Centralized versus distributed schedulers for multiple bag-of-task applications

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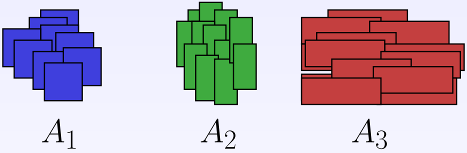
École Normale Supérieure de Lyon, France

Graal Working Group – October 2005

- Multiple applications:
  - competing for CPU and network resources
  - consisting in large number of identical independent tasks



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- Different communication and computation demands for different applications
- Important parameter: $\frac{\text{communication size}}{\text{computation size}}$ for one application

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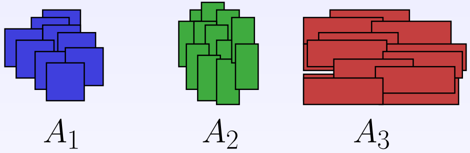

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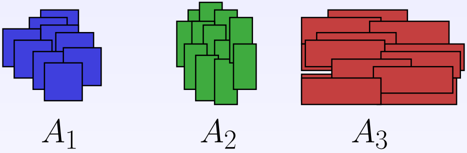

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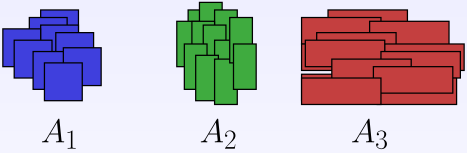

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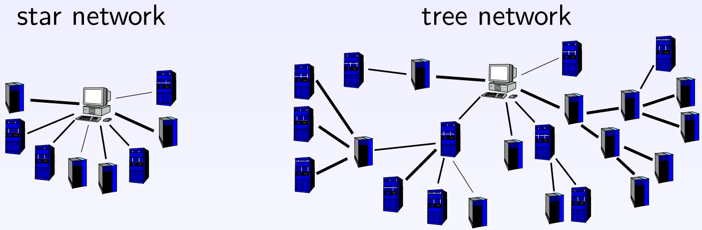
Introduction – Platform

- Target platform: master-worker



- Master holds all tasks initially

Introduction – Goals

- Maximize throughput
- Maintain balanced execution between application (*fairness*)
- Scheduling problems:
  - at master: which applications to which subtree
  - at nodes (tree): which tasks to forward to children
- Objective definition:
  - priority weight: $w^{(k)}$ for application A_k
  - throughput: $\alpha^{(k)} = \frac{\text{number of tasks completed at time } t \text{ for } A_k}{t}$
  - MAX-MIN fairness: $\textsc{Maximize} \min_k \left\{ \frac{\alpha^{(k)}}{w^{(k)}} \right\}$.

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Introduction – Strategies

- Centralized strategies
  - central scheduler at master
  - complete and reliable knowledge of the platform
  - compute optimal schedule (Linear Programming formulation)
  - convenient for small platform
- Decentralized strategies
  - more realistic for large scale platforms
  - only local information available at each node (neighbors)
  - limited memory
  - decentralized heuristics

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Outline

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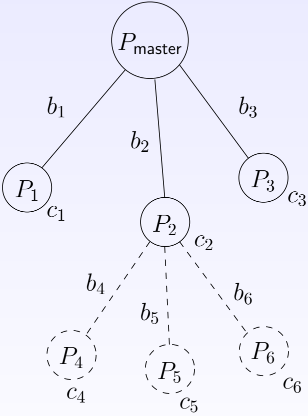

- star or tree network
- worker $P_1, \ldots, P_p$ master P_{master}
- parent of P_u: $P_{p(u)}$
- bandwidth of link $P_u \rightarrow P_{p(u)}$: b_u
- computing speed of P_u: c_u
- full communication/computation overlap
- single-port model

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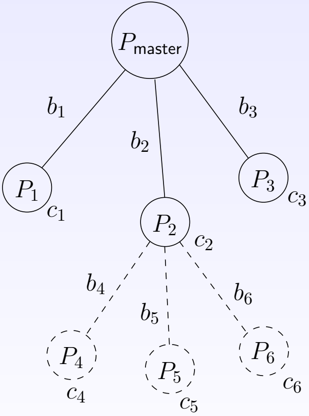

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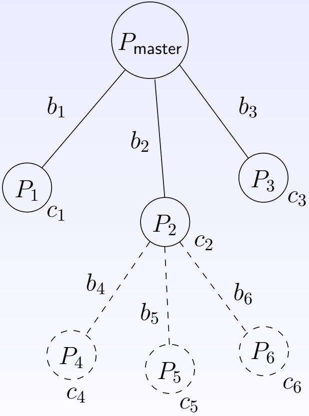

