AlGorille INRIA Project Team

Energy issues of GPU computing clusters

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What means « using a GPU cluster » ?

Programming a cluster of « CPU+GPU » nodes

- Implementing message passing + multithreading + vectorization
- Long and difficult code development and maintenance

→ How many software engineers can do it ?

Computing nodes requiring more electrical power (Watt)

- CPU + (powerful) GPU dissipate more electrical power than CPU
- Can lead to improve the electrical network and subscription

→ Can generate some extra-costs !

But we expect :

- To run faster

and / or

- To save energy (Watt.Hours)

1 - First experiment:

« hapilly parallel » application

- Asian option pricer (independant Monte Carlo simulations)
- Rigorous parallel random number generation

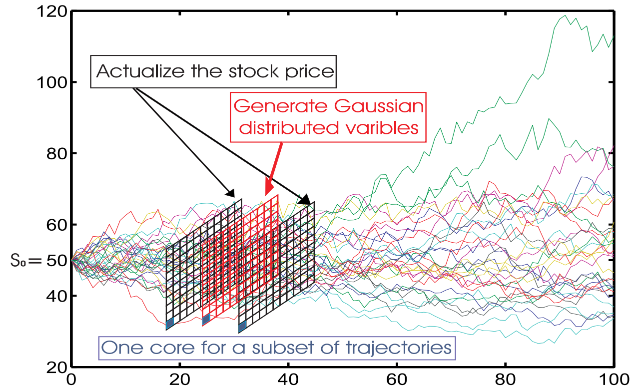
2008

Lokman Abas-Turki
Stephane Vialle
Bernard Lapeyre

1 - Happily parallel application

Application :

« Asian option pricer »:
Independent Monte Carlo trajectory computations



Coarse grain parallelism on the cluster:

- Distribution of data on each computing node
- Local and independent computations on each node
- Collect of partial results and small final computation

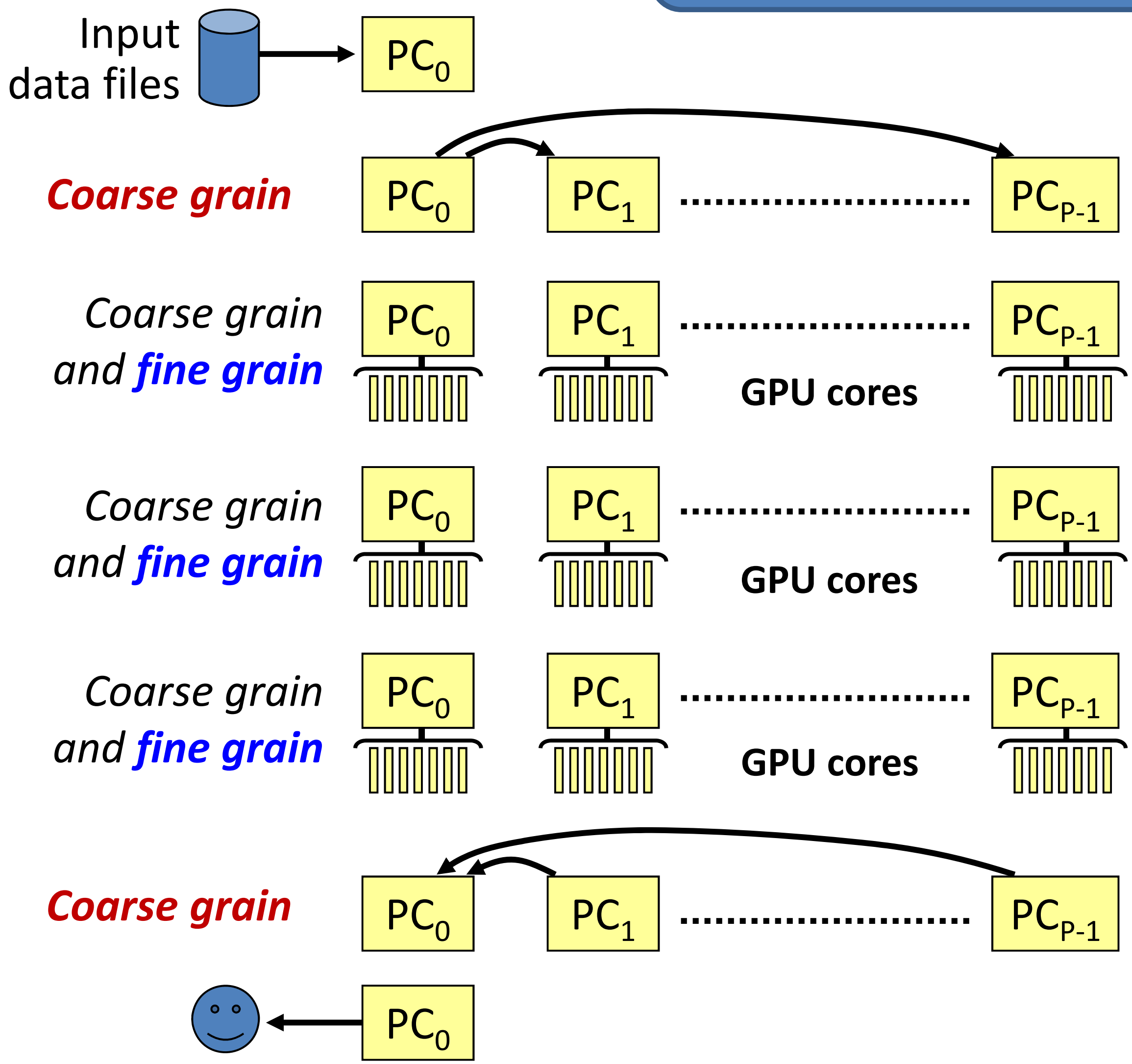
Fine grain parallelism on each node:

- Local data transfer on GPU memory
- Local parallel computation on the GPU
- Local result transfer from the GPU to the CPU memory

→ Coarse and fine grain parallel codes can be developed separately (nice!)

1 - Happily parallel application

Long work to design rigorous parallel random number generation on the GPUs



1 - Input data reading on P_0

2 - Input data broadcast from P_0

3 - Parallel and independent RNG initialization

4 - Parallel and independent Monte-Carlo computations

5 - Parallel and independent partial results computation

6 - Partial results reduction on P_0 and final price computation

7 – Print results and perfs

1 - Happily parallel application

Comparison to a **multi-core** CPU cluster (using all CPU cores):

