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Challenges for scheduling at the Edge

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Workshop on Mathematical Challenges on Scheduling, Sanya

Oct. 9, 2019
Today, the digital world is *in action*:

The number of digital objects connected to Internet is growing exponentially.
Cyber Physical Systems are in interaction to each other and with humans.

*...a Revolution.*

Parallel and distributed computing platforms turn towards the *Edge.*
Compute everywhere and anywhen.
Sketch of the landscape

Hierarchical computing systems (4 levels)

1. HPC and Data centers (clouds)
2. Fog – small clusters (hundreds/thousands cores)
3. Edge – laptops/smart phones
4. IoT – sensors

A good example of points 3 and 4 is connecting flights at the airport:
Interaction between public and private transports, getting a lot of (local) informations, managing critical situations, etc..
Hierarchical computing systems (4 levels)

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Challenges

Manage efficiently such complex infrastructures composed of multiple and heterogeneous digital/computing components.

- Large amount of polymorphic data issued from multiple sources.
- Resources appear and disappear.
- New storage capabilities.
- Heterogeneity characteristics of the different architectures, including OS kernels, compilers, etc.
- Network of different types and instability (different latencies).

**WHERE** running each workflow component?
Challenges synthesis

Some issues/questions:

- Compute as close as possible to the sensors/digital components to avoid data transfers (and also for privacy).

- Need of new data storage abstraction: object versus file systems data reduction/lossy compression.
- Task flow versus data flow: **data streaming**.
Pictorally

Diagram showing a cloud-based scheduler connected to multiple edge devices, which in turn are connected to a large number of sensors (IoT). The diagram illustrates the flow of data from the sensors to the edge devices and then to the scheduler.
Content of the talk

- Report a 3 years project (french nat. Research Agency) with the Qarnot Company
- Describe the problems
- Show and discuss preliminary scheduling solutions
- Simulation tools\(^1\)

\(^1\)Ideally, build a digital twin of the platform
From Heaters to Computing Resources: “**turn IT waste heat into a viable heating solution for buildings.**”

The actual Qarnot platform (Bordeaux and Paris):

- \( \sim 1,000 \) distributed QRads embedding \( \sim 3,000 \) diskless computing units
- \( \sim 20 \) local servers (QBoxes) with memory disks
- 1 global server (QNode) with a centralized storage server
Qarnot Platform
Two types of computing requests

Cloud tasks:
- Submitted to the QNode
- Have data-set dependencies in the centralized storage
- Have different priorities (low or high)

IoT tasks:
- Submitted to a – local – QBox
- Have data-set dependencies in the QBox disk
- Have different priorities (low, high or very high)
- Should be executed **locally**
Abstract view of the Qarnot Platform

Tasks/jobs (groups of **sequential instances**) are submitted on-line.
Target of the project

Main goal: design, implement and test different placement and scheduling policies at both QNode- and QBox-levels.

Involved People:

- A PhD student
- A PostDoc (18 months)
- A engineer (12 months)
Platform Dynamicity

Resources appear and disappear over time: **the inhabitants decide according to the weather or their schedule!**

- Available resources when heating is required (QRad is ON)
- Unavailable when ambient air is too warm (QRad is OFF)
→ Also depends on the task priority

Network uncertainties:

- Link failures
- Congestion/contention
Two-Level Scheduling Problem

Remind: The only computing power is in QRads

Make global decisions at QNode-level:
- Decide where to dispatch (groups of) instances
- Ensure global load-balancing

Make local decisions at QBox-level:
- Schedule instances on QRads
- Regulate room temperature (via DVFS – frequency scaling)
- Ensure heating needs are satisfied

Need to reach 100% of platform usage.

→ An idle QRad is a lack of heating
Multiple Objectives problem

Various objectives for different actors:

- Cloud users: Minimize waiting/completion time of tasks
- IoT tasks: Responsiveness
- Inhabitants: Minimize the gap to target temperature.
- Qarnot:
  - Maximize tasks throughput (profit)
  - Minimize lack of heating
Qarnot Solution: naive on-line

Periodic reports (∼30 sec.) from QBox to QNode with:
- Number of resources available for each task priority
- Amount of free space on disk

QNode-scheduling:
- Sort QBoxes by least available resources first (no temperature knowledge)
- Sort tasks by highest priority first
- For each task, dispatch as many instances as possible

QBox-scheduling:
- Retrieve data-set dependencies
- Schedule high priority instances on coolest QRads
- Schedule low priority instances on warmest QRads
Frequency and temperature regulator in each QRad:

- In general: speed scaling (DVFS) on each multi-core to adapt power consumption

- When too warm: instances are killed and re-submitted to the QNode

- When too cold (lack of heating): “background” compute-intensive instances are generated (best-effort blockchain mining\(^2\))

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\(^2\)Open problem: it could be improved
Global scheduler

Several policies for the QNode dispatcher:

- Standard
- Locality-Based
- Replicate 3 times data set on the Least Loaded Disk
- Replicate 10 times (again with LLD)
- FullReplicate (allows instantaneous transfers)

Implementation with standard Qarnot scheduler at QBox-level.

