Barcelona Supercomputing Center
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OpenMP tasking model: from the standard to the classroom

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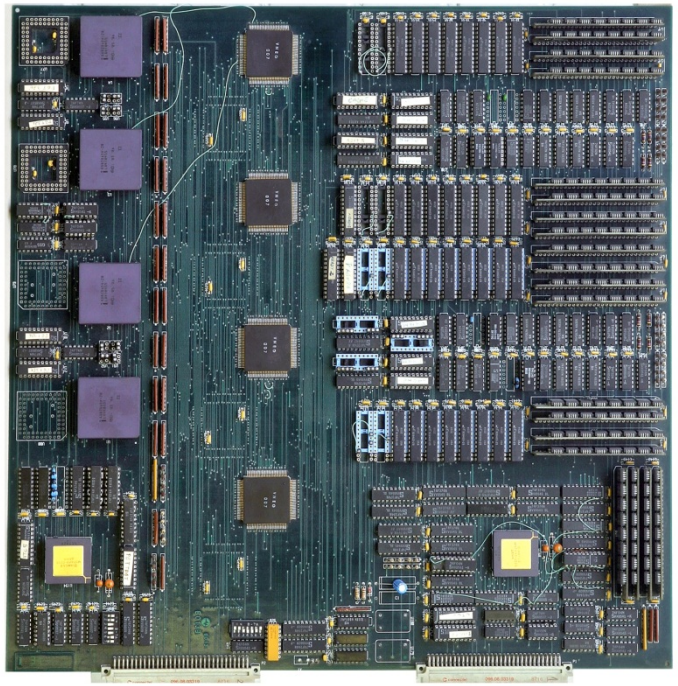
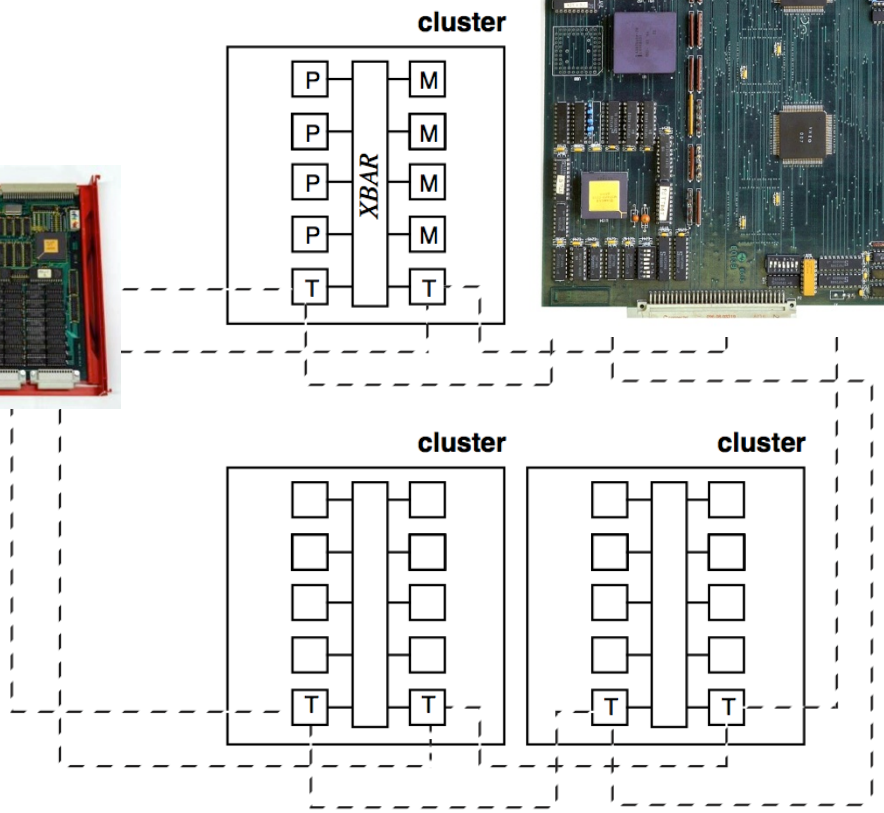
EXCELENCIA
SEVERO
OCHOA

Madrid. March 30, 2017

ICT386 multiprocessor architecture, late 80s





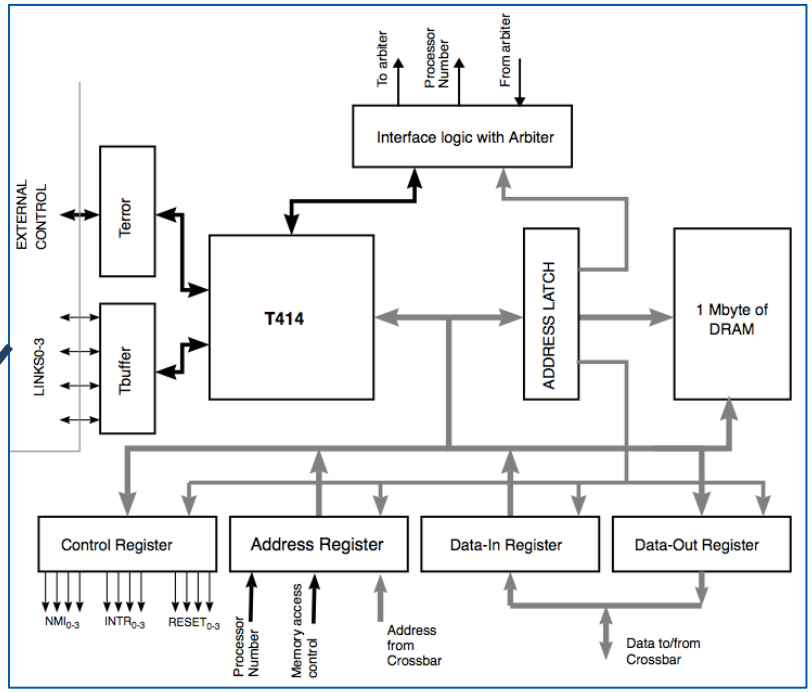
4 x CPU module
- i386/i387
- no private cache memory

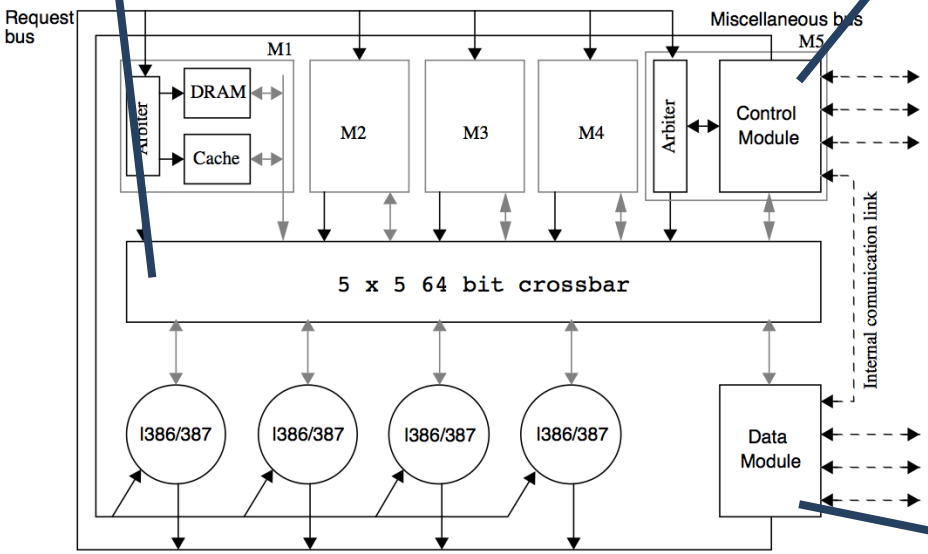
4 x Memory module
- 4 MB DRAM (100 ns)
- 64 KB **shared cache**
- 25 ns, direct-mapped

ICT386 multiprocessor architecture, late 80s

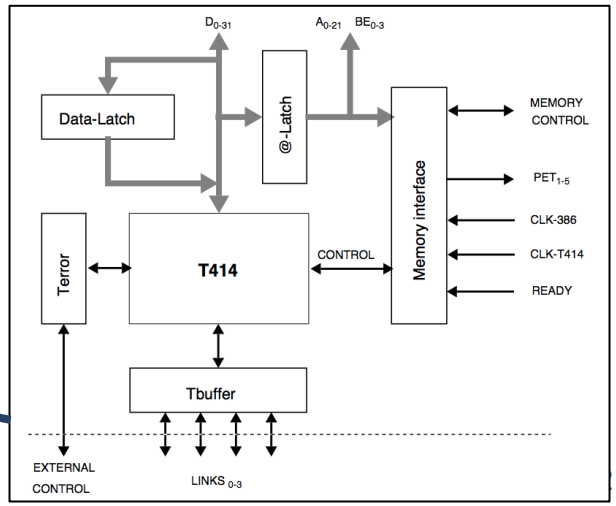
Crossbar 5x5
Gate array design
10 ns transfer