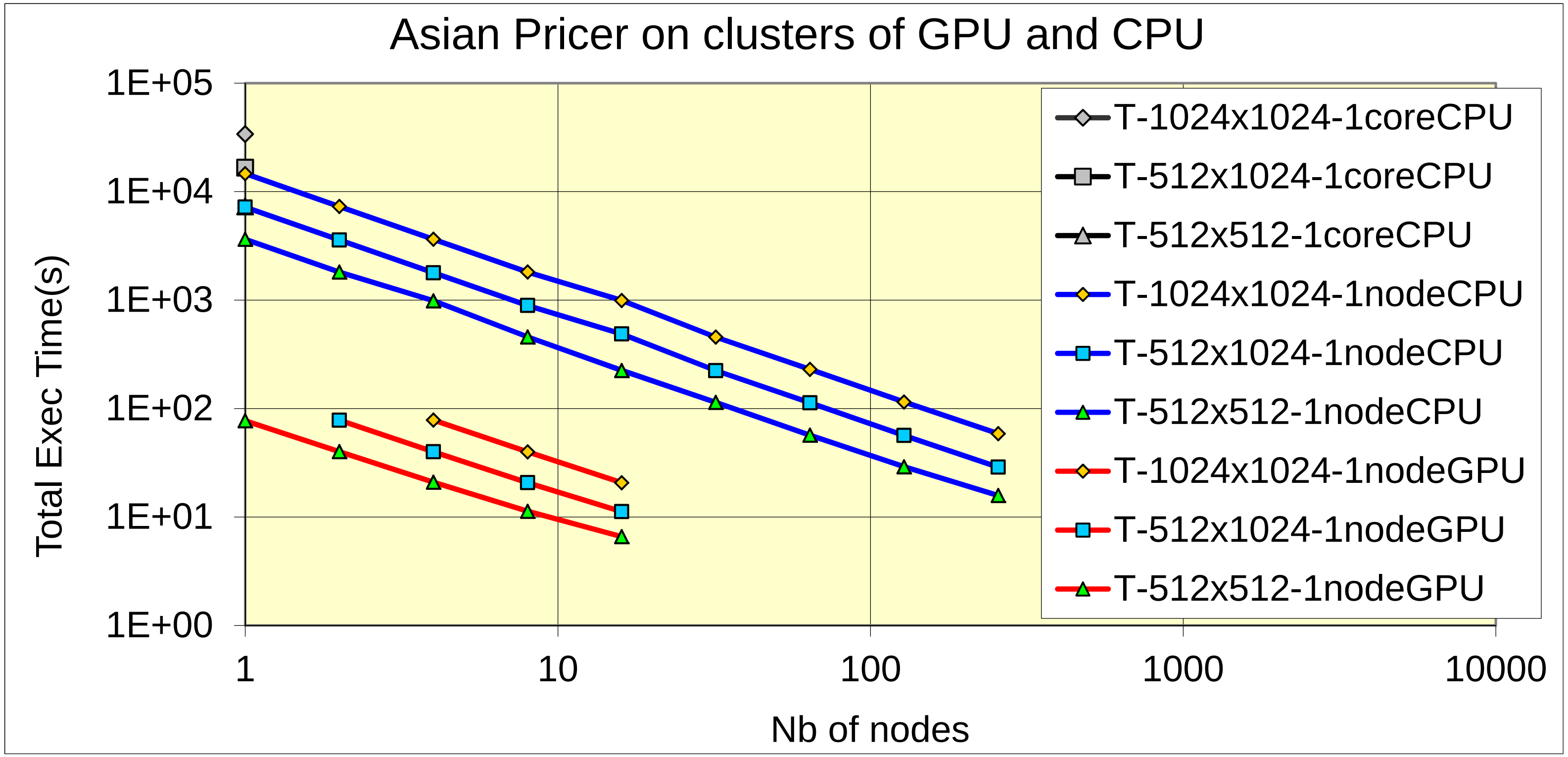
16 GPU nodes run **2.83** times faster than 256 CPU nodes

256 INTEL dual-core nodes

1 CISCO 256-ports switch, Gigabit-eth

16 INTEL dual-core nodes
1 GPU (GeForce 8800 GT) / node

1 DELL 24-ports switch, Gigabit-eth

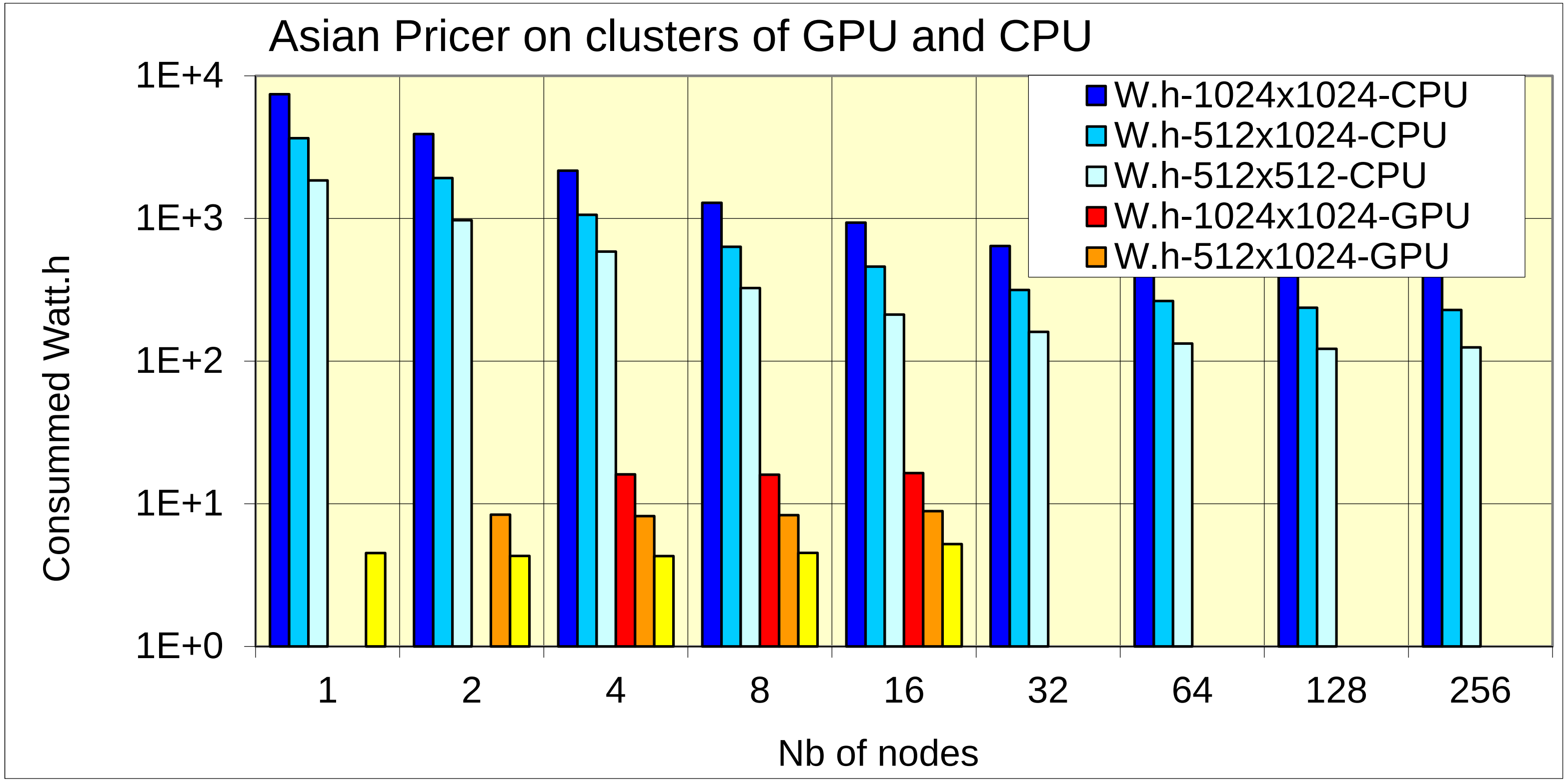


1 - Happily parallel application

Comparison to a **multi-core** CPU cluster (using all CPU cores):

16 GPU nodes consume **28.3** times less than 256 CPU nodes

GPU cluster is 2.83x28.3 = **80.1** times more efficient



2 – « Real parallel » code experiments:

Parallel codes including communications

- 2D relaxation (frontier exchange)
- 3D transport PDE solver

Sylvain Contassot-Vivier
Stephane Vialle
Thomas Jost
Wilfried Kirschenmann

2009

2 – Parallel codes including comms.

These algorithms remain synchronous and deterministic
But coarse and fine grained parallel codes have to be jointly designed

→ Developments become more complex

...
Internode CPU communications
Local CPU → GPU data transfers
Local GPU computations
Local GPU → CPU partial result transfers
Local CPU computations (not adapted to GPU processing)
Internode CPU communications
Local CPU → GPU data transfers
...

More synchronization issues between CPU and GPU tasks

More complex buffer and indexes management:

One data has a global index, node cpu-buffer index, node gpu-buffer index, a fast-shared-memory index in a sub-part of the GPU…

2 – Parallel codes including comms.

