - That doesn't exist yet…

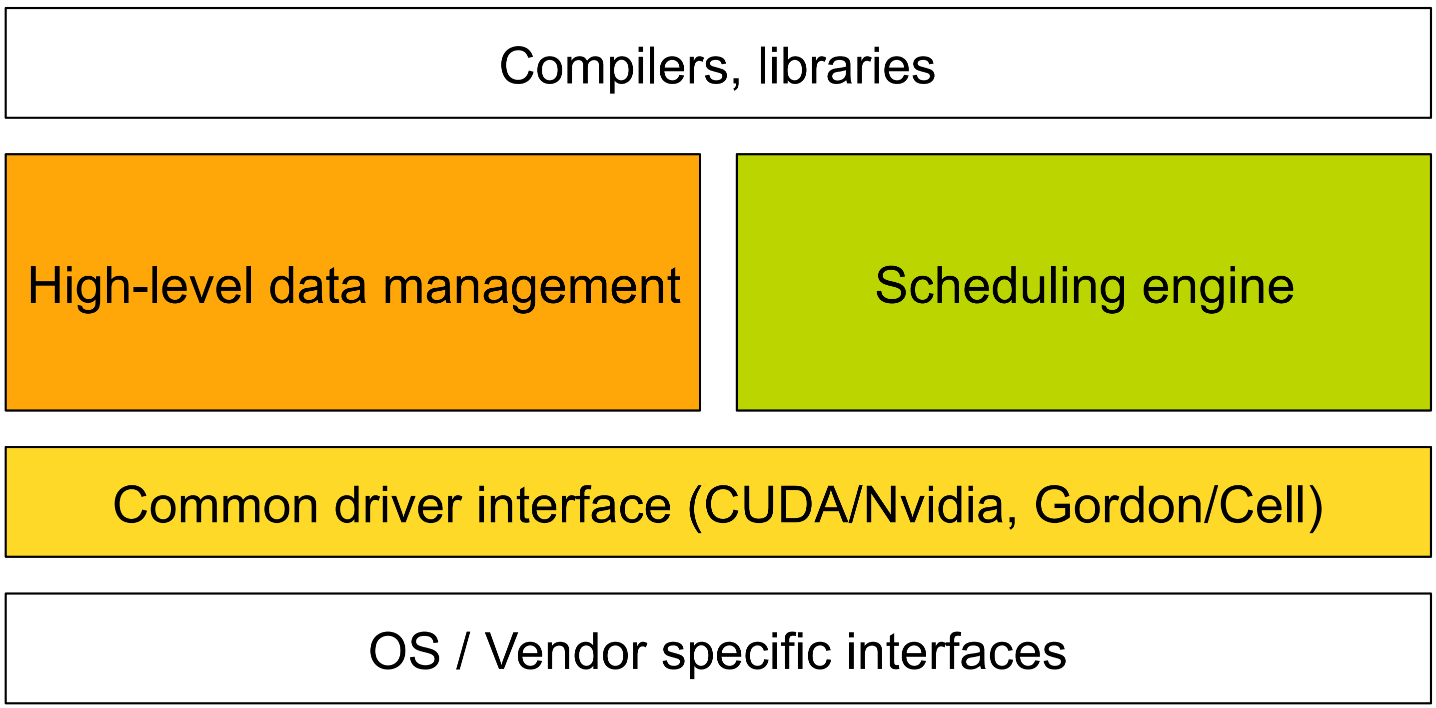
In either case,
a common runtime
system is needed!

Towards a unified execution model

- We wanted our runtime to fulfill the following requirements:
  - Dynamically schedule tasks on all processing units
    - See a pool of heterogeneous cores
  - Avoid unnecessary data transfers between accelerators
    - Need to keep track of data copies