Intellligent memory
Memory mapped
1 MB DRAM
Functions: management, **synchronization and scheduling**





Programmable NIC

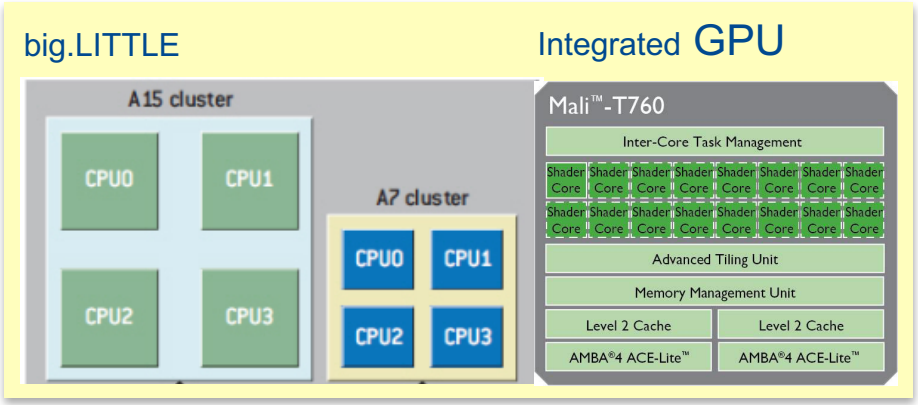


And the wall has become higher and higher …

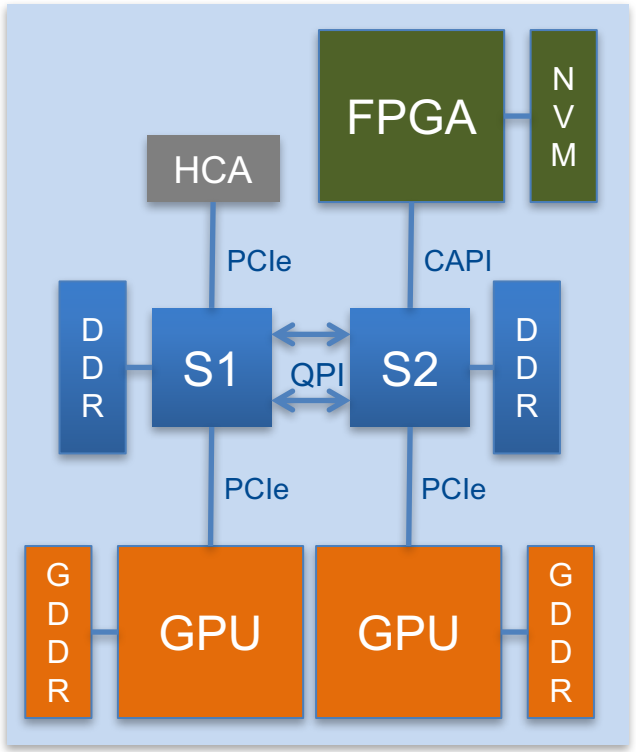
Rank	Name	Site	Computer	Total Cores	Accelerator/ Co-Proc. Cores
1	Sunway TaihuLight	National Supercomputing Center in Wuxi	Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway	10649600	0
2	Tianhe-2 (MilkyWay-2)	National Super Computer Center in Guangzhou	TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P	3120000	2736000
3	Titan	DOE/SC/Oak Ridge National Laboratory	Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x	560640	261632
4	Sequoia	DOE/NNSA/LLNL	BlueGene/Q, Power BQC 16C 1.60 GHz, Custom	1572864	0
5	Cori	DOE/SC/LBNL/NERSC	Cray XC40, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect	622336	0