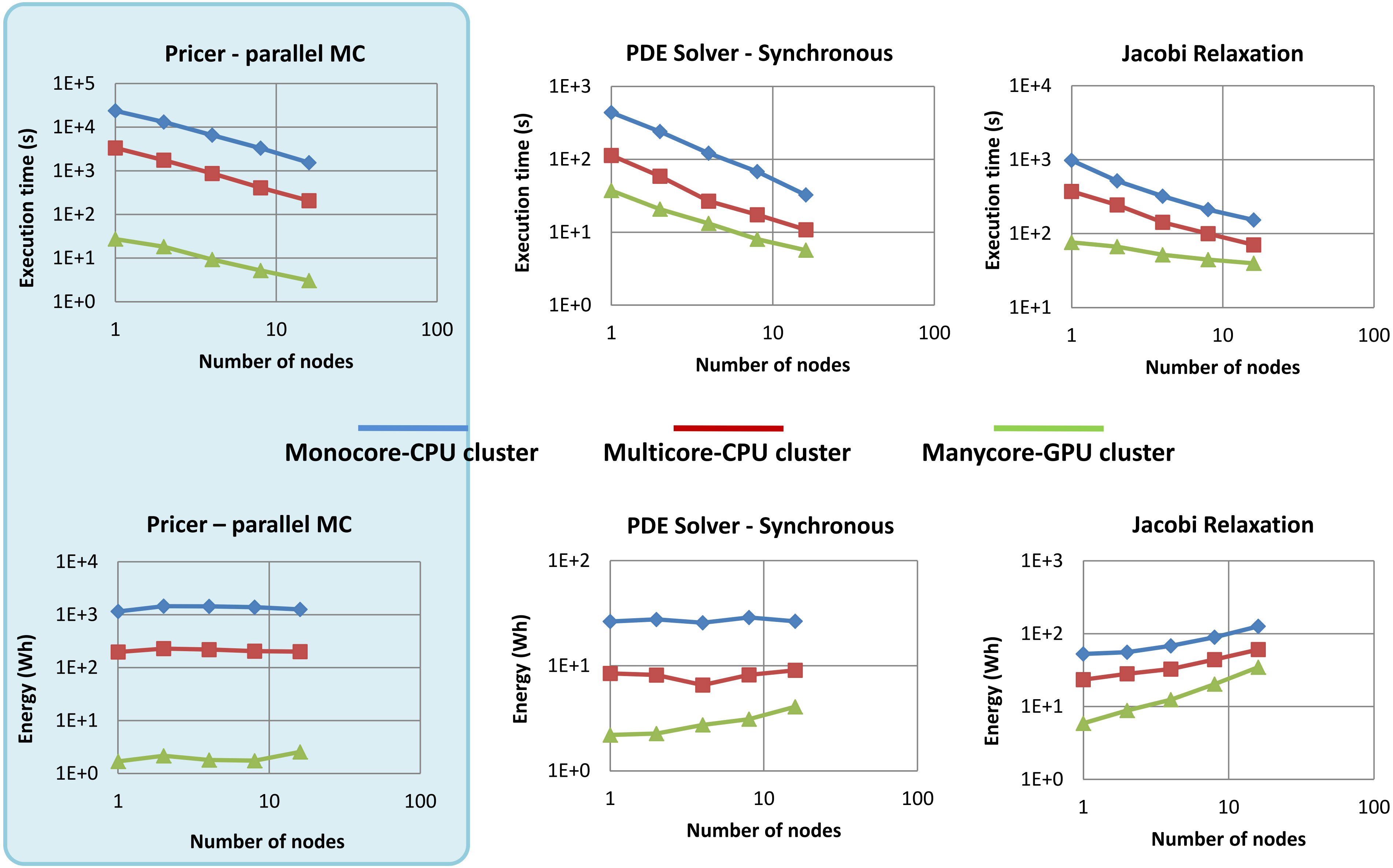
Developments become (really) more complex

→ Less software engineers can develop and maintain parallel code including communications on a GPU cluster

GPU accelerate only some parts of the code
GPU requires more data transfer overheads (CPU ←→GPU)

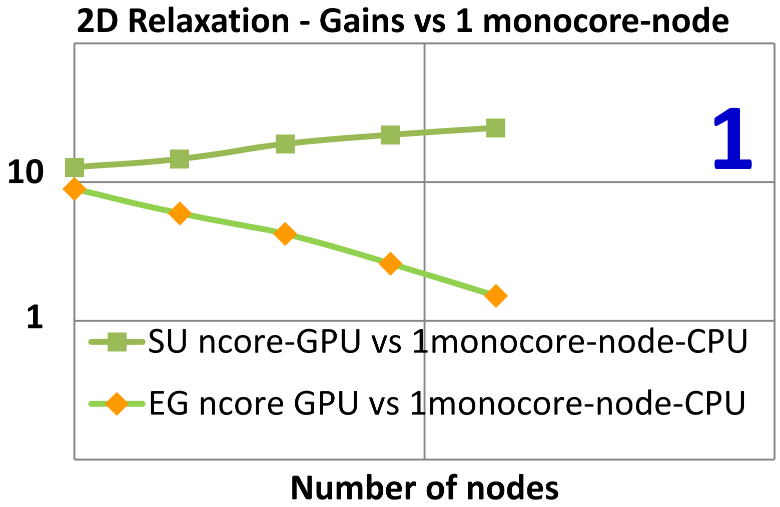
→ Is it possible to speedup on a GPU cluster ?
→ Is it possible to speedup enough to save energy ?

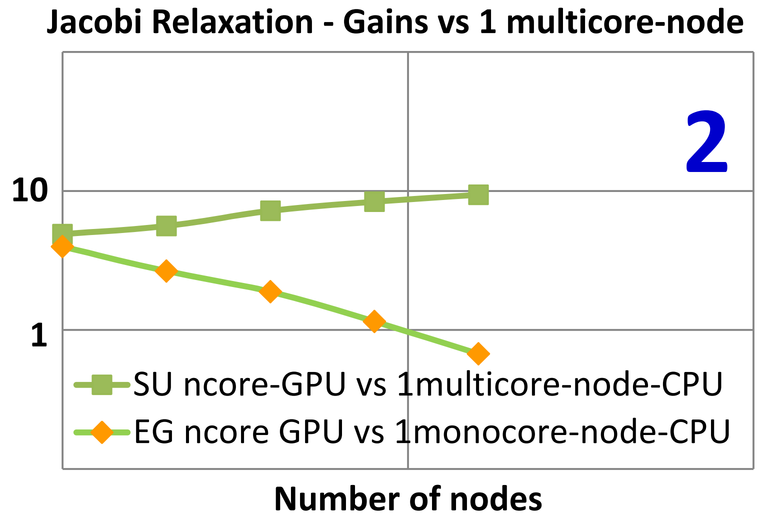
2 – Parallel codes including comms.

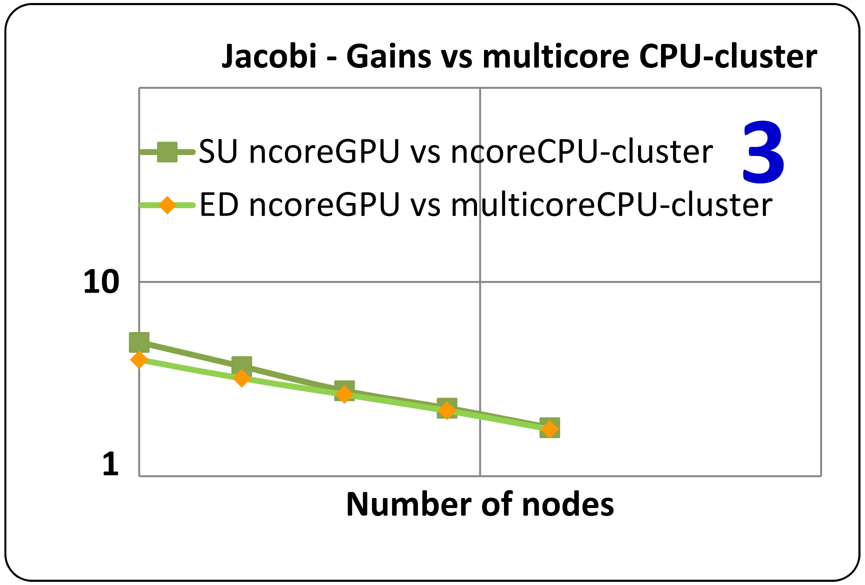


2 – Parallel codes including comms.