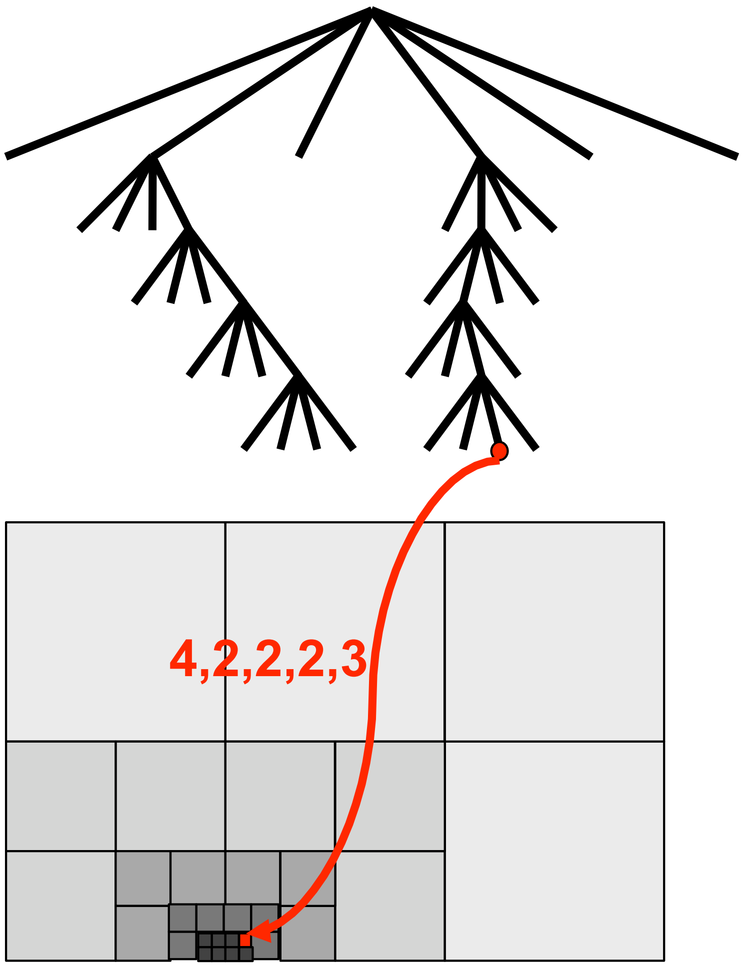
The StarPU Runtime System



Mastering CPUs, GPUs, SPUs ...
(hence the name: ***PU**)

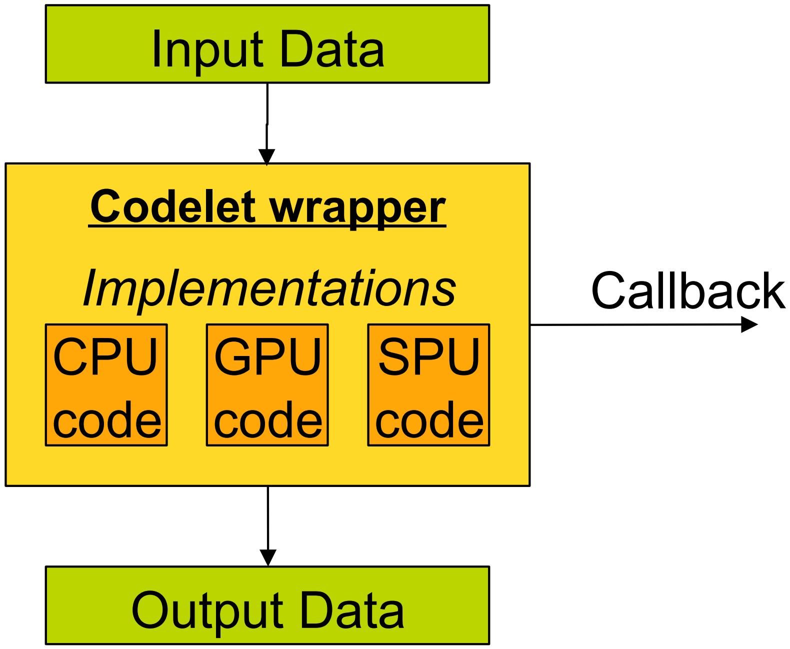
High-Level Data Management

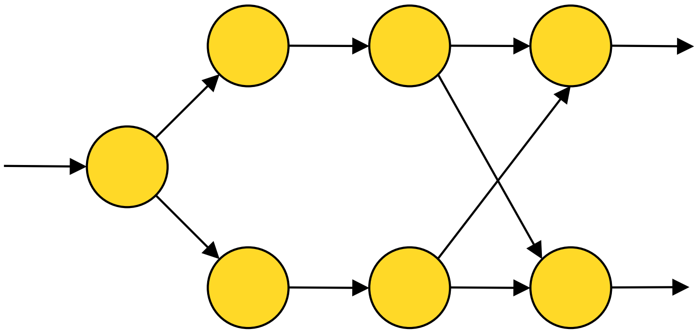
- All we need is a Software DSM system!
  - Consistency, replication, migration
  - Concurrency, accelerator to accelerator transfers
  - Memory reclaiming mechanism
    - Problem size > accelerator size
- Data partitioned with filters
  - Various interfaces
    - BLAS, vector, CSR, CSC
  - Recursively applied
    - Structured data = tree