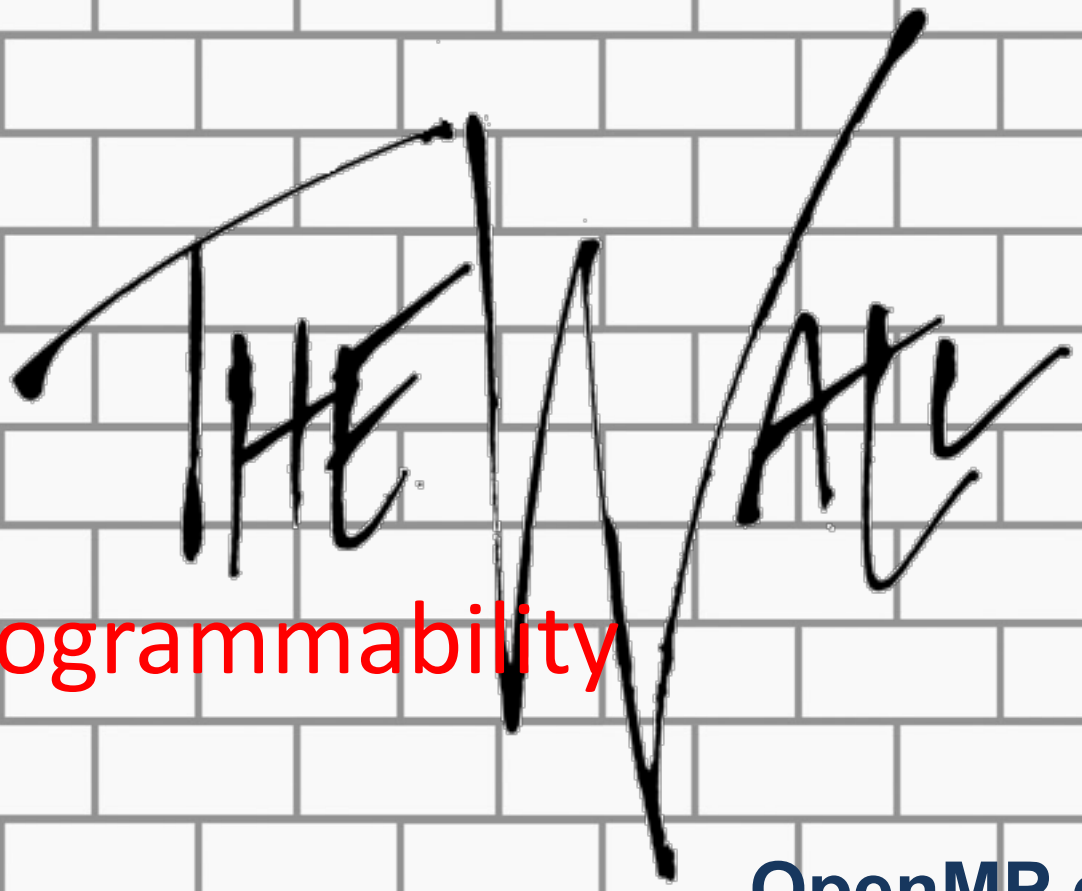
Top5 November 2016 list

Socket



Node





Programmability

OpenMP evolution and OmpSs influence

Runtime opportunities

Architecture opportunities

Teaching opportunities

1979 Pink Floyd's The Wall album,
Cray-1 delivering 80 Mflops, single processor

The vision

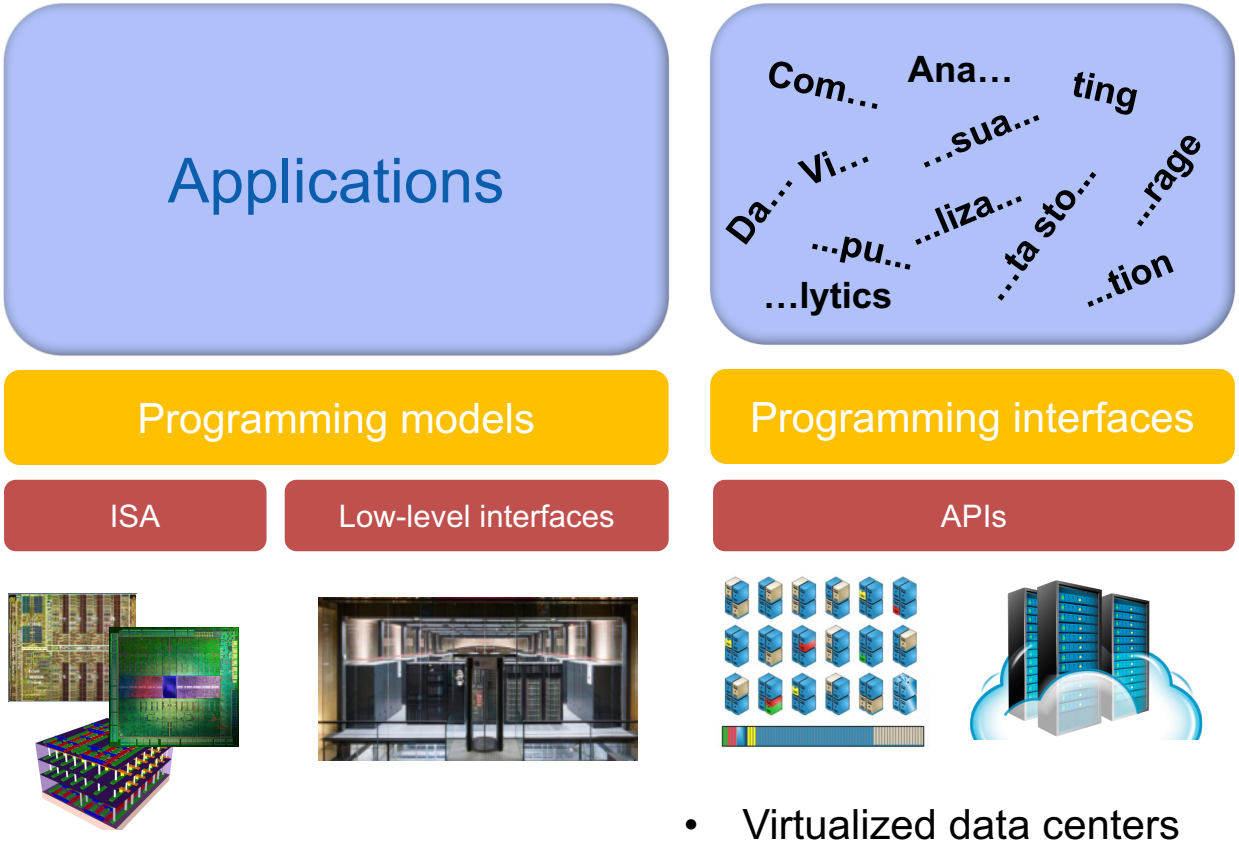
New **application domains**

Programmability and **porting/inter-operability**
- Legacy codes
- ”Legacy” mental models and habits

ISA/PM **leaks** and **variability/faults/errors** everywhere
- Programmer exposed
- Divergence between mental models and actual behavior

Plethora of architectures
- Heterogeneity
- Hierarchies

New **usage practices**
- Analytics and visualization
- New data models
- Interactive supercomputing, response time



- Virtualized data centers
- Cloud

The vision

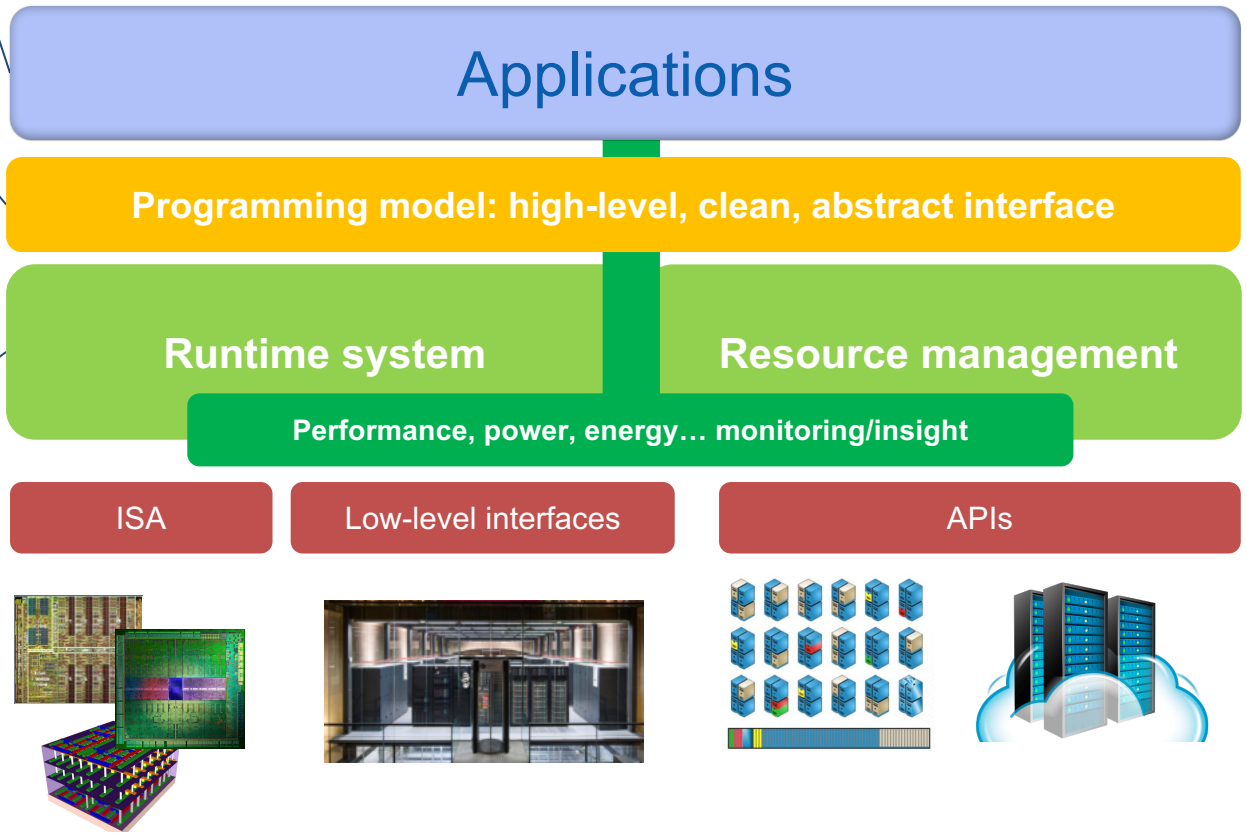
Program logic independent of computing platform

General purpose
Task based
Single address space

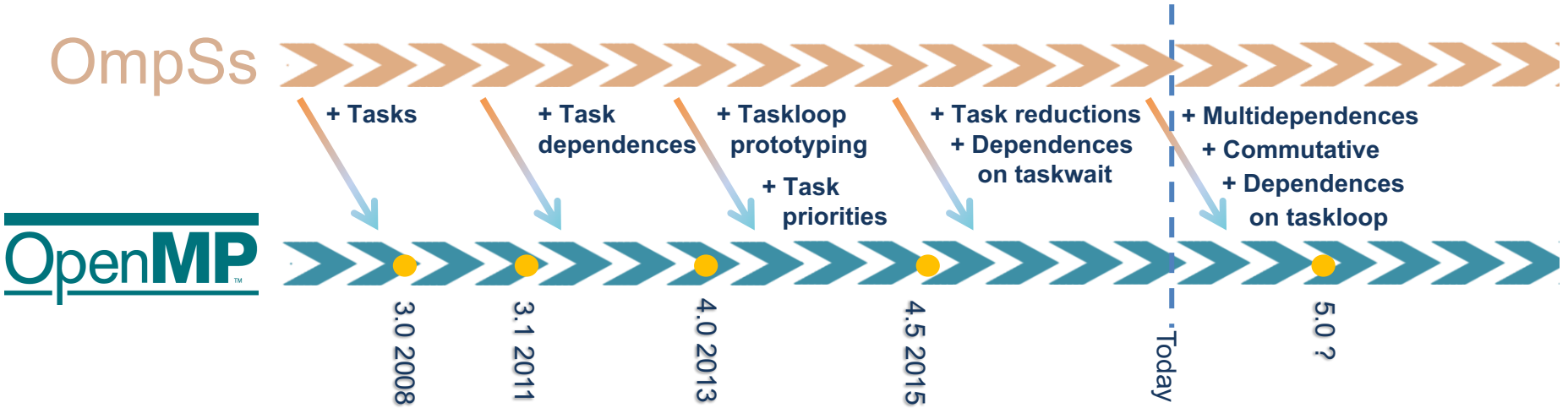
Intelligent runtime, parallelization, distribution, interoperability

Resource management

Performance- and power-driven optimization/tuning



The OmpSs forerunner for OpenMP



- Proposing ideas …
  - IWOMP workshop is the ideal scenario
  - Participation in the OpenMP language committee and sub-committees
- Demonstrated with …
  - Prototype implementation: Mercurium compiler and Nanos runtime
  - Benchmark/application suite
- Lots of discussions and final polishing

OmpSs influencing tasking model evolution (1)

- The big change …

task-based model, nesting of tasks (3.0)

```
#pragma omp task firstprivate(list) final(expr) priority(value)
{ code block }
```

