Reliable Scalabe Symbolic Computation: The Design of SymGridPar2

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Introduction — Why Do We Need SymGridPar?

Context: HPC-GAP aims to parallelise GAP for HPC platforms with 10^5 cores.

- GAP is a computer algebra system for computational group theory.
  - 25+ years old
  - 10m+ lines of code (including libraries and tables)

Computer Algebra differs from traditional HPC problem domains.

- Lots of parallelism
  - **BUT** very irregular task sizes, often dynamic task creation.
- Symbolic computation keeps integer ALU busy
  - **BUT** no floating point operations, may require lots of memory.

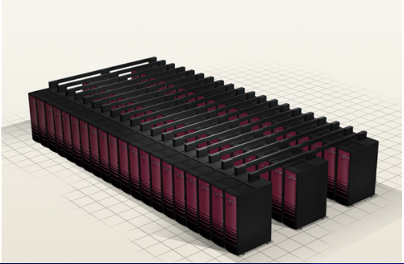
"Solution": SymGridPar middleware ($\sim$ 2007)

- Orchestrates parallel computation on black-box GAP servers across network.
- Distributes irregular tasks by on-demand random work stealing.
- Exposes general-purpose and domain-specific skeletons to GAP programmer.

Introduction — Why Do We Need SymGridPar2?

SymGridPar was developed for this:

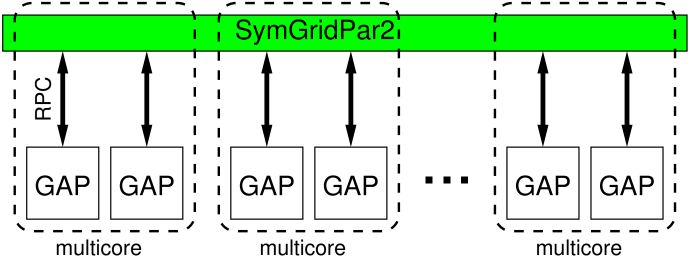
Today HPC clusters look like this:



Challenges for SymGridPar2 (SGP2)

- Rate of node/network failures increases with cluster size.
  ⇝ Requirement: fault tolerance
  - The failure rate of SGP2 computations on a large cluster should be comparable to failure rate on a single server.
- Non-uniform node-to-node latency.
  ⇝ Requirement: locality control
  - Work stealing should be aware of machine and network topology.
  - Maybe on-demand random stealing should be complemented with eager explicit pushing.

SymGridPar2 Overview



SGP2 architecture:

- Distributed middleware orchestrating (stateless) GAP servers across cluster.
- Communication via RPC-like protocol.

SGP2 programming model:

- Algorithmic skeletons (general-purpose or domain-specific).

SGP2 implementation:

- On top of HdpH, a Haskell EDSL for distributed-memory parallelism.

SymGridPar2 Overview — HdpH

HdpH = Haskell distributed parallel Haskell is

- a parallel Haskell (ie. EDSL for task parallelism)
- for distributed memory
- implemented entirely in Haskell (+ GHC extensions).

Types:

`Par a`	parallel computation (returning type a)
`Closure a`	serialisable closure (of type a)
`Task = Closure (Par ())`	serialisable parallel computation
`IVar a`	write-once buffer (for type a)
`PE`	location

Work distribution primitives:

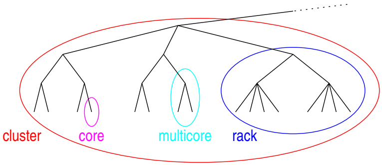
`spark  ::       Task -> Par ()`	implicit on-demand placement
`pushTo :: PE -> Task -> Par ()`	explicit eager placement

Sample skeleton:

`parMap :: Closure (a -> b) -> [Closure a] -> Par [Closure b]`	parallel map

SGP2 Locality Control — Distance Metric

Abstract view of hierarchical network topology via distance metric.