Scheduling Engine

- Tasks are manipulated through "codelet wrappers"
  - May provide multiple implementations
    - Scheduling hints
      - Optional cost model per implementation, priority, …
  - List data dependencies
    - Using the filter interface
  - Maybe automatically generated
- Schedulers are plug-ins
  - Assign tasks to run queues
  - Dependencies and data prefetching are hidden

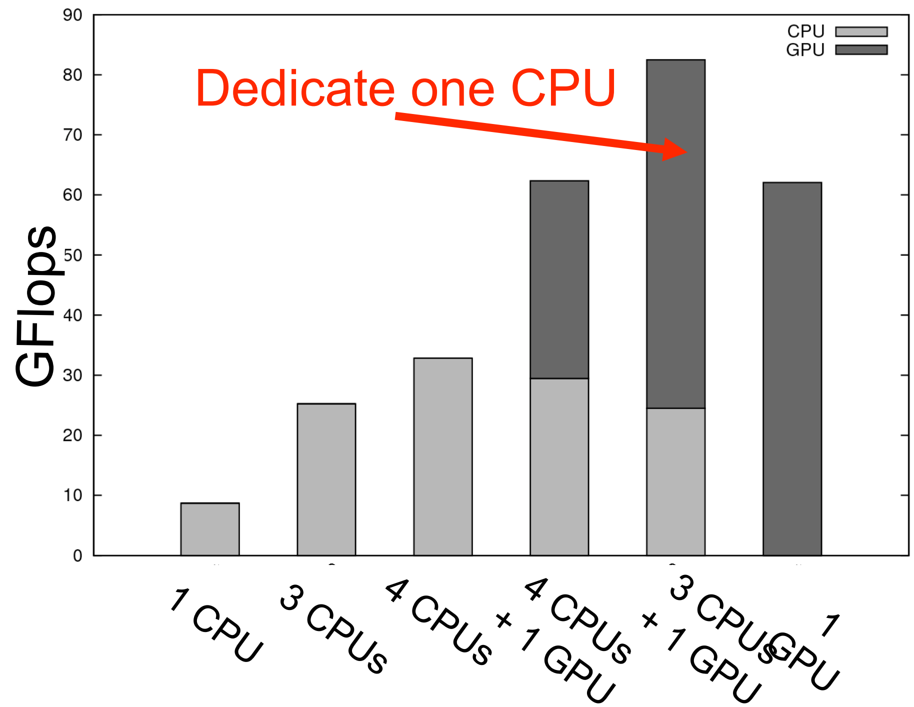




Evaluation

Blocked matrix multiplication

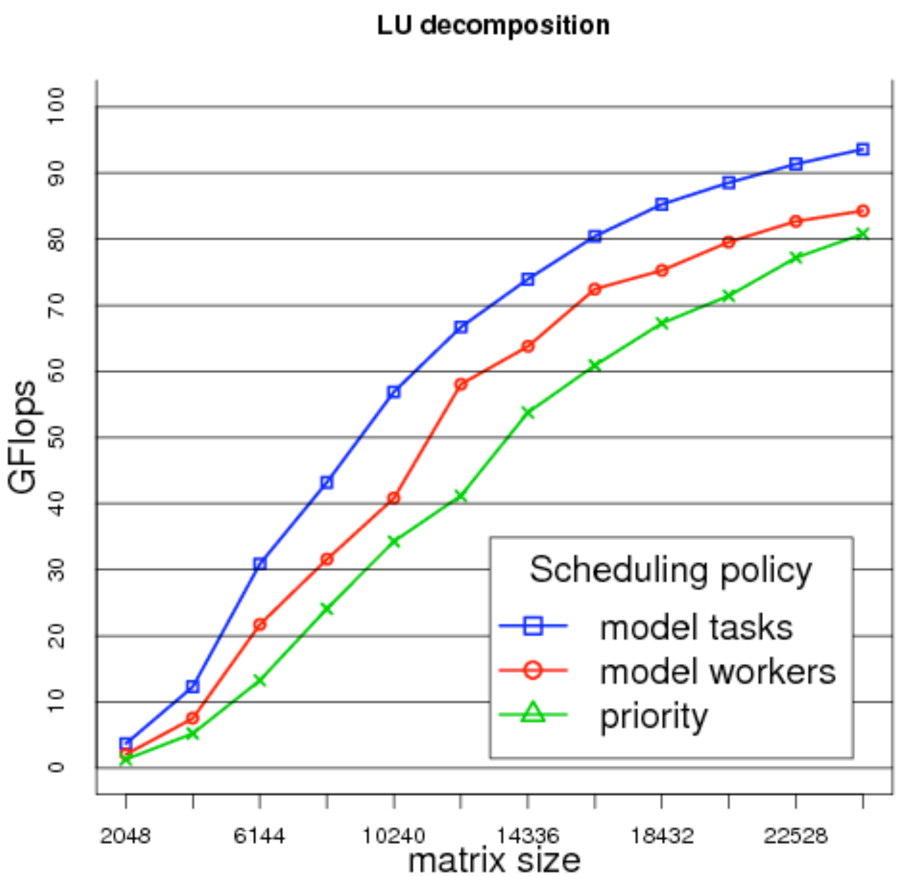
- ✓ Exploit heterogeneous platform
  - 4 CPUs + 1 GPU
- ✓ CPUs must not be neglected!
- ✗ Issues with 4 CPUs + 1 GPU
  - Busy CPU delays GPU management
  - Cache-sensitive CPU code
- Trade-off : dedicate one core