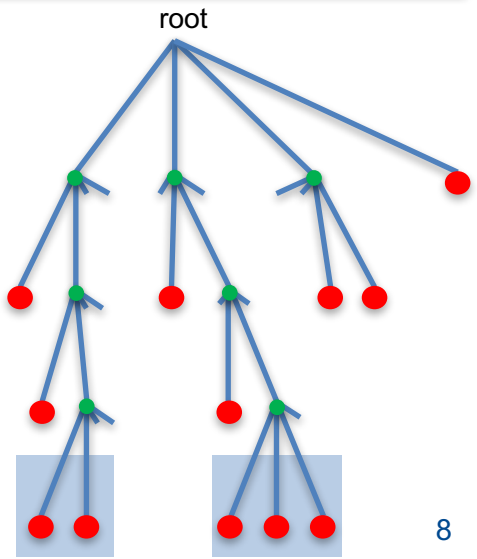
task generation cut-off (3.1)

task priorities (4.5)

```
#pragma omp taskwait
```

task generation waits for child tasks to finish (3.0)

- From loop-based model to task-based model
  - Dynamically allocated data structures (lists, trees, …)
  - Recursion

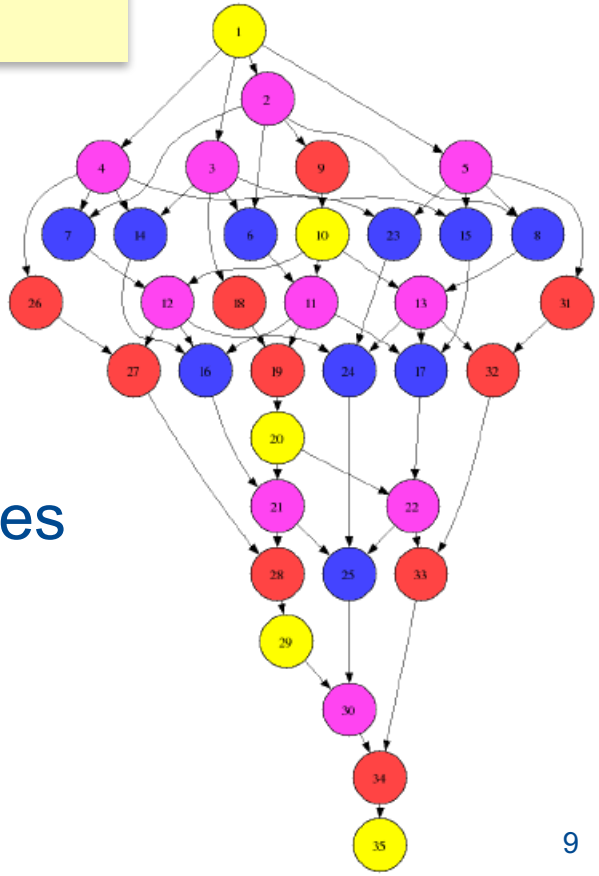


OmpSs influencing tasking model evolution (2)

- Directionality of task arguments

directionality for task arguments (4.0)

```
#pragma omp task depend(in: list, out: list, inout: list)
{ code block }
```



- Dependences between tasks computed at runtime
- Tasks executed as soon as all dependences are satisfied

OmpSs influencing tasking model evolution (3)

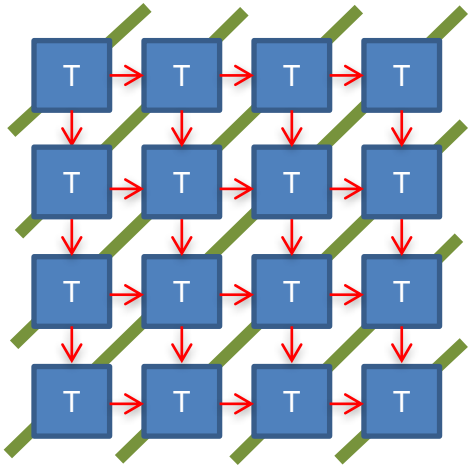
- Tasks become chunks of iterations of one or more associated loops

```
#pragma omp taskloop [num_tasks(value) | grainsize(value)]
   for-loops
```

tasks out of loops and granularity control (4.5)

- Dependences between tasks generated in the same or different taskloop construct under discussion

```
#pragma omp taskloop block(2) grainsize(B, B)
        depend(in : block[i-1][j], block[i][j-1])
        depend(in : block[i+1][j], block[i][j+1])
        depend(out: block[i][j])
for (i=1; i<n i++)
    for (j=1; j<n;j++)
        foo(i, j);
```



OmpSs influencing tasking model evolution (4)

- Reduction operations on task and taskloop not yet supported, currently in discussion

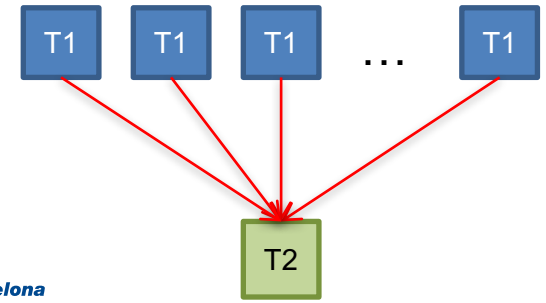
```
#pragma omp taskgroup reduction(+: res)
{
  while (node) {
    #pragma omp task in_reduction(+: res)
    res += node->value;

    node = node->next;
  }
}
```

```
#pragma omp taskloop grainsize(BS) reduction(+: res)
for (i = 0; i < N; ++i) {
  res += foo(v[i]);
}
```

OmpSs influencing tasking model evolution (5)

- The number of task dependences have to be constant at compile time → multidependences proposal under discussion

```
for (i = 0; i < l.size(); ++i) {
  #pragma omp task depend(inout: l[i])                    // T1
  { ... }
}

#pragma omp task depend(in: {l[j], j=0:l.size()}) // T2
for (i = 0; i < l.size(); ++i) {
  ...
}
```

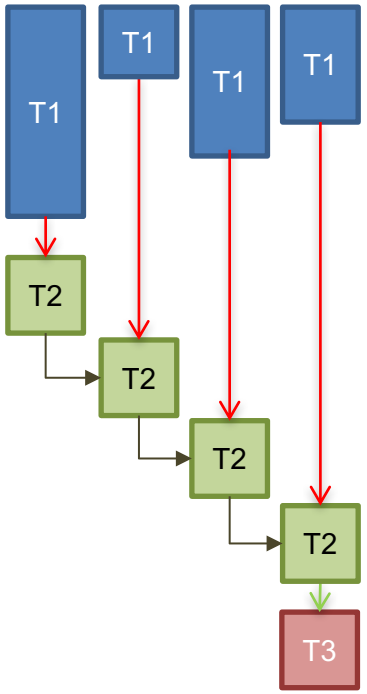


Defines an iterator with a range of values that only exists in the context of the directive. Equivalent to:
`depend(in: l[0], l[1], ..., l[l.size()-1])`

OmpSs influencing tasking model evolution (6)

- New dependence type that relaxes the execution order of commutative tasks but keeping mutual exclusion between them

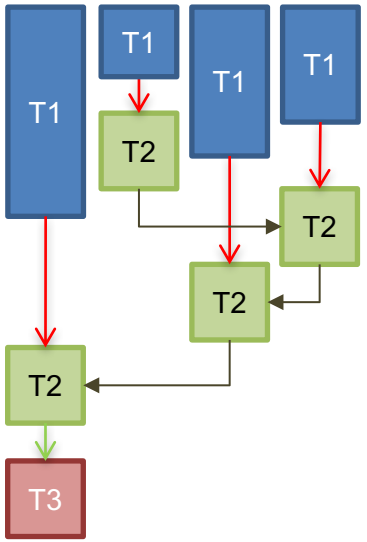
```
for (i = 0; i < l.size(); ++i) {
  #pragma omp task depend(out: l[i])
  // T1
}

for (i = 0; i < l.size(); ++i) {
   #pragma omp task shared(x) depend(in: l[i])
                              depend(inout: x)
   // T2
}

#pragma omp task shared(x) depend(in: x)          // T3
for (i = 0; i < l.size(); ++i) {
  ...
}
```



OmpSs influencing tasking model evolution (6)