Rmk: Which comparison ? Which reference ?







You have a GPU cluster
→ you have a CPU cluster!

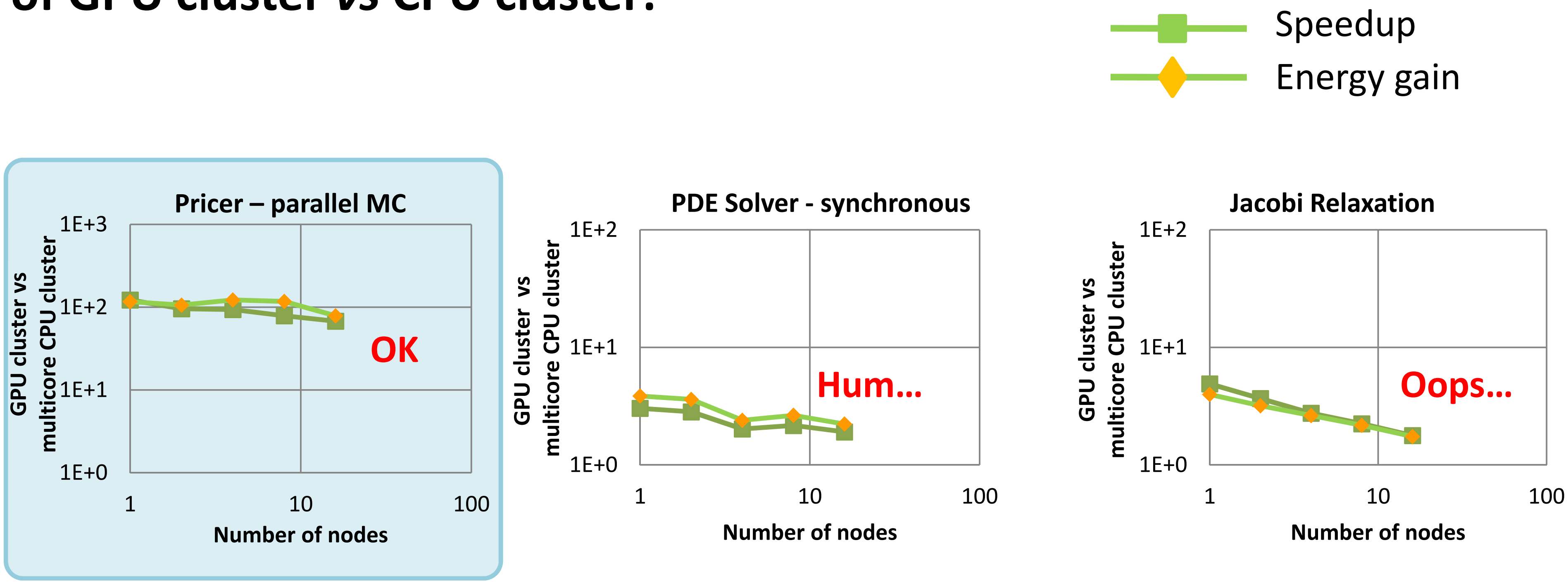
You succeed to program a GPU cluster
→ you can program a CPU cluster!

Compare a GPU cluster to a CPU cluster (not to one CPU core…) when possible

Comparison will be really different

2 – Parallel codes including comms.

Temporal gain (speedup) & Energy Gain of GPU cluster *vs* CPU cluster:



Up to 16 nodes this GPU cluster is more interesting than our CPU cluster, **but its interest decreases…**

2 – Parallel codes including comms.

	CPU cluster	GPU cluster
Computations	T-calc-CPU	If algorithm is adapted to GPU architecture: T-comput-GPU << T-compu-CPU else: do not use GPUs!
Communications	T-comm-CPU = T-comm-MPI	T-comm-GPU = T-transfert-GPUtoCPU + T-comm-MPI + T-transfert-CPUtoGPU T-comm-GPU ≥ T-comm-CPU
Total time	T-CPUcluster	T-GPUcluster < ? > T-CPUcluster

→ For a given pb on a GPU cluster: T-comm becomes strongly dominant and GPU cluster interest decreases

3 – Asynchronous parallel code experiments:

(asynchronous algorithm & asynchronous implementation)

- 3D transport PDE solver

Sylvain Contassot-Vivier
Stephane Vialle

2009-2010

3 - Async. parallel codes on GPU cluster

Asynchronous algo. provide implicit overlapping of communications and computations, and communications are important into GPU clusters.

→ **Asynchronous code <u>should</u> improve execution on GPU clusters specially on heterogeneous GPU cluster**

BUT :

- Only some iterative algorithms can be turned into asynchronous algorithms
- The convergence detection of the algorithm is more complex and requires more communications (than with synchronous algo)
- Some extra iterations are required to achieve the same accuracy.

3 - Async. parallel codes on GPU cluster

Rmk: asynchronous code on GPU cluster has awful complexity

Available synchronous PDE solver on GPU cluster (previous work)

- 2 senior rechearchers in parallel computing
- 1 year work

The most complex debug we have achieved !

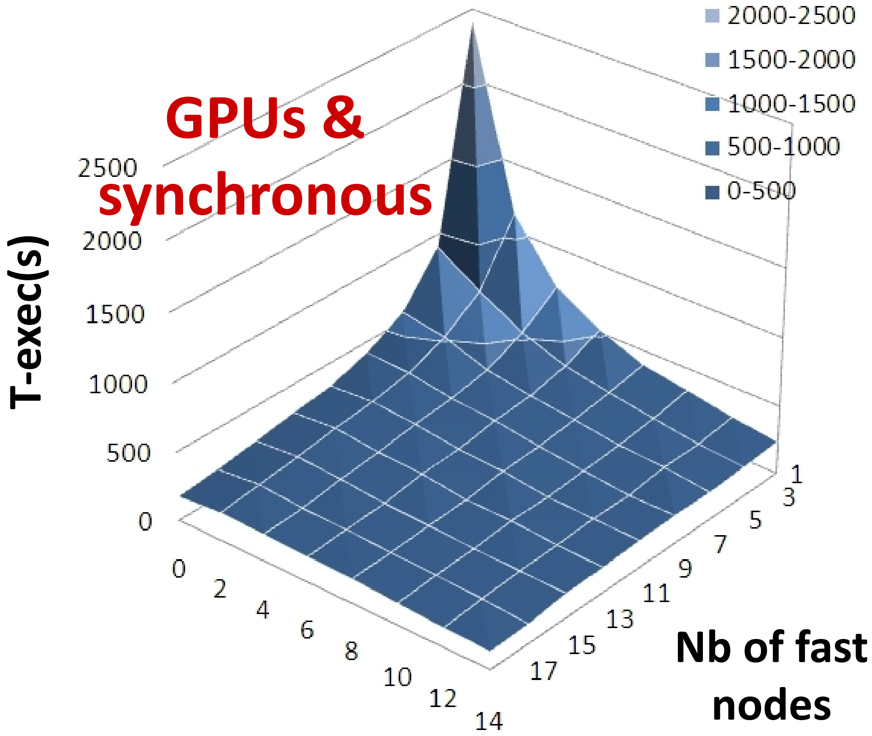
… how to « validate » the code ?