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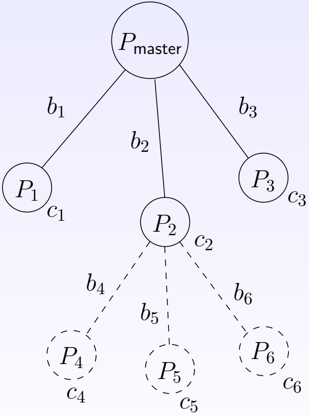

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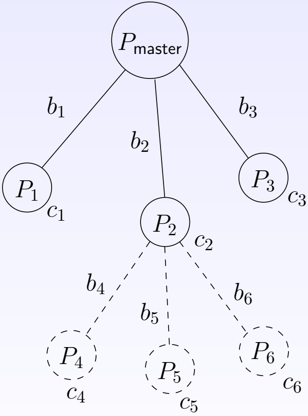

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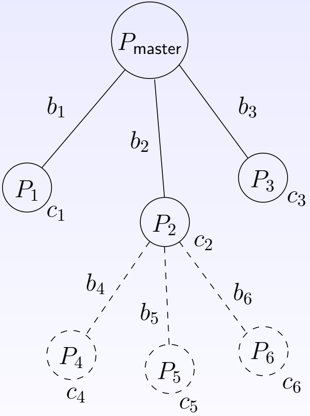

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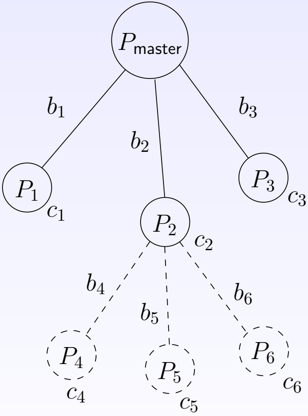

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Application Model

- K applications $A_1, \ldots, A_k$
- priority weights $w^{(k)}$: $w^{(1)} = 3$ and $w^{(2)} = 1 \iff$ we should process 3 times more A_1 than A_2
- A_k consists in many independent tasks:
  - with processing cost $c^{(k)}$ (MFlops)
  - with communication cost $b^{(k)}$ (MBytes)
- communication for data only (no result message)
- *communication-to-computation* ratio (CCR): $\frac{b^{(k)}}{c^{(k)}}$

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Linear Program for star network

- $\alpha_u^{(k)} =$ rational number of tasks of A_k executed by P_u every time-unit
- $\alpha_u^{(k)} = 0$ for all $A_k \iff P_u$ does not participate
- constraint for computation at P_u:

$$\sum_k \alpha_u^{(k)} \cdot c^{(k)} \leqslant c_u$$

- number of bytes sent to worker P_u: $\sum_{k=1}^{K} \alpha_u^{(k)} \cdot b^{(k)}$
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$$\sum_{u=1}^{p} \frac{\sum_{k=1}^{K} \alpha_u^{(k)} \cdot b^{(k)}}{b_u} \leqslant 1$$

- throughput for application A_k: $\alpha^{(k)} = \sum_{u=1}^{p} \alpha_u^{(k)}$
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Reconstructing an Optimal Schedule

- solution of the linear program: $\alpha_u^{(k)} = \frac{p_{u,k}}{q_{u,k}}$, throughput ρ
- set the length of the period: $T_p = \text{lcm}\{q_{u,k}\}$
- in each period, send $n_u^{(k)} = \alpha_u^{(k)} \cdot T_{\text{period}}$ to each worker P_u
- $\Rightarrow$ periodic schedule with throughput ρ
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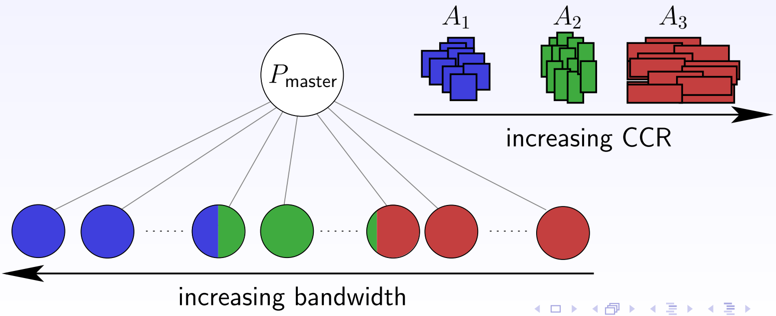
Structure of the Optimal Solution

Theorem

- Sort the link by bandwidth so that $b_1 \geqslant b_2 \ldots \geqslant b_p$.
- Sort the applications by CCR so that $\frac{b^{(1)}}{c^{(1)}} \geqslant \frac{b^{(2)}}{c^{(2)}} \ldots \geqslant \frac{b^{(K)}}{c^{(K)}}$.

Then there exist indices $a_0 \leqslant a_1 \ldots \leqslant a_K$, $a_0 = 1$, $a_{k-1} \leqslant a_k$ for $1 \leqslant k \leqslant K$, $a_K \leqslant p$, such that only processors P_u, $u \in [a_{k-1}, a_k]$, execute tasks of type k in the optimal solution.