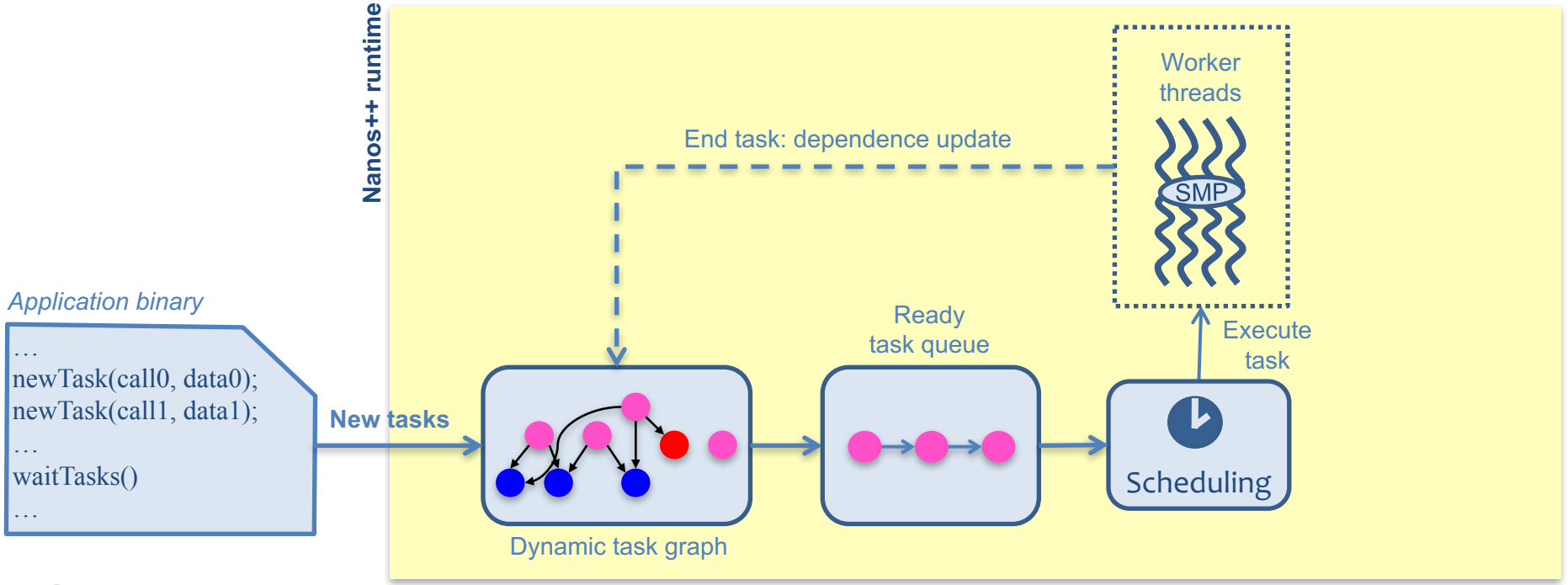
- New dependence type that relaxes the execution order of commutative tasks but keeping mutual exclusion between them

```
for (i = 0; i < l.size(); ++i) {
  #pragma omp task depend(out: l[i])
  // T1
}

for (i = 0; i < l.size(); ++i) {
   #pragma omp task shared(x) depend(in: l[i])
                              depend(commutative: x)
   // T2
}

#pragma omp task shared(x) depend(in: x)          // T3
for (i = 0; i < l.size(); ++i) {
  ...
}
```



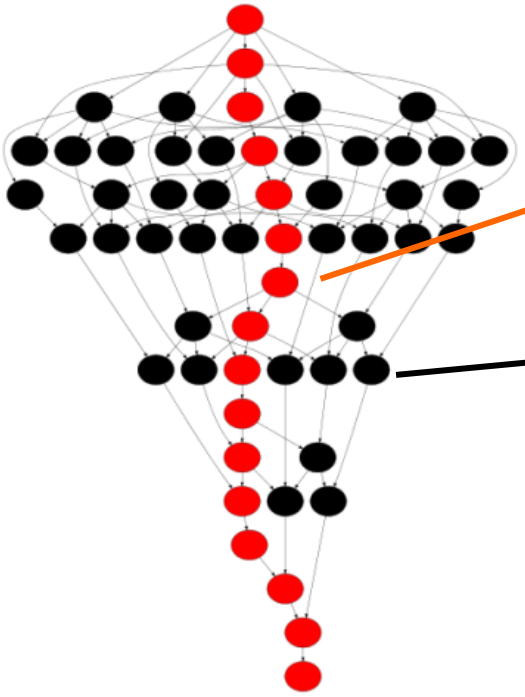
OmpSs: runtime opportunities (1)

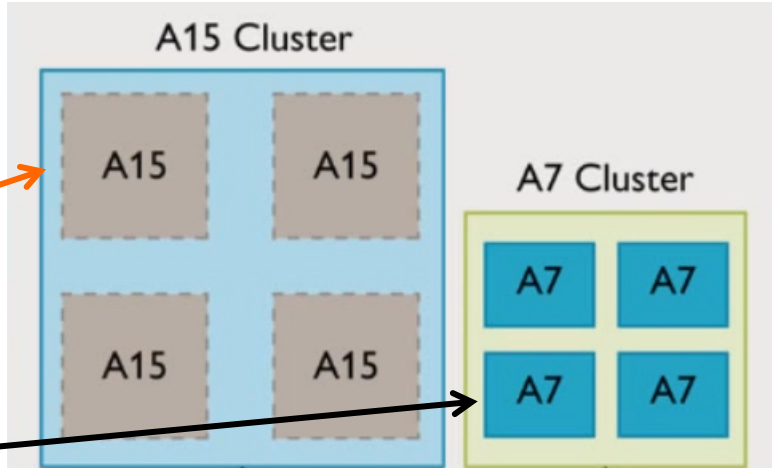
- Runtime parallelization
  - Compute data dependences among tasks → dynamic task graph
  - Dataflow execution of tasks → ready task queue
  - Look-ahead: task instantiation can proceed past non-ready tasks (with opportunities to find distant parallelism)

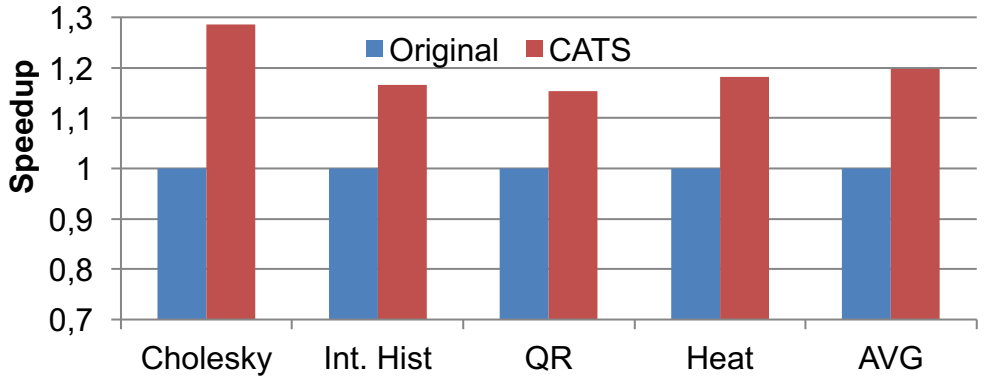


OmpSs: runtime opportunities (2)

- Criticallity-aware scheduler: managing heterogeneous SoC
  - Tasks in the critical path detected at runtime → execute in faster cores
  - Non-critical tasks executed in slower, more power-efficient cores
  - Work-stealing for load balancing