d	u	v	x	y	z
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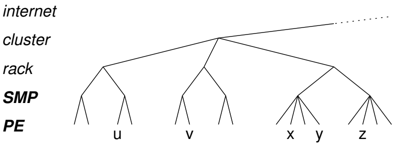

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Ultrametric distance function d on PEs defined by

$$d(p,q) = \begin{cases} 0 & \text{if } p = q \\ 2^{-n} & \text{if } p \neq q,\ n = \text{length of common path from root to } p \text{ and } q. \end{cases}$$

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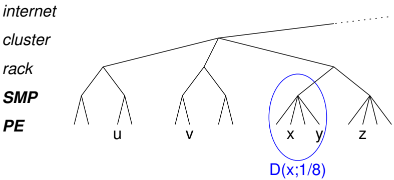

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Ball $D(p;r)$ with center p and radius r defined by $D(p;r) = \{q \mid d(p,q) \leq r\}$.

- Every PE q inside ball $D(p;r)$ is its center.
- Every ball $D(p;r)$ is uniquely partitioned by a set of balls of radius $r/2$.
  - ⇝ Equidistant basis for $D(p;r)$

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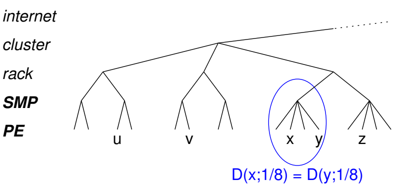

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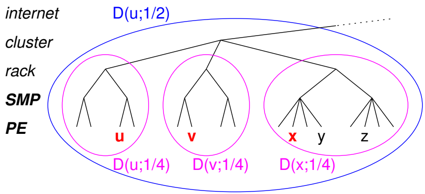

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SGP2 Locality Control — HdpH Primitives Exposing Metric

Distance Metric

```
dist :: PE -> PE -> Dist
```

Equidistant Basis

```
equiDist :: Dist -> Par [(PE, Int)]
-- equiDist r returns a sized equidistant basis of the ball D(p;r)
-- where p is the current PE.
```

Bounded Spark

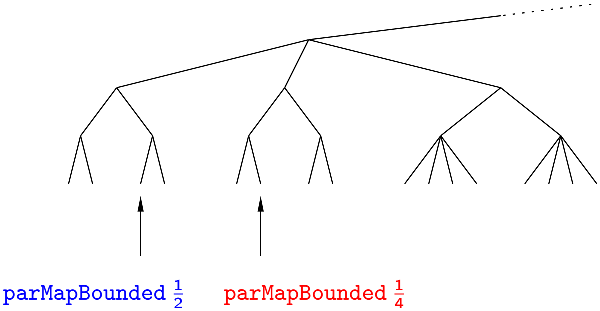
```
spark :: Dist -> Task -> Par ()
-- spark r task ensures that task never leaves the ball D(p;r)
-- where p is the current PE.
```

SGP2 Locality Control — Taming Random Work Stealing

Bounded parMap (implicit work distribution)

```
parMapBounded
  :: Dist                   -- bounding radius around current PE
  -> Closure (a -> b)       -- function closure
  -> [Closure a]            -- input list
  -> Par [Closure b]        -- output list
```

- Tasks sparked with radius `r` cannot be stolen by nodes beyond `r`.
- Tasks are preferentially stolen from nearby PEs (but accidents can happen).



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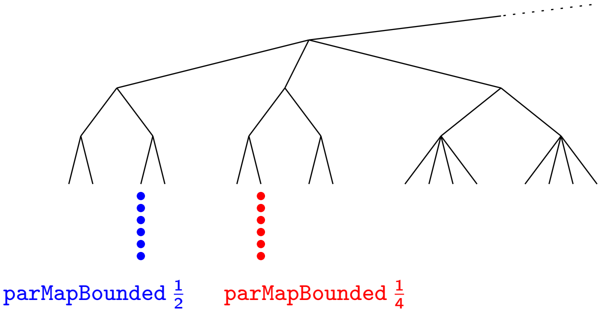