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Decentralized Heuristics

- General scheme for a decentralized heuristic:
  - finite buffer (makes the problem NP hard)
  - *demand-driven* algorithms
  - local scheduler:

    Loop
    - If there will be room in your buffer, request work from parent.
    - Select which child to assign work to.
    - Select the type of application that will be assigned.
    - Get incoming requests from your local worker and children, if any.
    - Move incoming tasks from your parent, if any, into your buffer.
    - **If** you have a task and a request that match your choice **Then**
      - Send the task to the chosen thread (when the send port is free)
    - **Else**
      - Wait for a request or a task
  - use only *local* information

Heuristics – LP

- Centralized LP based (LP)
  - solve linear program with global information
  - give each node the $\alpha_u^{(k)}$ for its children and himself
  - use a 1D load balancing mechanism with these ratios
  - $\rightarrow$ close to optimal throughput ?
- First Come First Served (FCFS)
  - each scheduler enforces a FCFS policy
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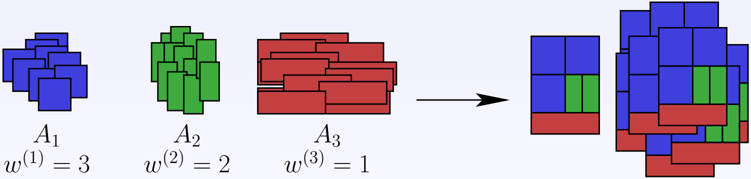
Heuristics – CGBC

- Coarse-Grain Bandwidth-Centric (CGBC)
  - bandwidth-centric = optimal solution for 1 type of task (send tasks to best communicating child first)
  - assemble different types of tasks in one:



  - not expected to reach optimal throughput: slow links are used to transfer task with high CCR

Heuristics – PBC

- Parallel Bandwidth-Centric (PBC)
  - superpose bandwidth-centric for each type of task
  - on each worker, K independent schedulers
  - fairness enforced by the master, distributing the tasks
  - independent schedulers $\longrightarrow$ concurrent transfers
    limited capacity on the outgoing port
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- Parallel Bandwidth-Centric (PBC)
  - superpose bandwidth-centric for each type of task
  - on each worker, K independent schedulers
  - fairness enforced by the master, distributing the tasks
  - independent schedulers $\longrightarrow$ concurrent transfers
    limited capacity on the outgoing port
    $\rightsquigarrow$ gives an (unfair) advantage to PBC (allows interruptible communications)

Heuristics – DATA-CENTRIC

- Data-centric scheduling (DATA-CENTRIC)
  - decentralized heuristic
  - try to convergence to the solution of the LP
  - intuition based on the structure of optimal solution of stars
  - start by scheduling only tasks with higher CCR, then periodically:
    - substitute tasks of type A (high CCR) for tasks of type B (lower CCR)
    - if unused bandwidth appears, send more tasks with high CCR
    - if only tasks with high CCR are sent, lower this quantity to free bandwidth, to send other types of tasks
  - needs information on neighbors
  - some operations are decided on the master, then propagated along the tree

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Outline

Methodology

- How to measure fair-throughput ?
  - concentrate on the phase where all applications are run
    $\rightarrow T =$ earliest time that all tasks of one applications are done
  - ignore initialization and termination phases
    time-interval $[0.1 \times T\ ;\ \ 0.9 \times T]$
  - compute throughput for each application on this interval
- Platform generation
  - 150 random platforms generated, preferring wide trees
  - links and processors characteristics based on measured values
  - buffer of size 10 tasks (of any type)
- Application generation
  - CCR chosed between 0.001 (matrix multiplication) and 4.6 (matrix addition)
- Heuristic implementation
  - distributed implementation using SimGrid,
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Theoretical v/ Experimental Throughput

- LP, CGBC: possible to compute expected (theoretical) throughput

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- we plot the distribution

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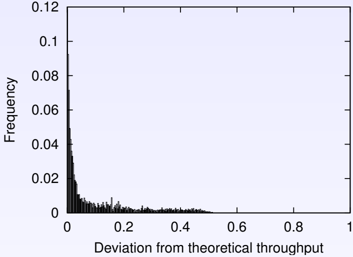
- 

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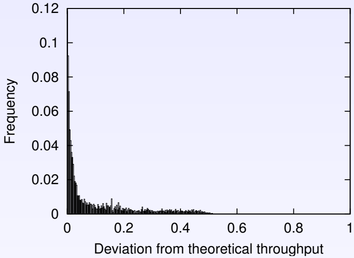
- 