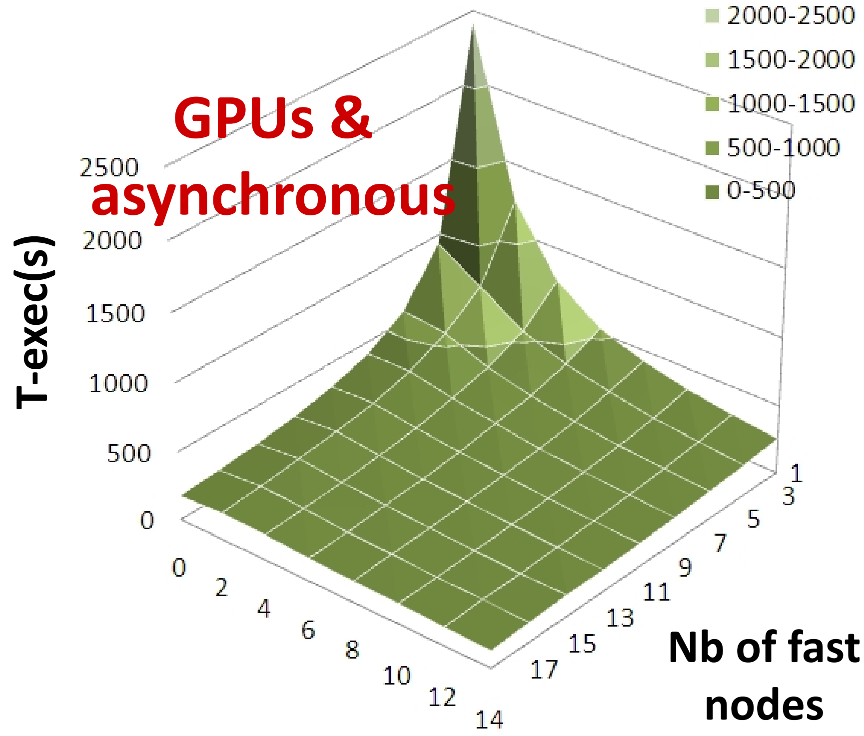
Operational asynchronous PDE solver on GPU cluster

3 - Async. parallel codes on GPU cluster

Execution time using 2 GPU clusters of Supelec:

- 17 nodes Xeon dual-core + GT8800
- 16 nodes Nehalem quad-core + GT285
- 2 interconnected Gibagit switches



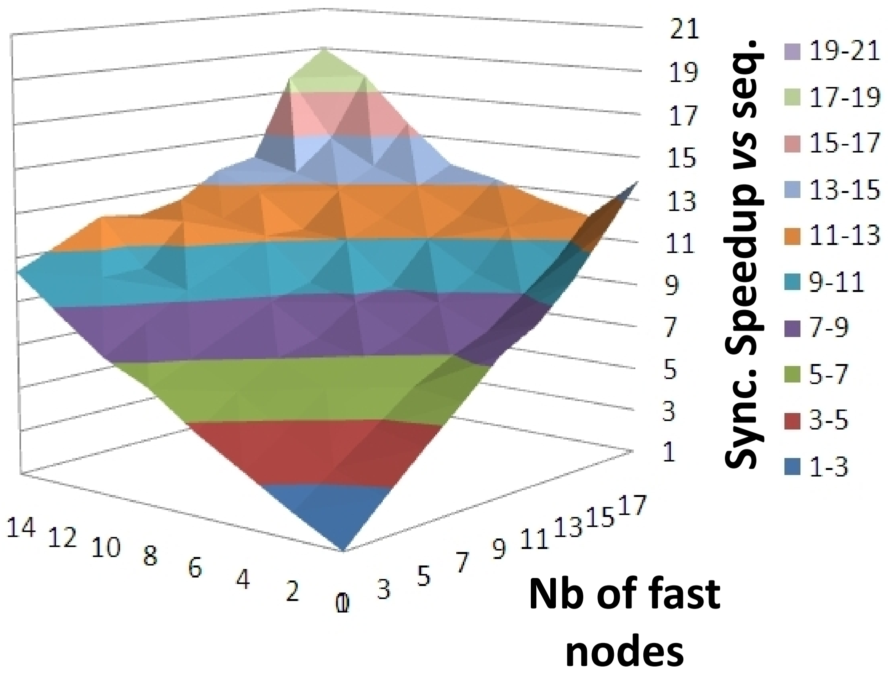


3 - Async. parallel codes on GPU cluster

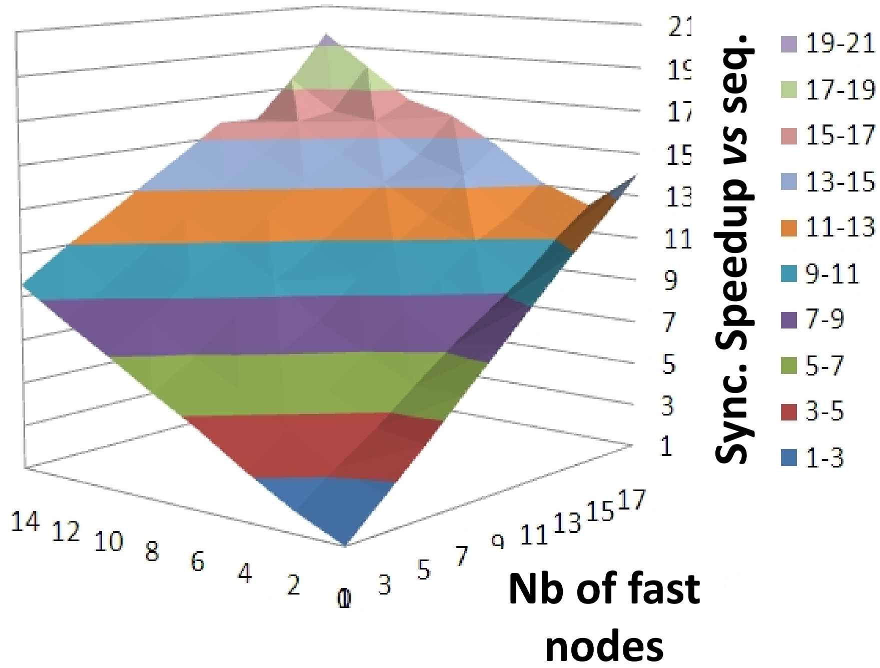
Speedup vs 1 GPU:

- asynchronous version achieves more regular speedup
- asynchronous version achieves better speedup on high nb of nodes