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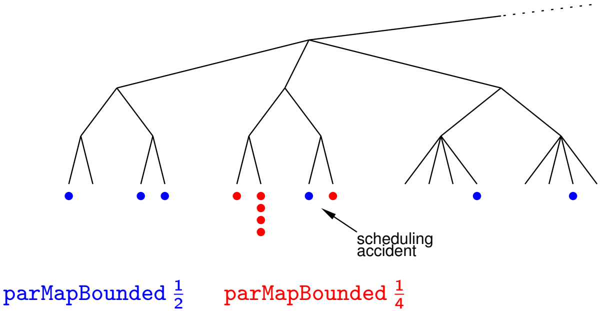
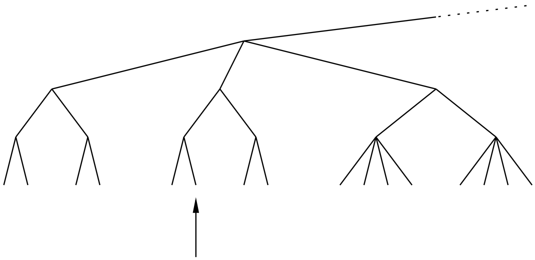


SGP2 Locality Control — Combining Pushing and Stealing

Two-level parMap (explicit and implicit work distribution)

```
parMap2Level
  :: Dist                  -- distance to push big tasks
  -> Closure (a -> b)      -- function closure
  -> [Closure a]           -- input list
  -> Par [Closure b]       -- output list
```

- Pushes big tasks to equidistant basis at distance `r` from current PE.
- Each big task sparks small tasks, bounded by radius `r/2` around its basis PE.



`parMap2Level` $\frac{1}{2}$

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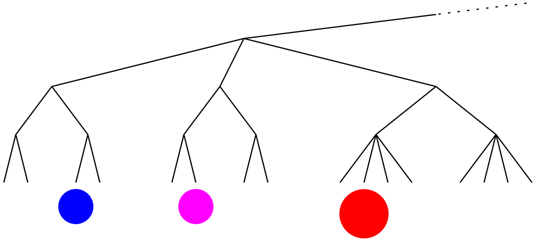

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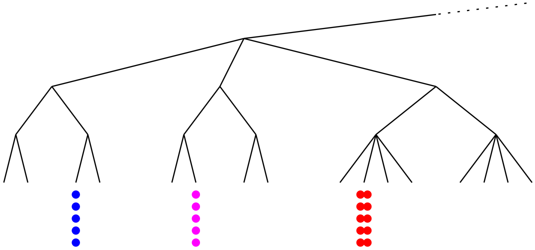

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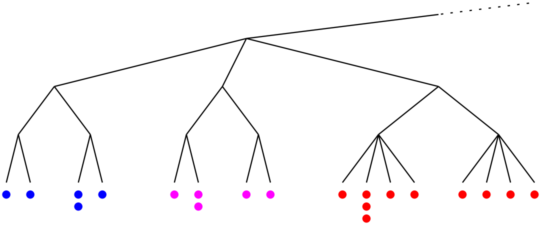

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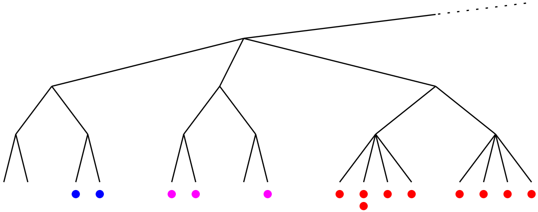