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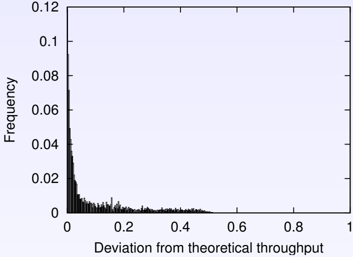
- 

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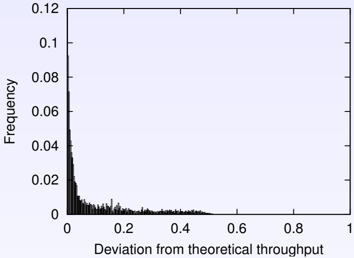
- 

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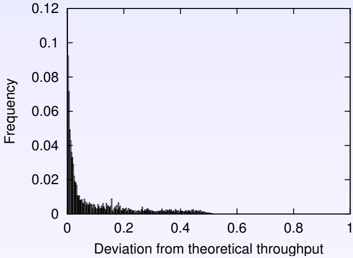
- 

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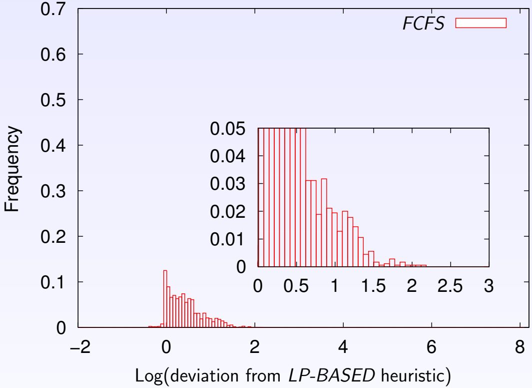
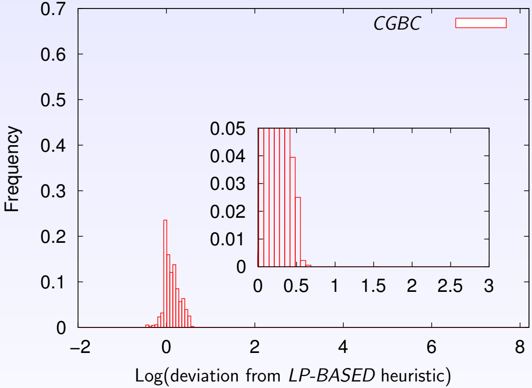
Performance of FCFS



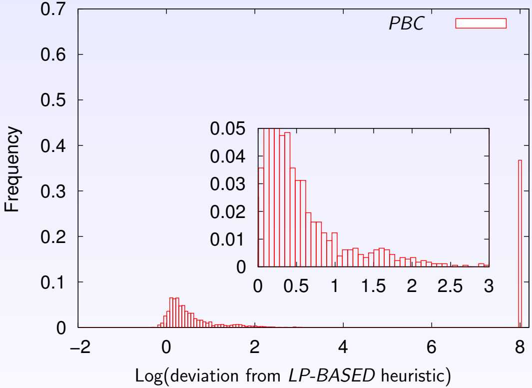
- geometrical average: FCFS is 1.56 times worse than LP
- worst case: 8 times worse

Performance of CGBC



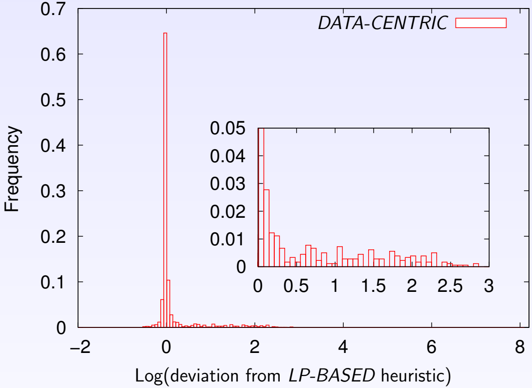
- geometrical average: CGBC is 1.15 times worse than LP
- worst case: 2 times worse

Performance of PBC



- in 35% of the cases: one application is totally unfavored, its throughput is close to 0.

Performance of DATA-CENTRIC



- geometrical average: DATA-CENTRIC is 1.16 worse than LP
- few instances with very bad solution
- on most platforms, very good solution
- hard to know why it performs bad in few cases

Outline

Conclusion

Contributions:

- centralized algorithm able to compute optimal solution with global information
- nice characterization of way to compute optimal solution on single-level trees
- design of distributed heuristics to deal with practical settings of Grids (distributed information, variability, limited memory)
- evaluation of these heuristics through extensive simulations
- good performance of sophisticated heuristics compared to the optimal scheduling

Perspectives

- Adapt the decentralized computation of MultiCommodity Flow (Awerbuch & Leighton) to our problem
  - decentralized approach to compute optimal throughput
  - slow convergence speed
- Consider other kinds of fairness: proportional fairness
  - reasonable (close to the behavior of TCP)
  - easy to realize with distributed algorithms