PEPPHER
Programmability & Portability

PEPPHER HiPeac workshop
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Work-stealing for mixed-mode parallelism by deterministic team-building

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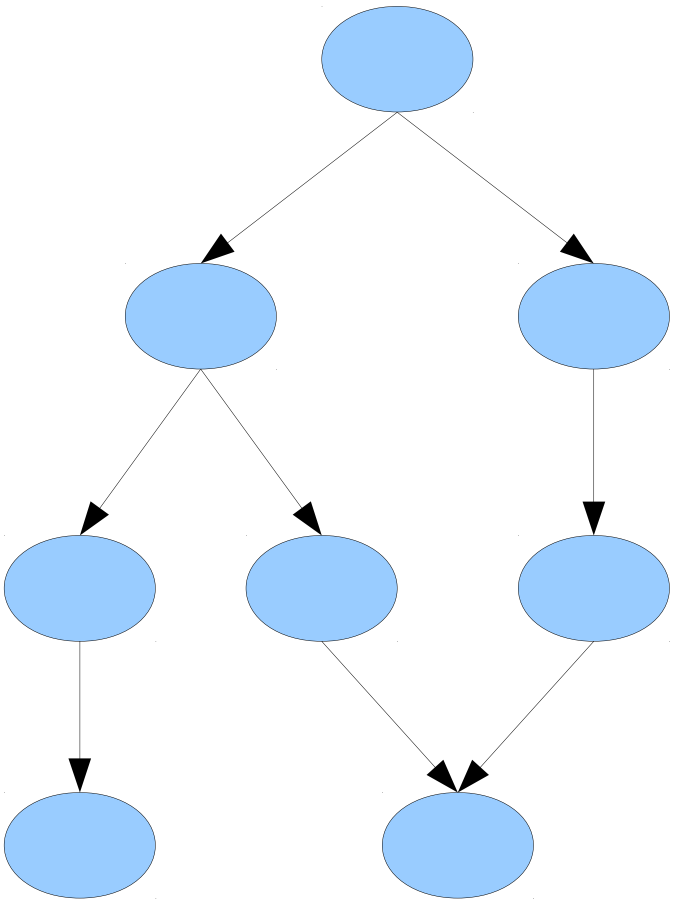
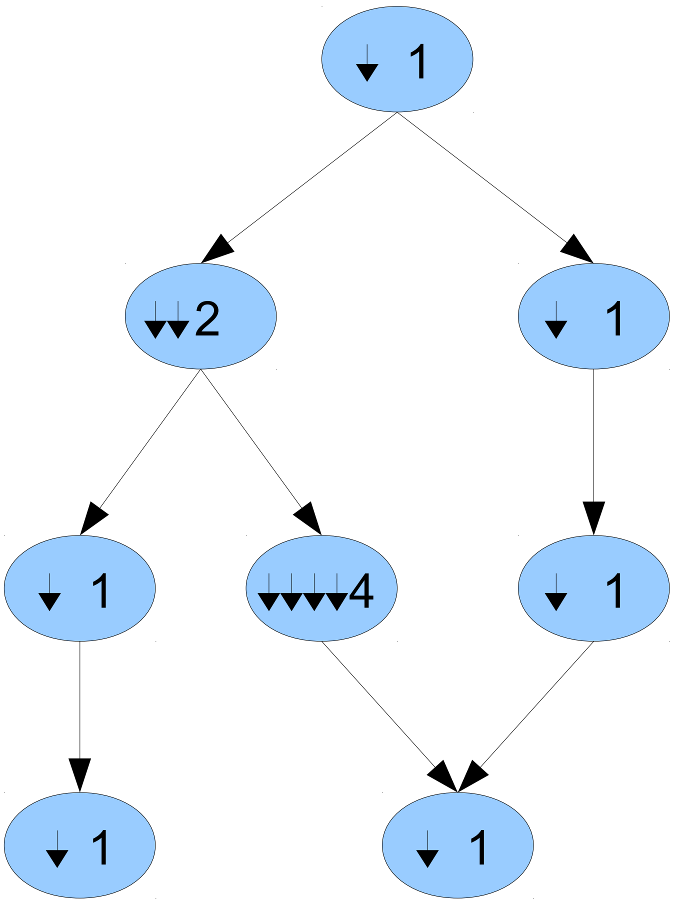
PEPPHER context