`parMap2Level` $\frac{1}{2}$

Two-level parMap (explicit and implicit work distribution)

```
parMap2LevelRelaxed
  :: Dist                  -- distance to push big tasks
  -> Closure (a -> b)      -- function closure
  -> [Closure a]           -- input list
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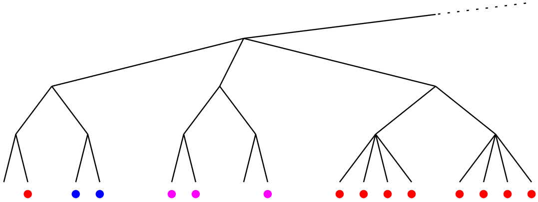
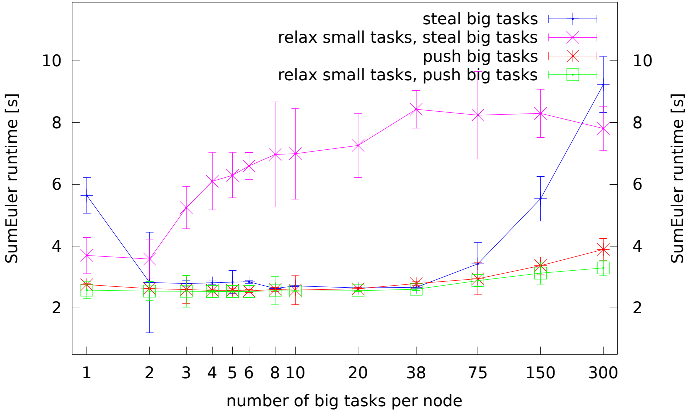


parMap2LevelRelaxed $\frac{1}{2}$

Limitation: Topology restricted to 2 levels (distances 0, $\frac{1}{2}$ and 1).

Big task granularity of 4 two-level skeletons on HECToR (128 cores)

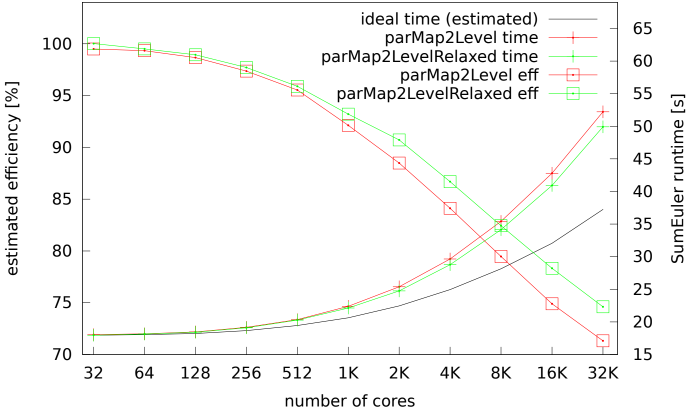


- Two-level work distribution outperforms plain random stealing.
- Pushing of big tasks (as `parMap2Level` does) is more robust than stealing.

SGP2 Locality Control — Preliminary Evaluation II

Limitation: Topology restricted to 2 levels (distances 0, $\frac{1}{2}$ and 1).

Weak scaling of two-level skeletons on HECToR (up to 32K cores)



- Estimated slowdown factor < 2 when scaling architecture by a factor of 2^{10}.
- `parMap2LevelRelaxed` beats `parMap2Level` with increasing irregularity.

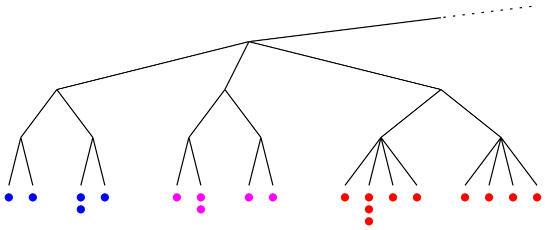
SGP2 Fault Tolerance — Recovering from Occasional Failure

High-level API: SGP2 fault tolerance is transparent to users.

- APIs of FT and non-FT skeletons are identical.

Low-level: Replicating failed tasks

- Each task supervises the nodes executing its subtasks
  - tracking movement of subtasks due to work stealing.
- On detecting node failure, supervising task re-distributes all failed subtasks