GPU cluster & synchronous
***vs* 1 GPU**



GPU cluster & asynchronous
***vs* 1 GPU**

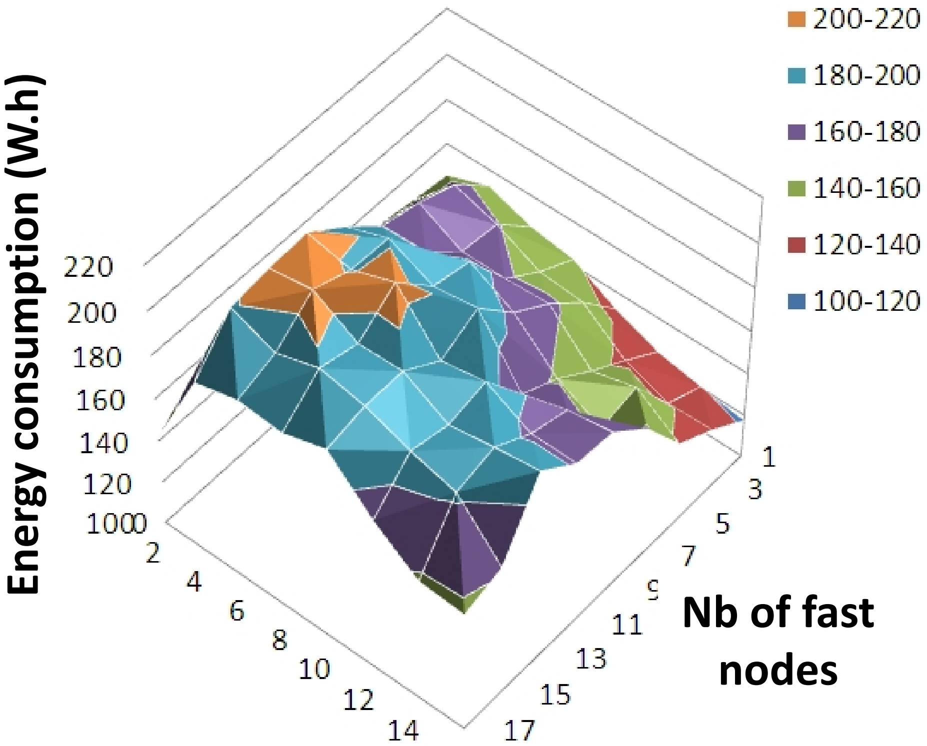


3 - Async. parallel codes on GPU cluster

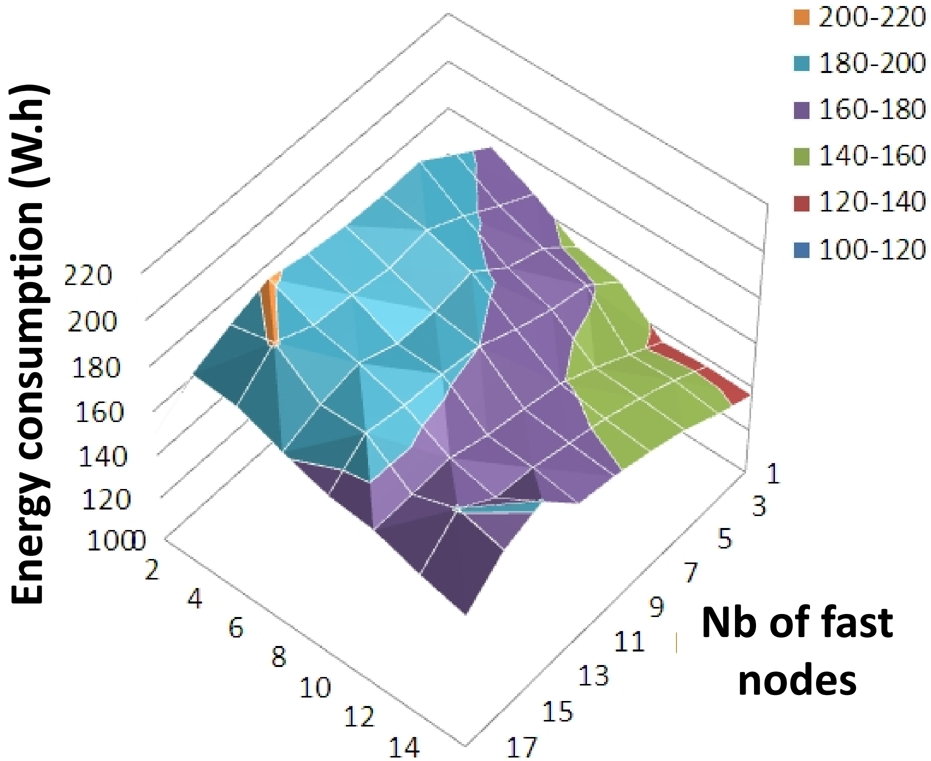
Energy consumption:

- sync. and async. energy consumption curves are (just) different

GPU cluster & synchronous



GPU cluster & asynchronous

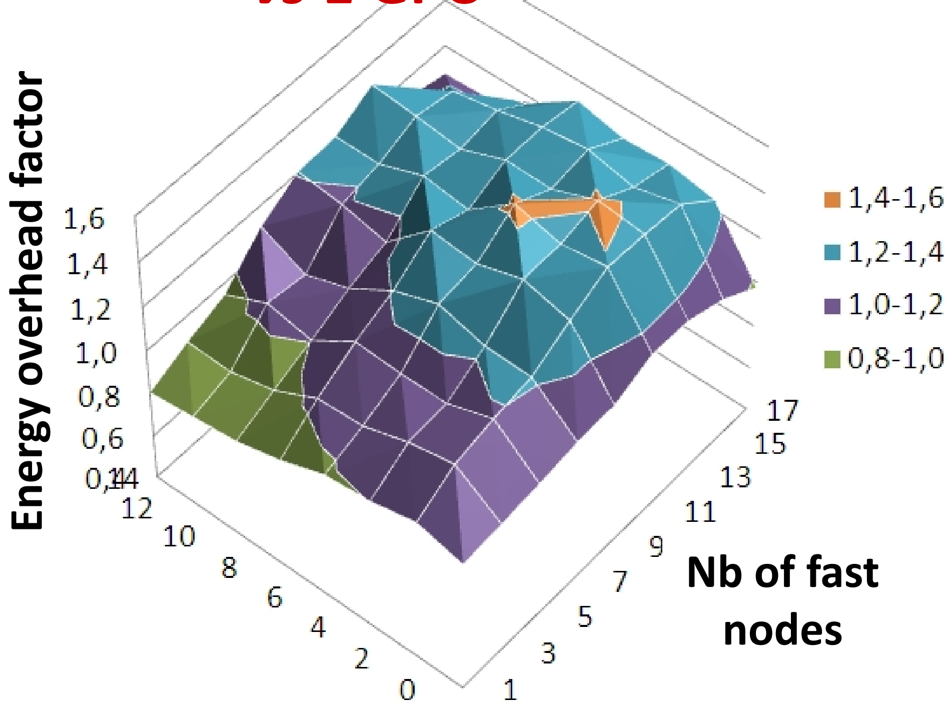


3 - Async. parallel codes on GPU cluster

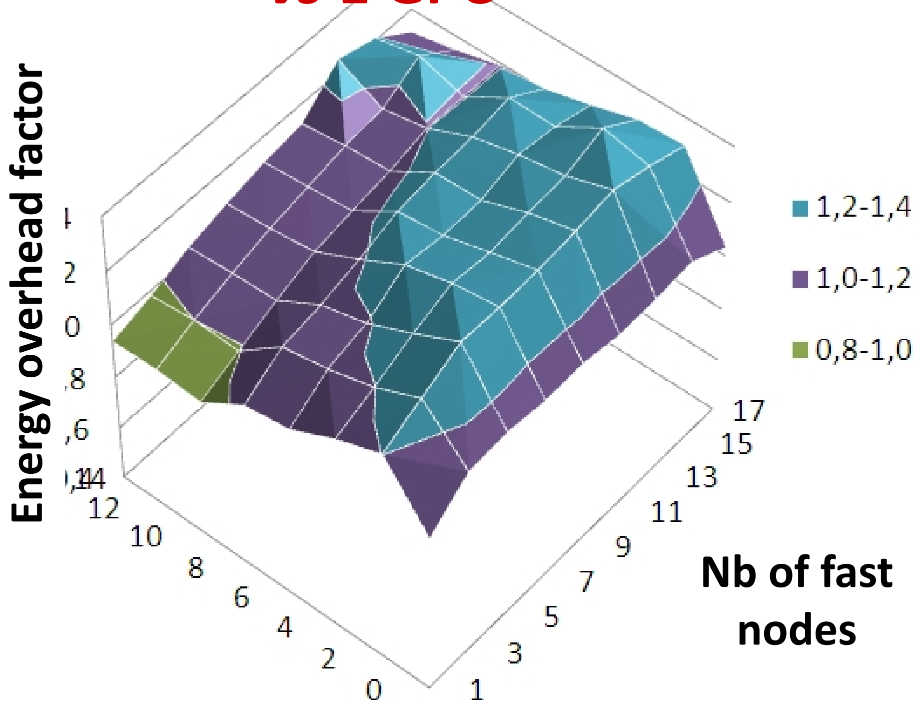
Energy overhead factor vs 1 GPU (overhead to minimize):

- overhead curves are (just) « differents »
  → no more global attractive solution !