- PEPPHER focusses on performance portability and programmability aspects
- Component-based model
  - algorithmic kernels as components
- DAG-structured model of computation with component-tasks
- Scheduler sees component-task as blackbox
  - It may be scheduled to different types of processors
  - Explicit resource requirements
  - <u>It may be a parallel kernel</u>
    - e.g. OpenMP kernel



PEPPHER context

- Support for parallel component-tasks requires extensions to classical DAG-scheduling
  - Co-scheduling on multiple processors
  - Support for blocking synchronization between threads of a task
  - Subsequent numbering of threads executing task
    - Many algorithms require numbering of threads
    - Required for OpenMP kernels
  - Memory locality issues



Programmability aspect

- Some parallel algorithms are easier/more efficient to implement in task-based models
  - e.g. divide-and-conquer algorithms
- Others require SPMD-style programming with blocking synchronization
  - Difficult to map to task-based models

- Ability to compose both types of kernels in single applications may be beneficial
- Term: **mixed-mode parallel** applications
- Model: Task can spawn other tasks with fixed thread-requirement >= 1

Some solutions for mixed-mode parallelism

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- Use continuations instead of blocking synchronization
  - Difficult to implement
  - Sometimes small granularity of tasks
- Language extension + compiler support
  - Phasers in Habanero Java
  - Clocks in X10
- Centralized scheduling approaches
  - e.g. Communicating M-tasks
  - Many others

Motivating example: Quicksort

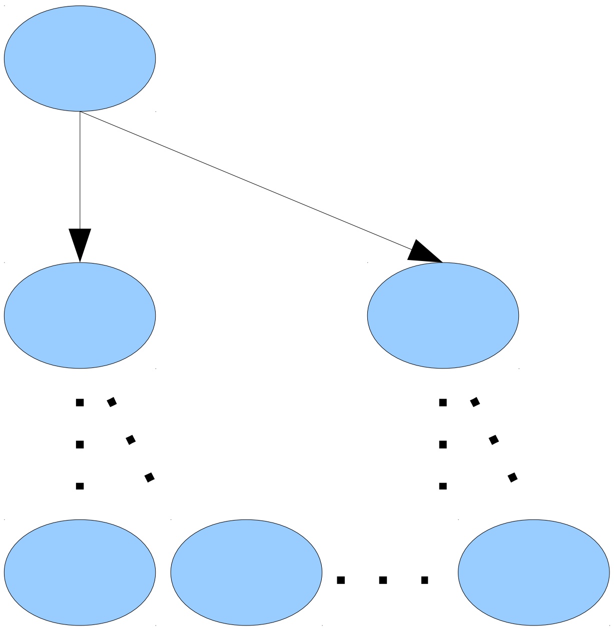
- The classical, well-known task-parallel quicksort:
  - Start off with single task
  - Partition data
  - Spawn one task for each generated subsequence
  - Switch to sequential sorting algorithm for smaller subsequences

```
if n ≤ CUTOFF then
      return sequential_sort(data, n)
else
      pivot ← partition(data, n)
      async qsort(data, pivot)
      async qsort(data + pivot +1, pivot -n - 1)
      sync
end if
```

Quicksort scalability problems

- At start, no parallelism
- Partitioning is sequential, O(n)
- Partitioning must be done at least once before first fork
- At least log p steps, before all processors have work

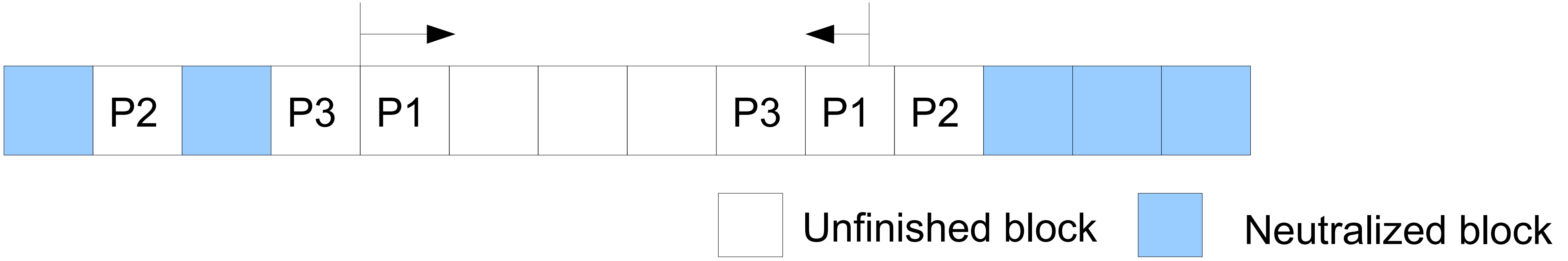
- <u>Sequential bottleneck at least O(n)</u>