For the moment, no local tasks are considered.
QBox-level Scheduling

Target temperature diagram

- Temperature required

20°C (home)
16°C (work)

Time of the day

0 ΔT=0 ΔT=-4 ΔT=0 ΔT=+4 ΔT=0 24
QBox-level Scheduling

Temperature required

Temperature

Time of the day

$\Delta T = 0$

$\Delta T = -4$

$\Delta T = 0$

$\Delta T = +4$

$\Delta T = 0$

20°C (home)

16°C (work)

Power required

200 W (heating)

60 W (stable)

30 W (stable)

Power diagram

Time of the day

0 24
**Main problem:** testing on the production platform is not conceivable (and it would take time...).

→ **Simulation is needed!**

Remark: the theoretical analysis is difficult.
Main problem: testing on the production platform is not conceivable (and it would take time...).

→ Simulation is needed!

Remark: the theoretical analysis is difficult.
Simulation Framework

**SimGrid**\(^{3}\): Large-scale distributed system simulator with execution and communication models.
→ Used to simulate platform (including temperature) and tasks execution.

**Batsim**\(^{4}\): Infrastructure simulator for jobs and I/O scheduling.
→ Used to drive the simulation, submit tasks and communicate with the decision process.

**Pybatsim**\(^{5}\): Batsim’s Python API exposing methods to easily communicate with the Batsim process.
→ Used to implement both QNode and QBox schedulers.

\(^{3}\)https://github.com/simgrid/simgrid
\(^{4}\)https://gitlab.inria.fr/batsim/batsim/tree/temperature
\(^{5}\)https://gitlab.inria.fr/batsim/pybatsim/tree/temperature
Implementation

Dedicated module for convert computations to temperature.

2 solutions have been developed:

- Learning on actual logs (problems: old generation of Qrads and missing contextual informations).
- Analytic expression (given by physicians).

Remark: better than what is available today at Qarnot (empirical law which causes a lot of instabilities).
Run 4 times the logs on a week (between may 3 and june 1, 2019).

The simulated platform was composed of 3390 QMobos of 669 QRads, managed by 20 QBoxes.

Two metrics studied:
- mean waiting time
- bounded slowdown (normalized average stretch)
Mean bounded slowdown
Mean waiting time (s)

<table>
<thead>
<tr>
<th>Workloads</th>
<th>Scheduler</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FullReplicate</td>
</tr>
<tr>
<td>week1</td>
<td></td>
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<tr>
<td>week2</td>
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<tr>
<td>week3</td>
<td></td>
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<tr>
<td>week4</td>
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</tr>
</tbody>
</table>

25/30
Local scheduler (model)

Two sets of tasks:

- $S_1$ global tasks.
  - off-line (sequential) tasks with their release dates (corresponding to data transfers).
- $S_2$ local tasks.
  - Sequential tasks arriving on-line.
  - Not too many (10 to 20 %), usually small ones.

Qarnot platform is rather homogeneous (uniform machines).

Notice here that rejection (interrupt a task and re-execute it elsewhere) makes sense.
Local scheduler (Objectives)

Two directions are under investigation.

- **Single objective.**
  Minimize max flow time for $\mathcal{S}_2$ under the capping on sum flow for $\mathcal{S}_1$.

- **Bi-objective.**
  Minimize average flow time or tardiness for $\mathcal{S}_1$ and minimize max flow time for $\mathcal{S}_2$
Some results

Qarnot platform.

- Preliminary results assuming periodic arrivals in $S_2$: Study the problem for one machine, then extend.
- Interface between global and local schedulers: add a module which gives the pressure of local tasks.
- Learning algorithms have been developed (get a better idea of the leaving habits).

Extend to more general edge platforms.
Conclusion

General message: It is not so easy to build a bridge between theory and practical tools.

- Model of the actual Qarnot/edge platform.
- Simulator (almost complete).
- We proposed several scheduling problems. Some are still under investigation.
- Theoretical analysis remains to be done.
- A preliminary solution has been implemented and assessed on real execution traces.