GPU cluster & synchronous *vs* 1 GPU



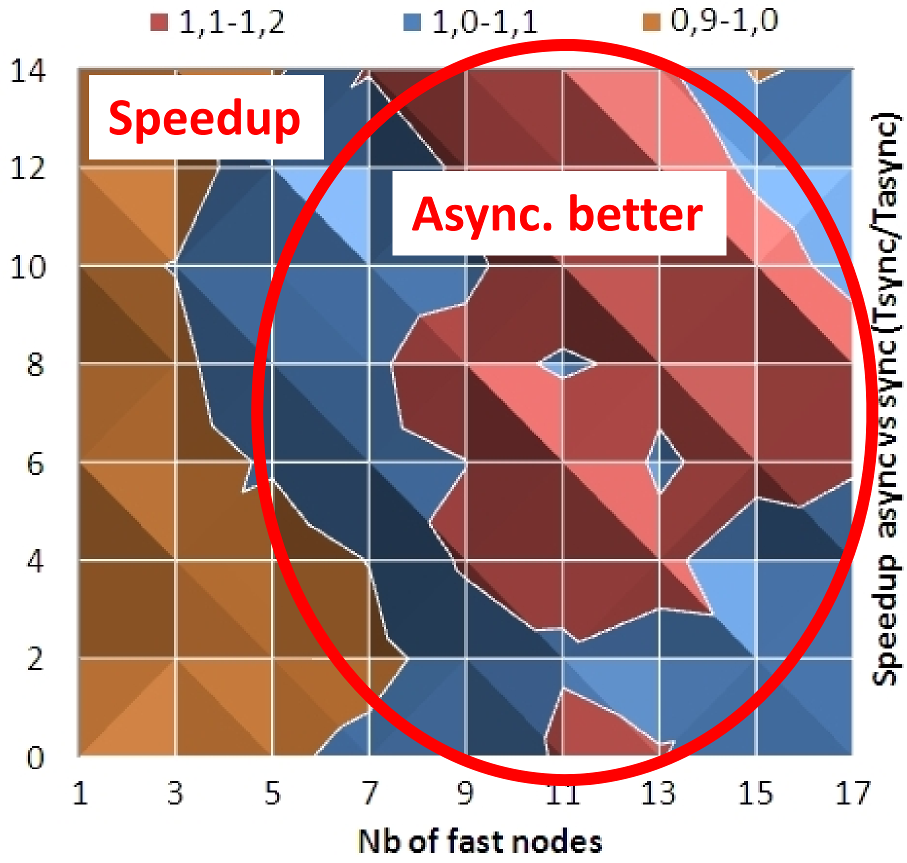
GPU cluster & asynchronous *vs* 1 GPU

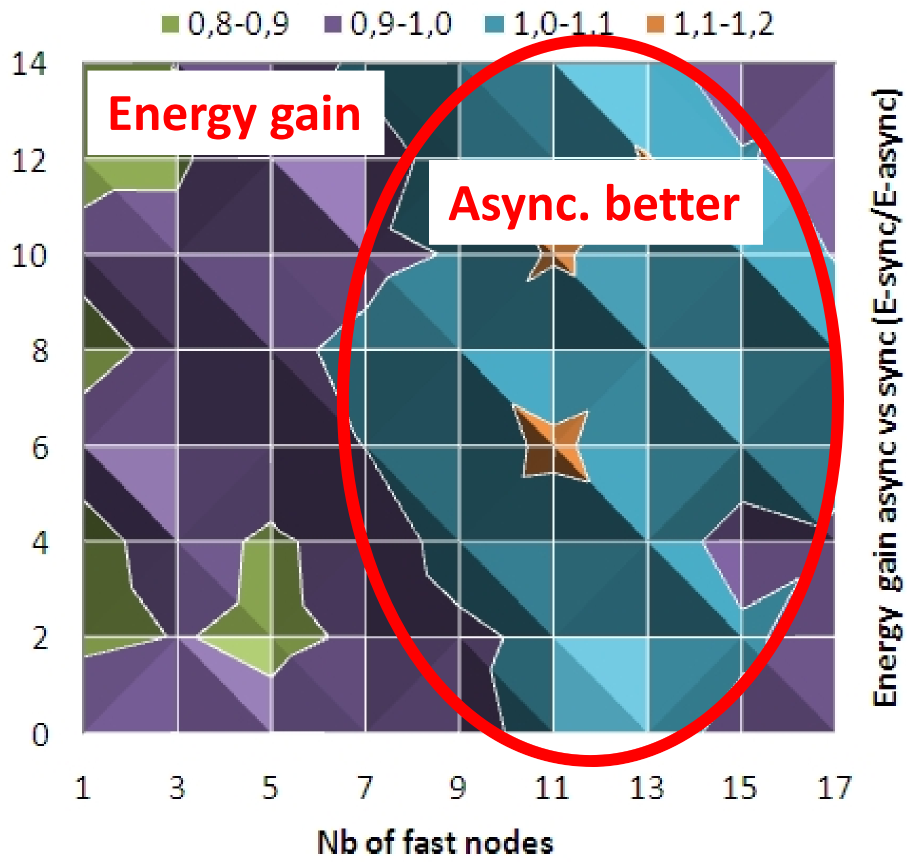


3 - Async. parallel codes on GPU cluster

Async *vs* sync speedup and async vs sync energy gain

- Can be used to choose the version to run
- But region frontiers are complex: **need a fine model to predict**





3 - Async. parallel codes on GPU cluster

Overview of asynchronous code expriments:

Can lead to better performances on heterogeneous GPU clusters

But:

- Very hard to develop
- Difficult to identify when it is better than a synchronous code

→ Not the « magical solution » to improve performances on GPU clusters

We are investigating new asynchronous approaches …

4 – Synchronous parallel application including communications and designed for GPU clusters

- American option pricer

Lokman Abbas-Turki
Stephane Vialle

Supélec
Université Paris-Est Marne-la-Vallée

2010-2011-2012

4 – Sync. code designed for GPUs

American option pricing:

- Non linear PDE problem
- Many solutions does not require too much computations BUT :
  - Have limited accuracy
  - Are not parallel (bad scaling when parallelized)

Our solution:

- New mathematic approach based on Maillavin calculus
- Use Monte Carlo computation: we have efficient solution on GPU
- Design a BSP-like parallel algorithm: separated big computing steps and communication steps

To get:

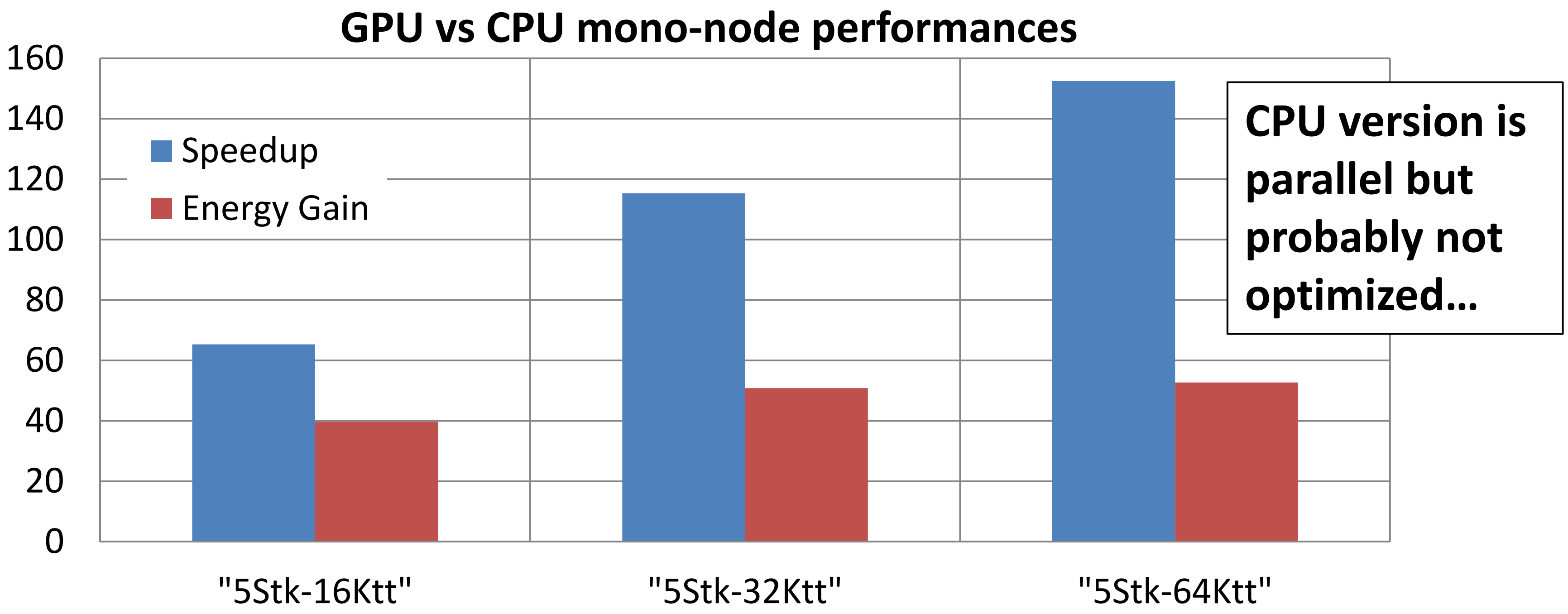
- **high quality results**
- **GPU efficient code**
- **scalable parallel code on GPU cluster**