Data-parallel partitioning

- Attacking sequential bottleneck
- Proposed by P. Tsigas and Y. Zhang in 2003
- Block-wise decomposition of data
- Threads acquire blocks at each side - try to neutralize

  (all data in neutralized blocks are larger or smaller than pivot)
- Remaining blocks sequentially neutralized at end



Quicksort with parallel tasks

- Start off with parallel tasks that do parallel partitioning
- For each newly spawned task determine best number of threads
- For 1-processor tasks use sequential partitioning

```
if np = 1 then
        return fork_join_qsort(data, n)
else
        pivot ← parallel_partition(data, n)
        if localId = 0 then
                async(getBestNp(pivot))
                        par_qsort(data, pivot)
                async(getBestNp(n-pivot-1))
                        par_qsort(data+pivot+1, n-pivot-1)
                sync
        end if
end if
```

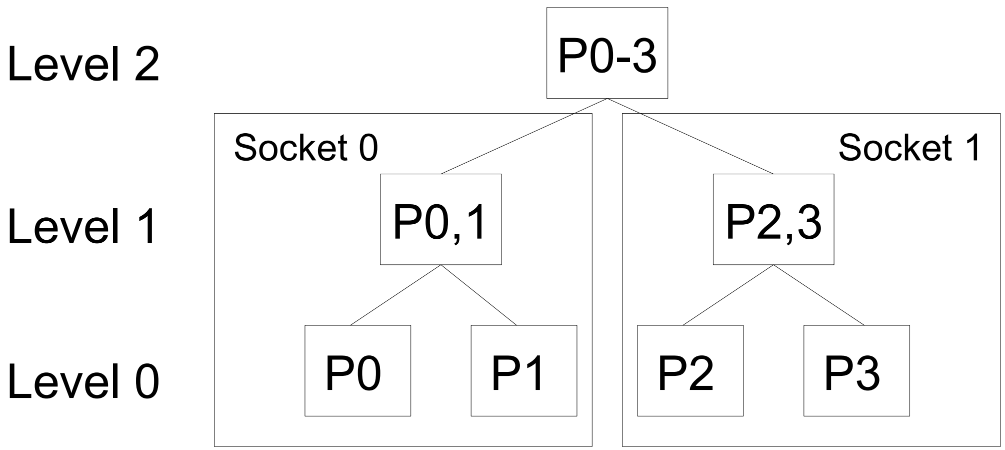
A mixed-mode work-stealing scheduler

- Decentralized scheduling for mixed-mode parallelism

- Our solution: work-stealing with deterministic team-building
  - Follows the work-stealing philosophy
    - Local work queues
    - Threads act autonomously
    - Only communicate if out of work
    - Depth-first scheduling
  - Low overhead

Modifications to standard work-stealing

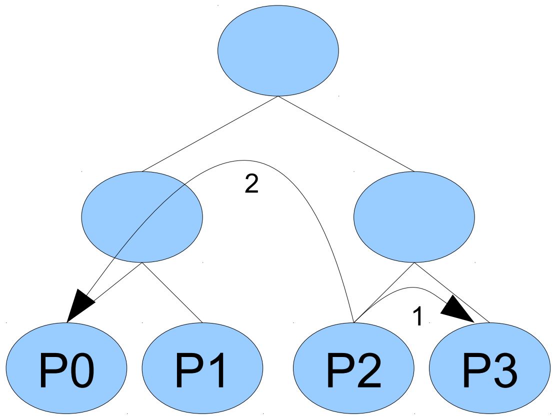
- Impose a hierarchy on processors in system
  - Should take memory hierarchy into account
- At level 0 each processor is in a group of its own
- At higher levels, processors are grouped together



- Teams will be built out of processor groups
- We assume a binary tree for the hierarchy
  - allows to calculate partner thread ids on the fly

