Using simulation to develop efficient algorithms on distributed heterogeneous computing platforms: why and how?

Graal project: jointly operated by CNRS, ENS Lyon and INRIA
Algorithm design, scheduling and load balancing for heterogeneous platforms
Outline

1. Scheduling on an heterogeneous environment: validation
2. Simulation: a brief state of the art
   - networks
   - applications
3. SIMGRID, a modular trace-based simulator
4. Obtaining a realistic platform model.
   - Random topology
   - Real topology
   - Getting traces
5. Conclusion
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Scheduling on an heterogeneous environment: the validation problem
Scheduling parallel applications is already a challenging problem on simple homogeneous platforms. On an heterogeneous one, it is even more complicated.

Even when an optimal solution to a scheduling problem can be found in polynomial time, small modifications of the underlying assumptions (e.g. addition of non-zero network latencies) often render the problem NP-hard:

\[ \rightarrow \text{low complexity heuristics} \]

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Simulation has been used extensively as a way to evaluate and compare scheduling strategies as simulation experiments are repeatable, configurable, and generally fast. But...

- **No standard**: “throw-away” simulators make it difficult to reproduce results. This lack of standard simulation procedure and software was somewhat justifiable when the simulation models in use were simplistic but traditional models and assumptions about computing platforms are no longer valid for modern platforms.

- **Need for realistic and more complex models** than the one used for designing algorithms. The assumption that the behavior of the computing platform is perfectly predictable also needs to be revisited as modern platforms exhibit dynamic resource availabilities.

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Simulation:
state of the art
Network Simulators

Goal:

- understanding networks behavior, routing protocols, QoS, ...
- identifying limitations of network protocols and developing improvements.

→ requires a precise simulation of the movement of packets along the network links: NS [?], DaSSF [?], OMNeT++ [?].

Inadequate

We are interested by the network behavior as it is experienced by an application.

- Due to their highly detailed simulation models, most network simulators induce long simulation times (e.g. they implement the TCP stack).
- Adding CPU resources to model applications using the network is labor-intensive.
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Platform Emulation

A few examples:

**MicroGrid [?] (UCSD)**
- The computing platform is mapped onto a fast cluster: a fraction of CPU is allocated to each process according to the speed and the load of the simulated host.
- Network simulation is handled through DaSSF [?]
- No external load for the network.

**PANDA [?] (Amsterdam)**
- Two-level grid (High speed LAN or slow WAN) and no processor heterogeneity: one-to-one mapping of the computing platform on a cluster; virtual inter-cluster links are artificially slowed down.
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The code is run for real \(\Rightarrow\) too slow, too “precise”, too difficult for simple tests or the design phase.
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- Application Level Scheduling (AppLeS): to a given application corresponds a given scheduler. Many students have been working on scheduling on the grid with specific needs.

- From these experiences, Henri Casanova (UCSD) designed a minimal set of low-level basic functions essential for building a simulator that uses traces: SG (SimGrid v.1)

- MSG is a simulator built on top of SG and adapted to the study of non-centralized scheduling (SimGrid v.2). Simulation is described in terms of communicating processes.

Strong points:

- Ability to use complex and realistic platforms.

- Fast simulations: ratio \( \frac{\text{simulation time}}{\text{simulated time}} \approx 10^{-6} \).
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Two different types: resources and tasks.

**SG_Resource** Name, availability trace (CPU, bandwidth), time access trace (latency), sharing policy (sequential, shared, TCP).

**SG_Task** Name, amount of work

SG allows to create those objects and to schedule a task on a resource.

- Starting a transfer of $S$ bytes on a resource at time $t_0$ requires $T$ units of time with $T$ s.a.:

$$\int_{t_0+L(t_0)}^{t_0+T} B(t) \, dt = S$$

- On shared resources, all tasks get an amount of power proportional to their priority.
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**SG_Resource** Name, availability trace (CPU, bandwidth), time access trace (latency), sharing policy (sequential, shared, TCP).

**SG_Task** Name, amount of work

SG allows to create those objects and to schedule a task on a resource.

- Starting a transfer of $S$ bytes on a resource at time $t_0$ requires $T$ units of time with $T$ s.a.:

  $\int_{t=t_0+L(t_0)}^{t_0+T} B(t) dt = S$

- On shared resources, all task get an amount of power proportional to their priority.
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Using some traces

Ordonnanceur

$P_1$

$P_2$
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Schedule($T_1, P_1$)
Schedule($T_2, P_2$)
Simulate(10 s)

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$P_1$

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Simulate()
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\[ P_1 \]

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PSTS\textsuperscript{IM}, a centralized scheduler

Given a master, some slaves, and a set of independent tasks that may share some input files.

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Store & Forward: bad model for contention
How to model a file transfer along a path?
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WormHole: computation intensive (packets), not that realistic
How to model a file transfer along a path?

$$\forall l \in \mathcal{L}, \quad \sum_{r \in \mathcal{R} \text{ s.a. } l \in r} \rho_r \leq c_l,$$

Analytical model
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TCP behavior [?] Close to max-min. In MSG: max-min + bound by \( \frac{1}{RTT} \).

Analytical model
Non-centralized scheduling?

Centralized scheduling do not scale and SG is not well suited to study such scheduling policies.