  - implicitly if subtask was created by `spark`,
  - explicitly if subtask was created by `pushTo`.



fault tolerant `parMap2Level` $\frac{1}{2}$

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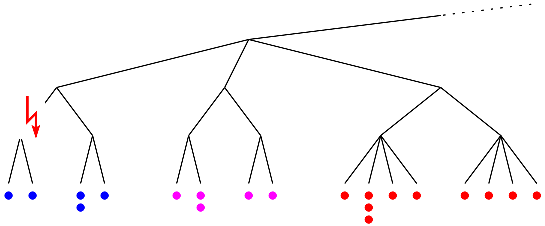

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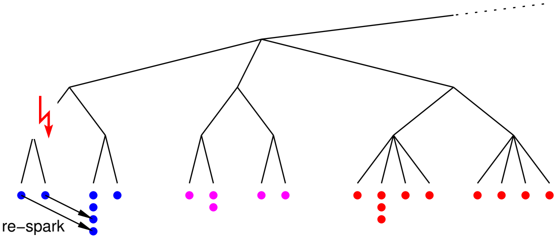
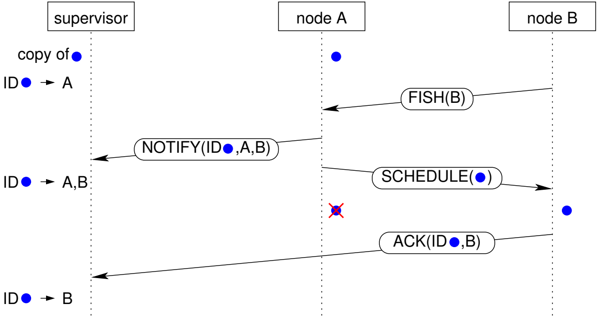


fault tolerant `parMap2Level` $\frac{1}{2}$

SGP2 Fault Tolerance — Tracking Work Stealing

Fault tolerant work stealing protocol



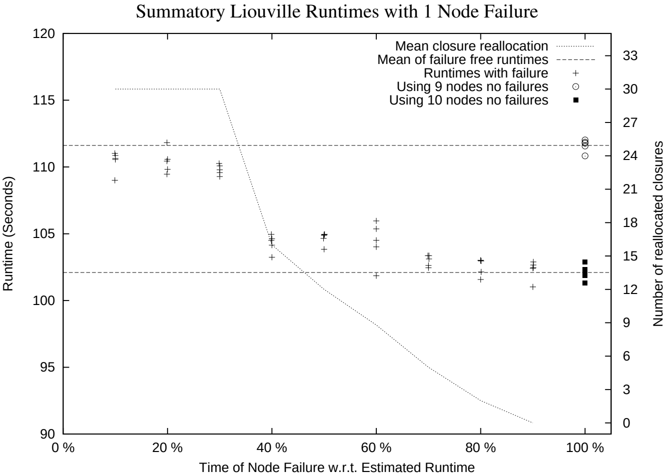
- **Assumption:** Nodes fail but message passing is reliable (no silent losses).
- **Overheads:**
  - Network: 2 messages (small, asynchronous)
  - Supervisor memory: copy of spark, map of spark ID to 1 or 2 locations

SGP2 Fault Tolerance — Preliminary Evaluation

Limitation: No tracking of task movement due to work stealing.

Cost of no failure: 5% - 7% overhead.

Cost of one failure:



Thanks for Listening

Summary:

- SGP2 locality control improves random stealing of irregular tasks, on large architectures.
- SGP2 fault tolerance protects computations from occasional node failures, with low overhead.

References:

- P. Maier, P. W. Trinder. *Implementing a High-level Distributed-Memory parallel Haskell in Haskell*. IFL 2011.
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  `www.macs.hw.ac.uk/~pm175/papers/Maier_Stewart_Trinder_SAC2013.pdf`

For Haskellers: SGP2 is not yet publicly available, but HdpH is.

- cabal install hdph