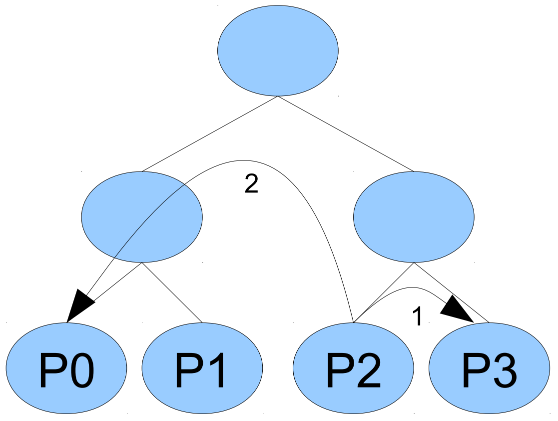
Modified stealing procedure

- Deterministic stealing pattern
  - Visit log p partners (one for each level in hierarchy) until we find some work
- Partner for level l is selected by XOR of thread-id with x in the range: $2^{l-1} \leq x < 2^{l}$
  - Depending on policy, x may be fixed (for completely deterministic schemes) or random



Modified stealing procedure (ctd.)

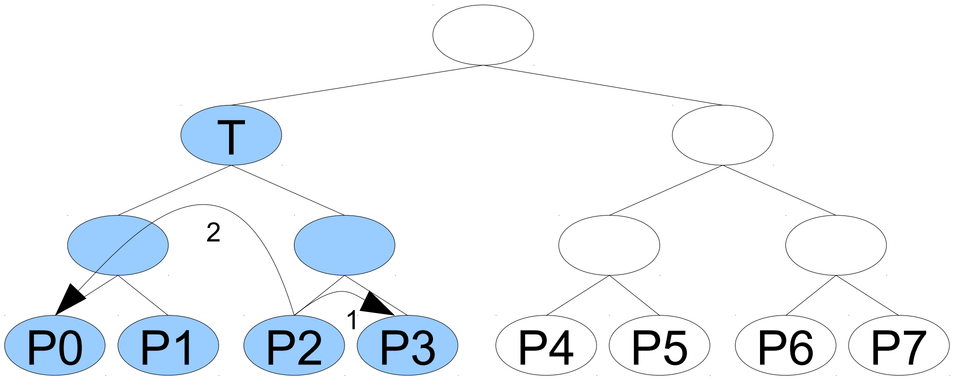
- For partner visited at level l:
  - Check whether it is building a team requiring at least 2^l threads
    - If so, join team and exit
  - Try to steal task requiring at most 2^{l-1} threads
    - On success, exit and coordinate stolen task
  - Move on to next level



Team building (coordination) procedure

- Required to build team to execute parallel task
- Executed by all threads already in the team

- If team is built, start task execution
- Otherwise go through hierarchy as in stealing
  - Only visit partners required for task execution
  - On successful steal exit coordination
  - Deterministic tie-breaking if conflicting teams are built



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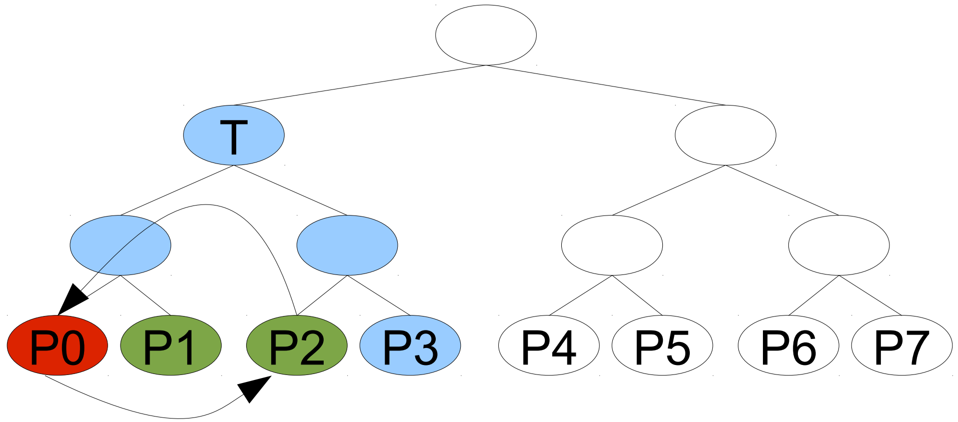