quadcore Intel Xeon
+ nVidia Quadro FX4600

Evaluation

About the importance of performance models



Modeling **workers**' performance

- "1 GPU = 10x faster than 1 CPU"
- Reduce load imbalance
- Fuzzy approximation

Modeling **tasks** execution time

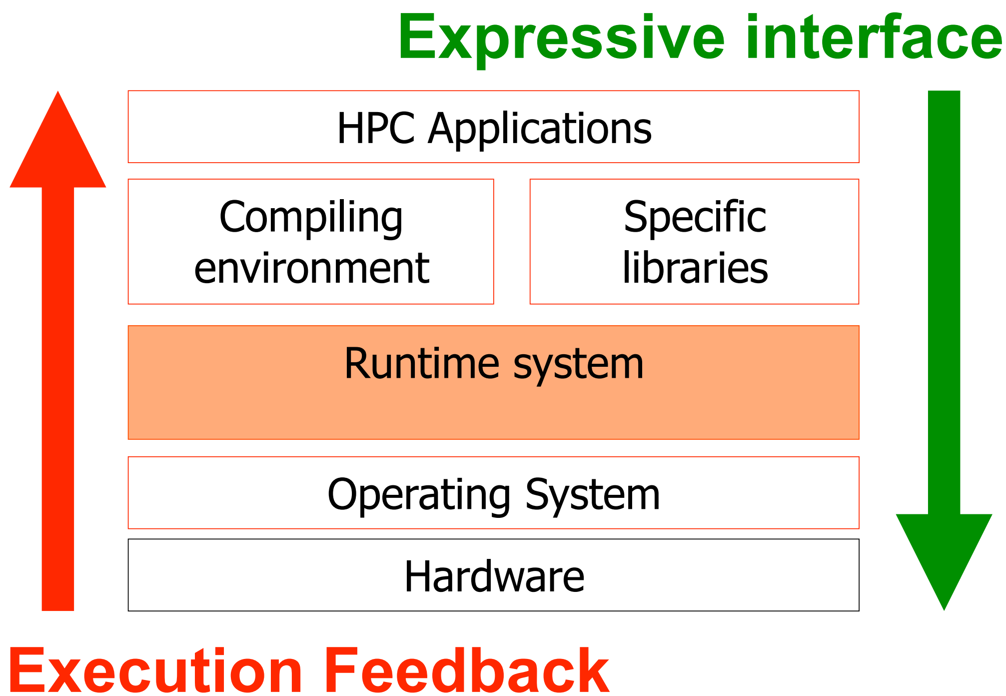
- Precise performance models
  - "mathematical" models
  - user-provided models
- automatic "learning" for unknown codelets

What did we learn?

- All computing units must be used simultaneously to achieve high performance
  - "Pure offloading" is not sufficient
- Performance models and scheduling policies have a high impact on performance
  - The scheduling platform must be open
- Finding the best task granularity is *very* difficult
  - Has to be decided dynamically!

What did we learn?

- Programmers (usually) know their application
  - Don't guess what we know!
  - Scheduling hints
- Feedback is important
  - E.g. Performance counters
  - Adaptive applications?
- Other Issues
  - Can we still find a unified execution model?
  - How to determine the appropriate task granularity?