4 – Sync. code designed for GPUs

Comparison on one node : CPU *vs* GPU

- 1 INTEL 4-core hyperthreaded (« Nehalem »)
- 1 NVIDIA GTX480 (« Fermi »)

Parallel CPU and parallel GPU codes



→ The parallelization seems well adapted to GPU

(it has been designed for this architecture)

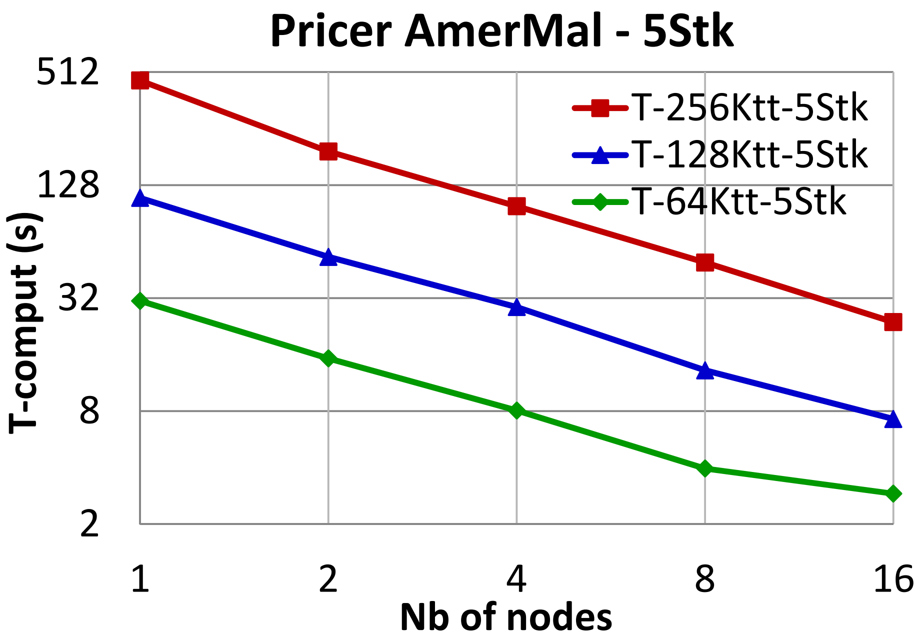
4 – Sync. code designed for GPUs

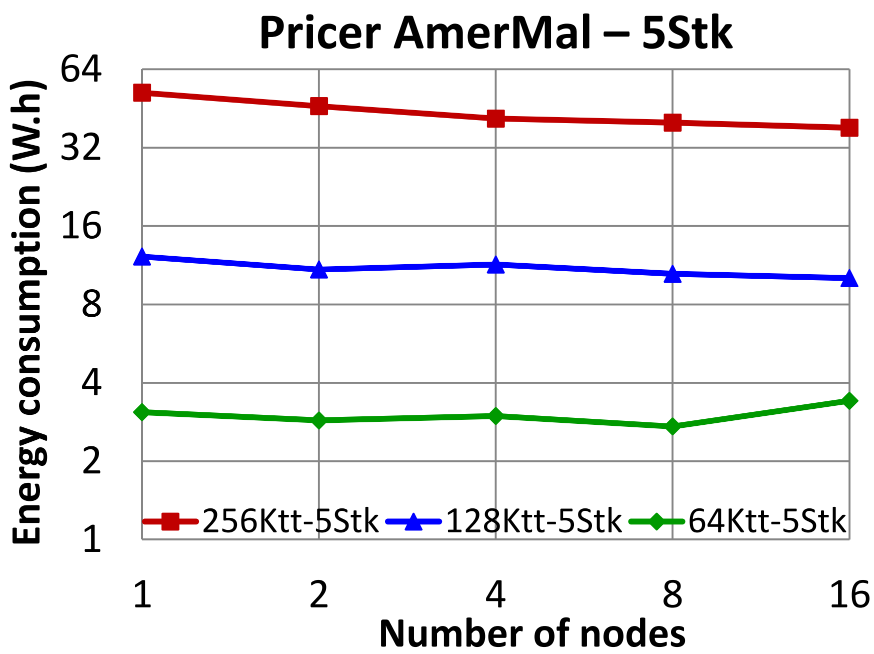
Good scalability of parallel code on GPU cluster

Energy consumption remains constant when using more nodes

And results have high quality !

Missing exepriments on multicore CPU clusters… (long to measure…)





4 – Sync. code designed for GPUs

After somes years of experience in « option pricing on GPU clusters »

- Redesign of the mathematic approach
- Identification of a solution accurate and adapted to GPU clusters
- Many debug steps, many benchmarks-perf analysis-optimization
- Good results and performances!

- Still a bottleneck in the code limits the full scalability…
  … under improvement.

- Has required long development times
  1-2 years (part time)
  1 mathematician, with strong knowledge in GPGPU
  1 computer scientist in parallel computing (and GPGPU)

5 – Can GPU clusters decrease the energy consumption ?

5 – GPU cluster energy consumption

When using GPUs
- Development time Tdev ↗
- Electrical Power P (Watt) ↗
- Execution Time Te (s) ↘
- Flops/Watt ratio ↗ (usually)

→ **Energy consumption (W.h (Joule)) …. ???**

In all our experiments: Te decreases → Energy decreases

« Te decreases stronger than P increases »

But sometimes Speedup and Energy Gain are low (< 5) !

Warning ! Electrical Power increase can require some changes:

Improve the electrical network !
Increase of the electrical subscription !
Improve the maximal electrical production …

5 – GPU cluster energy consumption

Different use-cases when you add GPUs in a PC cluster:

- **Limited amount of computations to run (unsaturated machines)**

  During computations : P ↗, Te ↘, Flops/Watt ↗ …… and E ↘
  When machine is unused and switched on : P ↗ …… and E ↗

  An unused and switched on GPU cluster wastes a lot of energy (under improvement ?)

- **Add GPUs and reduce the nb of nodes: total Flops unchanged**

  P ↘, Te ↘, Flops/Watt ↗ …… and E ↘

  But applications not adapted to GPU will run slowly !

5 – GPU cluster energy consumption

Different use-cases when you add GPUs in a PC cluster:

- **Add GPU in each node: increase the total Flops**

  If unlimited amount of computations to run (saturated machines)

  P ↗, Te ↘, Flop/Watt ↗ …… but E ↗

  Each computation is faster and less consuming
  But more and more computations are run

Conclusion

GPU and GPU-clusters remain complex to program to achieve high performances:

- Re-design mathematic solutions
- Optimize code for GPU clusters
- Compare to multicore CPU clusters

Add GPUs in a PC cluster increase the electrical power dissipation:

- Poor usage of GPUs will waste (a lot of) energy

GPU is a « vector co-processor » with high impact:

- Can speedup application and reduce the energy consumption and satisfy users
- Can be not adapted to a code and can increase the energy consumption … and make users angry!

→ Analyse the requirements and knowledge of users before to install (actual) GPUs

AlGorille INRIA
Project
Team

Energy issues of GPU computing clusters

Questions ?