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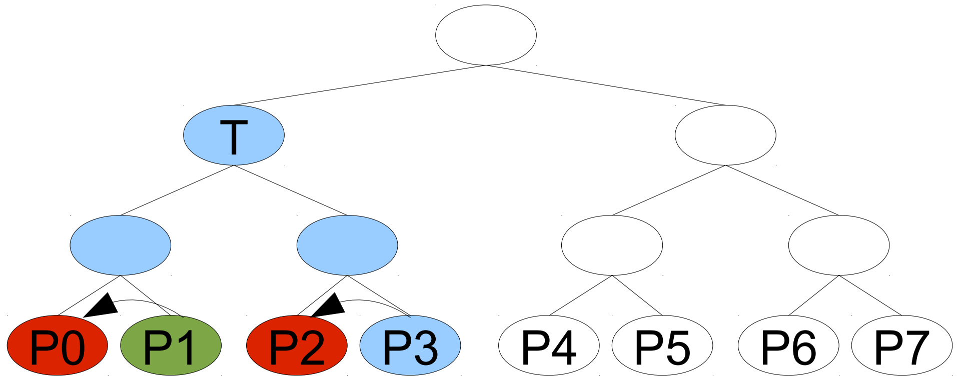

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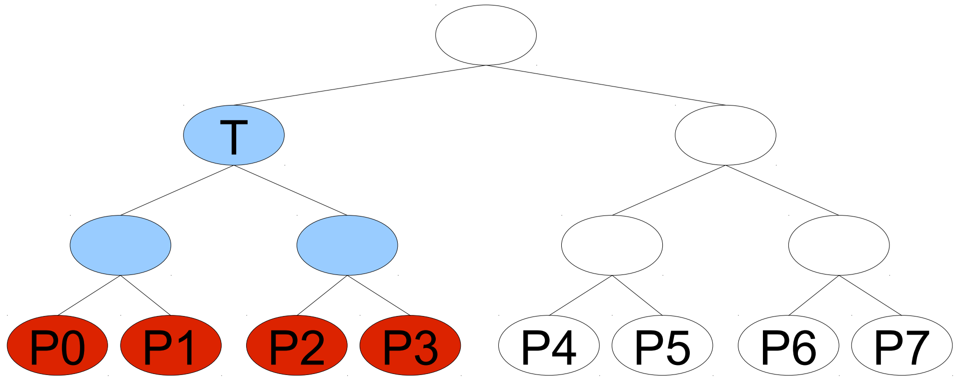

Implementation

- Implemented in C++ with pthreads
- Interface comparable to tasks in Intel TBB
- Lock-free implementation
  - Uses compare-and-swap (CAS) and fetch-and-add
  - Registration and deregistration for a team requires a single CAS per thread
  - One word per thread stores team-building information
- Standard lock-free queue implementation for task queues
- Completely deterministic, configurable stealing policy

Experimental results

- Measured on a 32 core Intel Nehalem EX system.
- Average time over 10 runs in seconds

Type	Size	Seq/STL	SeqQS	Fork	SU	Cilk++	SU	MMPar	SU
	10000000	1,231	1,352	0,326	3,8	0,207	5,9	0,202	6,1
	100000000	13,319	13,742	2,891	4,6	2,421	5,5	1,372	9,7
Random	1000000000	133,850	147,453	25,359	5,3	23,971	5,6	17,750	7,5
	8388607	1,028	1,123	0,294	3,5	0,193	5,3	0,186	5,5
	33554431	4,863	5,265	0,903	5,4	0,657	7,4	0,587	8,3
	134217727	15,888	16,617	3,103	5,1	2,525	6,3	1,835	8,7

More numbers in: M. Wimmer and J. L. Träff. Work-stealing for mixed-mode parallelism by deterministic team-building. CoRR, abs/1012.5030, 2010

Future Work

- Investigate further mixed-mode parallel applications
  - PEPPHER benchmarks
- Integration into the PEPPHER framework
  - StarPU scheduler plugin
  - Standalone scheduler
- Support for malleable/moldable tasks within certain limits
  - Automatic selection of thread requirements on spawn
    - depending on processor utilization and task performance
  - Vary thread requirements after stealing

M. Wimmer and J. L. Träff. Work-stealing for mixed-mode parallelism by deterministic team-building. CoRR, abs/1012.5030, 2010

M. Wimmer and J. L. Träff. A work-stealing framework for mixed-mode parallel applications. Submitted, 2011