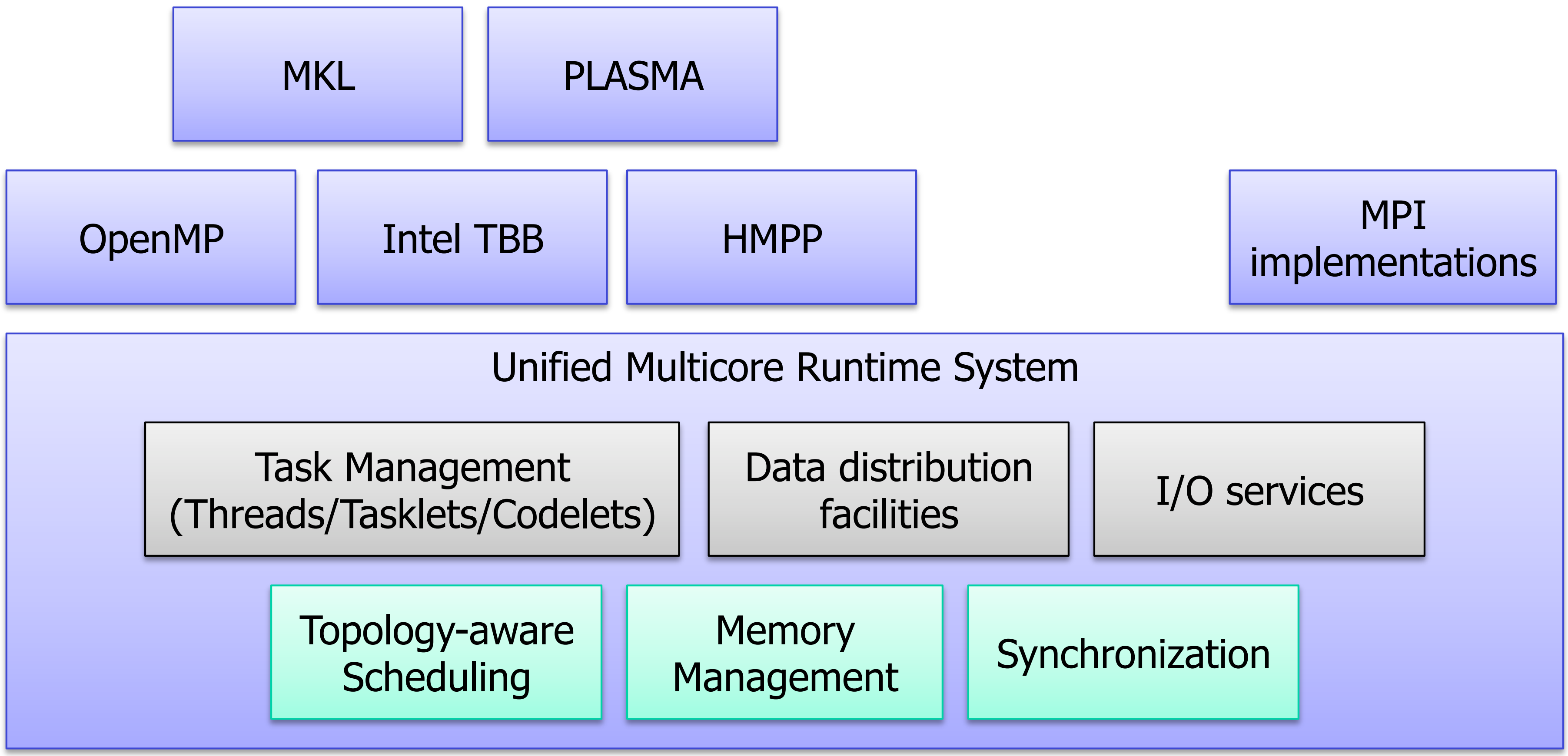


Challenges for the upcoming years

- Integrate more than just two programming models
  - We can’t seriously consider codeletizing the world…
  - E.g. support execution of MPI + OpenMP + StarPU programs
- Provide an open scheduling framework
  - Adaptive, portable scheduling/optimization strategies
  - Using hardware feedback to refine/correct scheduling directives
- Enhance cooperation between runtime systems and compilers
  - Runtime support for “divisible tasks”
- Understanding performance, debugging

Challenges for the upcoming years

- The main challenge is composability
  - Future application will be composed of several types of bricks



Thank you!

- More information about Runtime

  http://runtime.bordeaux.inria.fr

- More information about StarPU and ForestGOMP

  http://runtime.bordeaux.inria.fr/starpu

  http://runtime.bordeaux.inria.fr/forestgomp

- Software available on INRIA Gforge:

  http://gforge.inria.fr/projects/pm2/