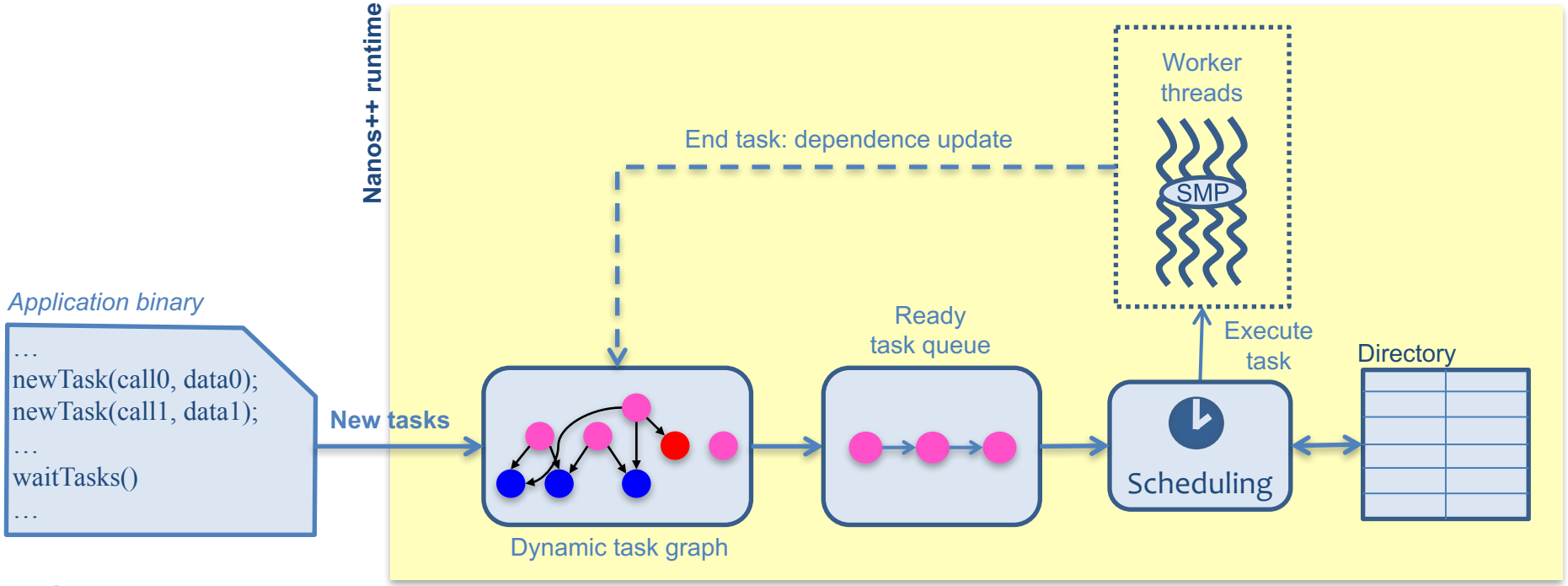




"Criticality-Aware Dynamic Task Scheduling on Heterogeneous Architectures". K. Chronaki et al. ICS-2015

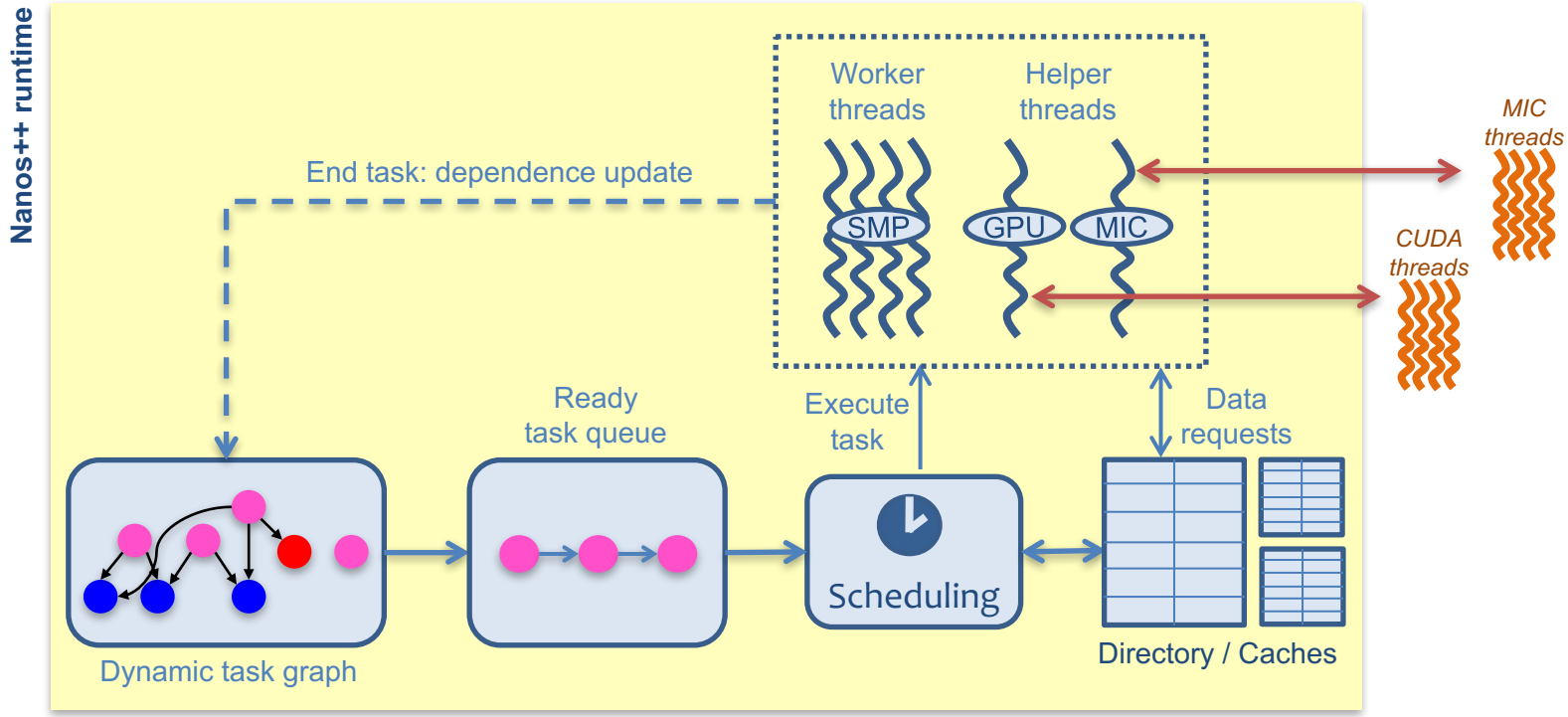
OmpSs: runtime opportunities (3)

- Runtime parallelization
- Directory with per-core arguments utilization
  - Locality-aware task scheduling strategies
  - Driving argument prefetching



OmpSs: runtime opportunities (4)

- Management of address spaces and coherence
  - Directory@master: identifies for every region reference where data is
  - Per-device software cache: translate host to device address spaces
  - Use of device specific mechanisms to move data, if needed
  - Locality-aware scheduling when multiple devices exist



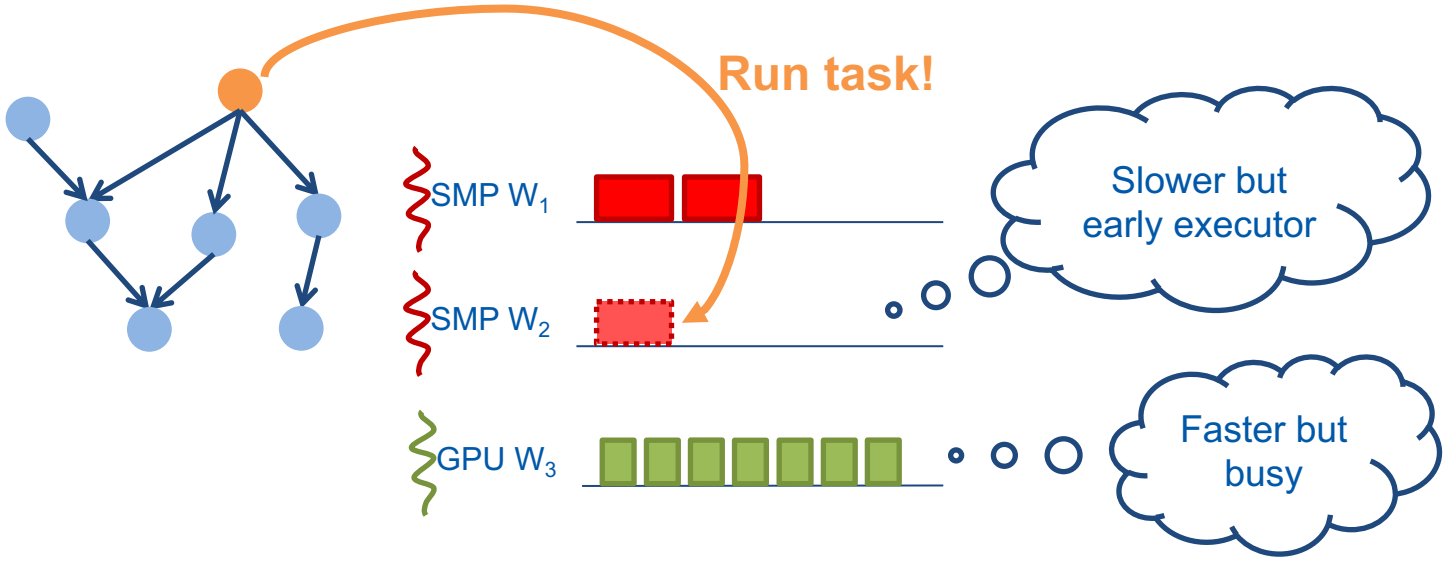
"Self-Adaptive OmpSs Tasks in Heterogeneous Environments". J. Planas et al., IPDPS 2013.