MSG abstractions:

**Agents** some code, private data, and the location at which it executes;

**Locations** a computational resource, a number of mailboxes that enable communication with other agents, and private data that can be only accessed by agents at the same location;

**Task** an amount of computing, a data size, and private data;

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- Grid Operating System
- Grid Information Service
- Forecasting Service
- SG : Event Manager
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![Diagram showing the components of the Grid Operating System, Grid Information Service, Forecasting Service, and Event Manager.]
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- MSG_link_create
- MSG_process_create
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Agent basic actions

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Obtaining a realistic platform model
Realistic platforms are complex and building such platforms is generally fastidious since it requires to create a large number of elements:

- Hosts
- Links
- Routing
- Traces

Different ways to automatically build a platform

- Random topology
- Real topology
- Getting traces
Building a platform is a pain

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**Flat models**

**Brain-dead** $N$ dots are randomly chosen (using a uniform distribution) in a square. Then they are randomly connected with a uniform probability $\alpha$.

**Waxman** [?] Dots are randomly placed on a square of side $c$ and are randomly connected with a probability $P(u, v) = \alpha e^{-d/(\beta L)}$, $0 < \alpha, \beta \leq 1$ where $d$ is the Euclidean distance between $u$ and $v$ and $L = c\sqrt{2}$. The edge number increases with $\alpha$ and the edge length heterogeneity increases with $\beta$.

**Exponential** Dots are randomly placed and are connected with a probability $P(u, v) = \alpha e^{-d/(L-d)}$.

**Locality** [?] This model is due to Zegura. Dots are randomly placed and are connected with a probability $P(u, v) = \begin{cases} \alpha & \text{if } d < L \times r \\ \beta & \text{if } d \geq L \times r \end{cases}$. 
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Node placement

Uniform
Node placement

Heavy Tailed
Faloutsos brothers have analyzed the topology at the AS level and have established power-laws describing this topology.

The rank $r_v$ of a note $v$ is its index in the order of decreasing degree.
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The rank $r_v$ of a node $v$ is its index in the order of decreasing degree.

**Power Law (rank exponent).** Given a graph, the degree $d_v$ of a node $v$ is proportional to the rank of the node $r_v$ to the power of a constant $\mathcal{R}$.

$$d_v \propto r_v^\mathcal{R}$$

<table>
<thead>
<tr>
<th></th>
<th>Nov. 97</th>
<th>Apr. 98</th>
<th>Dec. 98</th>
<th>Router 95</th>
</tr>
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<tbody>
<tr>
<td>$\mathcal{R}$</td>
<td>0.81</td>
<td>0.82</td>
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Incremental growth and affinity lead to Power Laws [?]).

Nodes are incrementally added. The probability that \( v \) is connected to \( u \) depends on \( d_u \):

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P(u, v) = \frac{d_u}{\sum_k d_k}
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What about Power Laws?

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What about hierarchy?

Top-Down

**N-level**  
Starting from a connected graph, at each step, a node is replaced by another connected graph (Tiers, GT-ITM).

**Transit-stub**  
2-levels of hierarchy and some additional edges (GT-ITM, BRITE).
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Let us check two Power-Laws

Interdomain November 1997
Let us check two Power-Laws

GT-ITM flat?
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Waxman (BRITE)
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Transit-Stub (GT-ITM)
Let us check two Power-Laws

Barábasi Albert (BRITE)
Are these measurements meaningful?

Some of the power laws observed by the Faloutsos brothers are correlated. What kind of measurements can be used?

- Expansion
- Distorsion
- Resilience
- Excentricity distribution
- Eigenvalues distribution
- Set cover size, …

Observation [?]:

- AS-level and router-level have similar characteristics
- Degree-based generators are significantly better at representing large scale properties of the Internet than structural ones.
- Hierarchy seem to arise from degree-based generators.
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For a 100 node platform, power laws do not make sense and structural generators may be more appropriate.

We need some additional informations (e.g. routing, bandwidth, latency, sharing capacity, . . .).

**Idea 1:** use a structural generator (e.g. Tiers) with a simple edge classification scheme (LAN/MAN/WAN) and annotate with some real measurements.

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- **Level 1**: unreachable, too close to hardware
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Grid2 school (Besançon): January 22, 2004
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ENV : methodology

the-doors ——— any host
ENV : methodology

the-doors

any host

the-doors

cluster
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Running ENV on the ENS network
Running ENV on the ENS network

- the-doors
- canaria
- moby

- routeur_backbone
- routeur_giga

- myri0
- popc0
- sci0
- sci1
- sci2
- sci4
- sci5
- sci6

- domain ens-lyon.fr
- domain popc.private

- 10 Mbps
- 100 Mbps
Running ENV on the ENS network

<NETWORK type="ENV_Switched">
  <LABEL name="sci0" />
  <PROPERTY name="ENV_base_BW" value="32.65" units="Mbps" />
  <PROPERTY name="ENV_base_local_BW" value="32.29" units="Mbps" />
  <MACHINE name="sci1.popc.private" />
  <MACHINE name="sci2.popc.private" />
  <MACHINE name="sci3.popc.private" />
  <MACHINE name="sci4.popc.private" />
  <MACHINE name="sci5.popc.private" />
  <MACHINE name="sci6.popc.private" />
</NETWORK>
ENV limitations

- Firewall ⇔ fusion
- Precision, time limitation, experimental thresholds
- Master/slave oriented
  - Asymmetric routing
  - Inter-cluster links
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Network Weather Service

- Developed at UCSB
- Provides accurate data on a metacomputing platform
- Forecasting on links and processors performances
- Almost automatized deployment from the ENV output [?].
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Modeling hubs, switches and routers

Master
Link A
Hub
Link B Link C
Slave A Slave B
Modeling hubs, switches and routers

Master

Link A

Hub

Link B

Slave A

Link C

Slave B

Master

Link A'

Slave A

Slave B
Modeling hubs, switches and routers

Master

Link A

Switch

Slave A  Slave B  Slave C
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Bandwidth of Link A cannot be measured by NWS
Modeling hubs, switches and routers
Conclusions
**A few remarks**

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