Example: nbody

```
#pragma omp target device(smp) copy_deps
#pragma omp task depend(out: [size]out), in: [npart]part)
void comp_force (int size, float time,  int npart, Part* part, Particle *out, int gid);

#pragma omp target device(fpga) ndrange(1,size,128) copy_deps implements (comp_force)
#pragma omp task depend(out: [size]out), in: [npart]part)
__kernel void comp_force_opencl (int size, float time,  int npart, __global Part* part,
                                                    __global Part* out, int gid);

#pragma omp target device(cuda) ndrange(1,size,128) copy_deps implements (comp_force)
#pragma omp task depend(out: [size]out), in: [npart]part)
__global__ void comp_force_cuda (int size, float time,  int npar, Part* part, Particle *out, int gid);



void Particle_array_calculate_forces(Particle* input, Particle *output, int npart, float time) {
   for (int i = 0; i < npart; i += BS )
        comp_force (BS, time, npart, input, &output[i], i);
}
```

OmpSs: runtime opportunities (5)

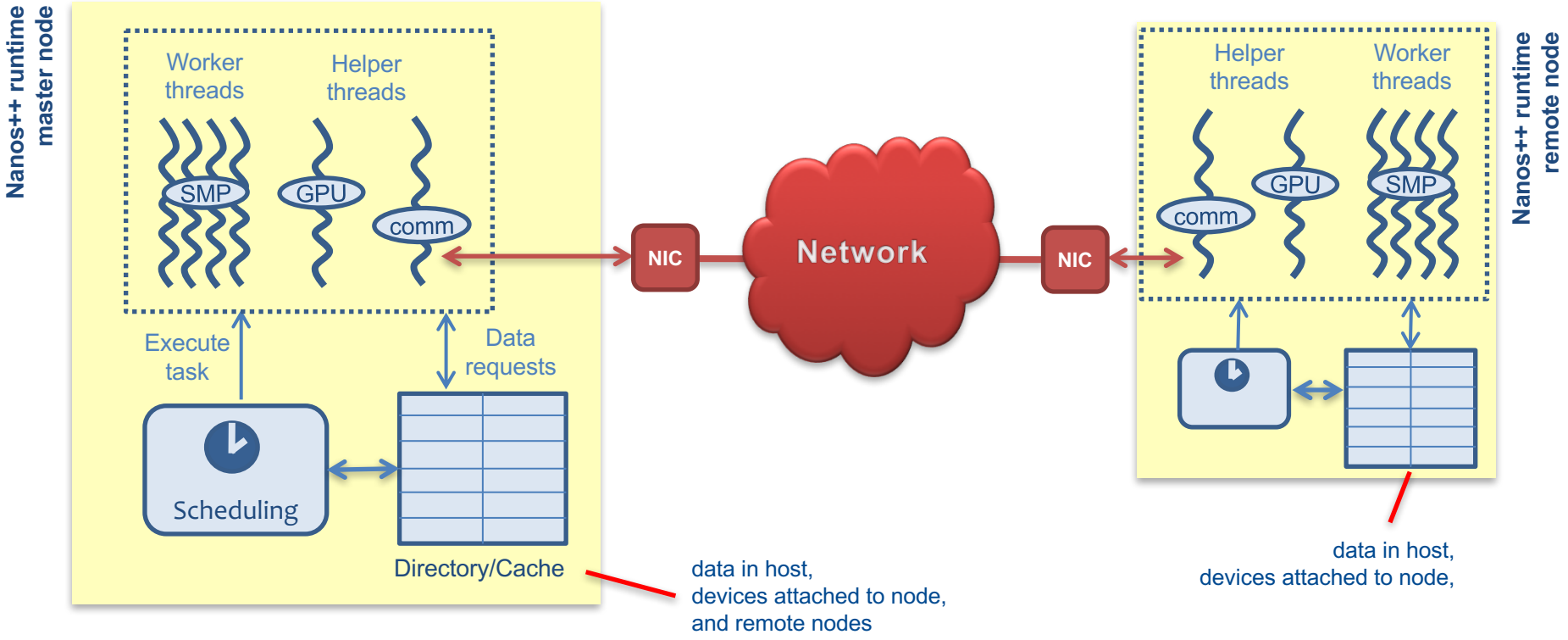
- Support for multiple implementations for same task
  - Versioning scheduler:
    - Monitoring (learning) phase and scheduling phase
    - Most suitable implementation is selected each time depending on monitoring, simple model and OmpSs worker's work load



"Self-Adaptive OmpSs Tasks in Heterogeneous Environments". J. Planas et al., IPDPS 2013.

OmpSs: runtime opportunities (6)

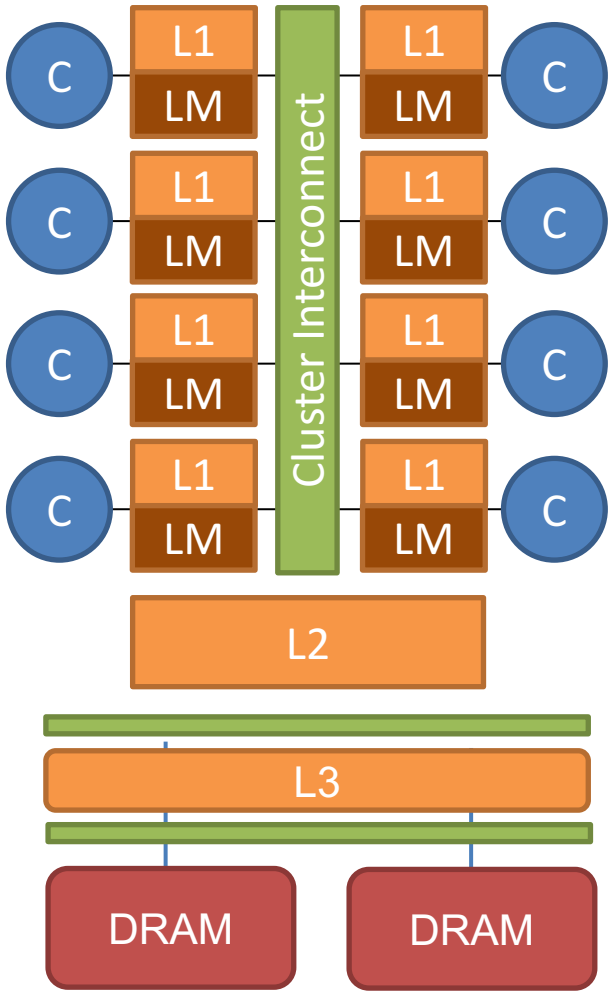
- At cluster …
  - Task creation starts at master node, outermost tasks may be executed on remote nodes and spawn inner tasks
  - Locality-aware scheduler, overlap transfers/computation, work stealing



"Productive Cluster Programming with OmpSs". J. Bueno et al. EuroPar 2011.
"Productive Programming of GPU Clusters with OmpSs". J. Bueno et al., IPDPS 2012.

OmpSs: architecture opportunities (1)

- Novel hybrid cache/local memory
  - Cache: irregular accesses
  - Local memory (energy efficient, less coherence traffic): strided accesses
- Runtime-assisted prefetching
  - Task inputs and outputs mapped to the LMs
  - Overlap with runtime
  - Double buffering between tasks
- 8.7% speedup, 14% reduction in power, 20% reduction in network-on-chip traffic



"Runtime-Guided Management of Scratchpad Memories in Multicores." Ll. Alvarez et al. Ç PACT-2015

OmpSs: architecture opportunities (3)

- Task dependence manager to speedup task management and dependence tracking

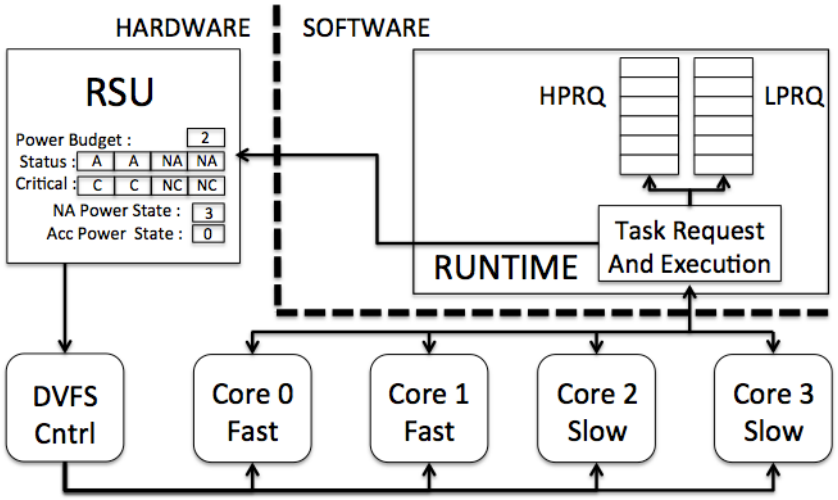
  X. Tan et al. Performance Analysis of a Hardware Accelerator of Dependency Management for Task-based Dataflow Programming models. ISPASS 2016.
  X. Tan et al. General Purpose Task-Dependence Management Hardware for Task-based Dataflow Programming Models. IPDPS 2017.

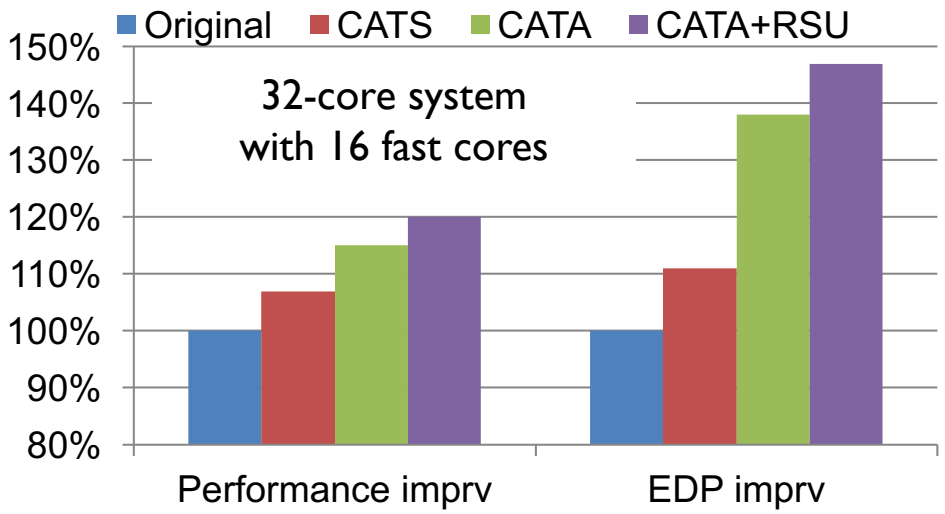
- Hardware support for reductions
  - Privatization of variables to speedup reduction → Significant overhead when performing reductions on a vector or matrix block.
  - HW support to perform simple reduction operations (+, -, *, max, min) in the last-level cache or in memory → In-memory computation

  J. Ciesko et al. Supporting Adaptive Privatization Techniques for Irregular Array Reductions in Task-parallel Programming Models. IWOMP 2016.

OmpSs: architecture opportunities (2)

- CATA: criticallity-aware task acceleration
  - Runtime drives per-core DVFS reconfigurations meeting a global power budget
  - Hardware Runtime Support Unit (RSU) to minimize overheads that grow with the number of cores



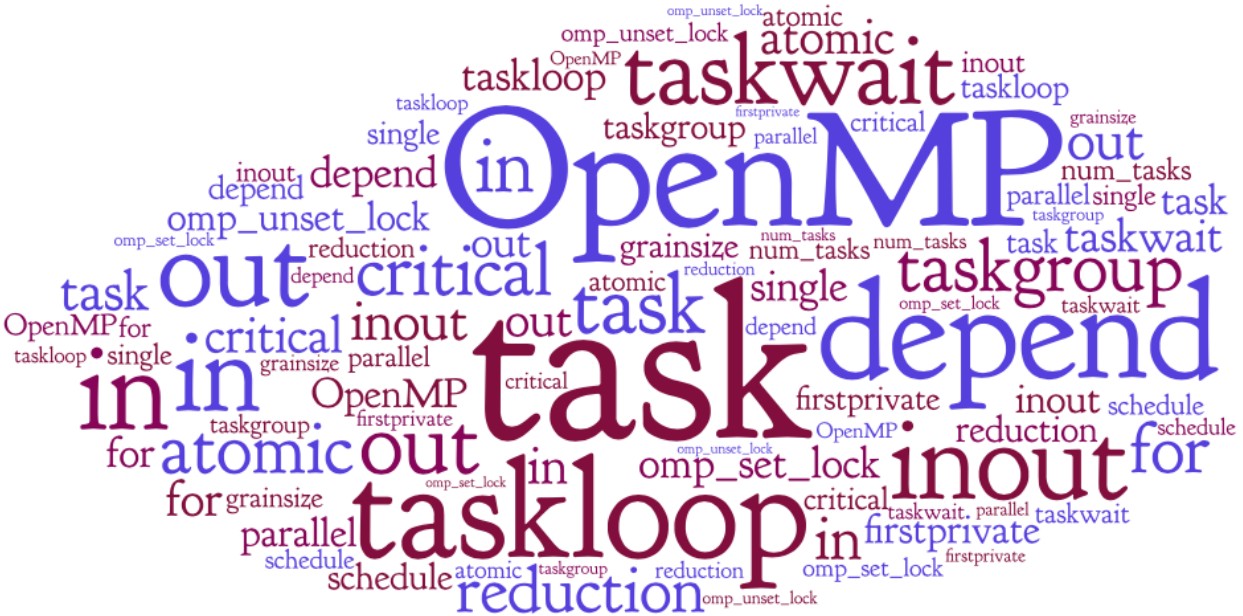


E. Castillo et al., CATA: Criticality Aware Task Acceleration for Multicore Processors. IPDPS 2016.

Teaching opportunities (1)

- Two courses in Computer Science BSc @ FIB (UPC)
  - PAR – Parallelism: 5th semester, mandatory course
  - PAP – Parallel Architectures and Programming: optional, computer engineering specialization

- OpenMP task-based programming @ node level



Teaching opportunities (2)

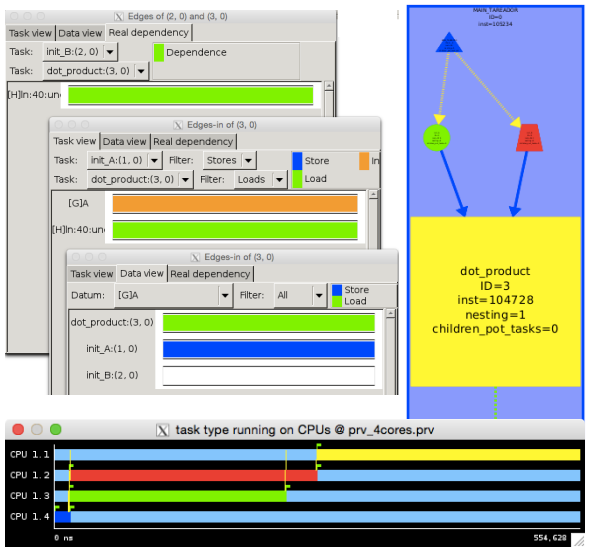
Syllabus

- Tasks, task graph, parallelism
- Overheads and model: task creation, synchronization, data sharing
- Task decomposition: linear, iterative, recursive
- Task ordering and data sharing constraints
- The magic of the architecture: cache coherency and synchronizatio support
- Data decomposition and influence of memory

OpenMP tasks at its heart, going towards task-only parallel programming

- Embarrassingly parallel, recursive task decomposition, task/data decomposition, and branch and bound
- Tareador tool for the exploration of task decomposition strategies

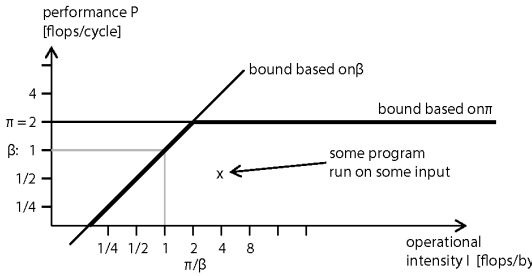
Innovation:
(pseudo-) flipped-classroom model



Teaching opportunities (2)

Syllabus

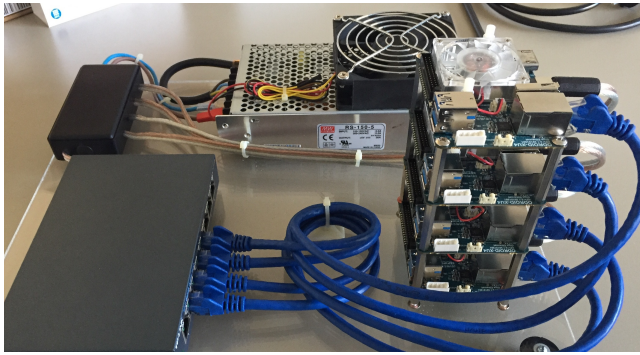
- Compiler and runtime support to OpenMP
- Pthreads API and lib intrinsics
- Designing an HPC cluster: components and interconnect, roofline model for flops/bw
- Message-passing interface MPI



PAP

OpenMP for node programming, with MPI towards cluster programming

- OpenMP tasking review
- Implementing a runtime to support OpenMP
- Building a 4xOdroid cluster: hard and soft installation: the effect of heterogeneity
- Programming the 4xOdroid cluster with MPI: Stencil with Jacobi



Innovation: puzzle work in groups when designing cluster


Thanks
https://www.bsc.es