OpenCL implementation of PSO: a comparison between multi-core CPU and GPU performances

Stefano Cagnoni[1], Alessandro Bacchini[1,2], Luca Mussi[1]

[1]Dept. of Information Engineering, University of Parma, Italy

[2]Henesis srl, Parma, Italy

Overview

- Motivation
- PSO parallelization
- GPU / Multi-core CPU implementation
- Experimental results
- Conclusions

Motivation

- GPUs
  - massively parallel execution of tasks on hundreds of cores
- Multi-core CPUs
  - coarser grain
  - fewer, more powerful and complex cores

Motivation

- GPU-based code is overwhelmingly faster than single-threaded sequential code
- Most papers describing GPU-based parallel algorithms report only this comparison; the power of multi-core CPUs is underexploited
- What about the performance of multi-core CPU implementations ?

Goal

- Comparing performances of GPU-based and multi-core CPU-based parallelization of a bio-inspired metaheuristic

- OpenCL chosen as development environment, since it can produce code for both GPUs and multi-core CPUs

- Based on our previous implementations, we chose PSO parallelization as a test-bed

Why is PSO so attractive ?

Not the best metaheuristic at all …

However…

- Easy to implement
- Fast-converging
- Effective for many practical problems

and (last but not least)

- **Very well parallelizable**

Why is PSO so attractive ?

Parallelization opportunities offered by many fitness functions

- Functions based on cumulative sums of independent computations
- Functions implying operations on large matrices,
- etc…

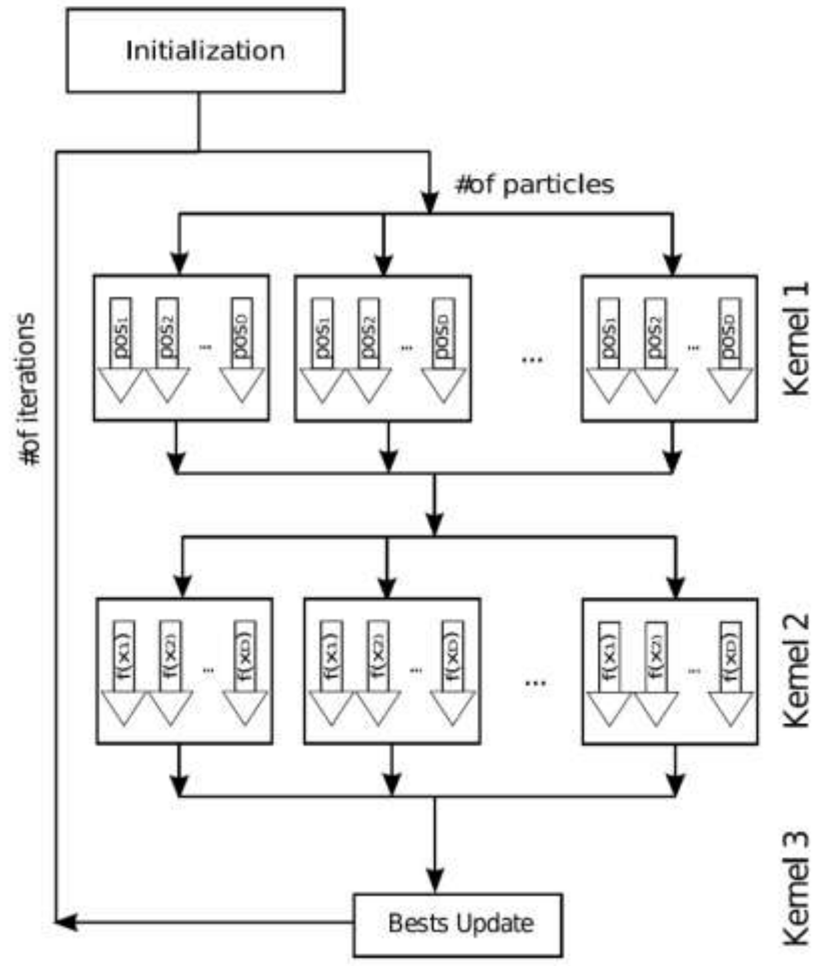
Previous GPU-PSO implementations

- Three-kernel synchronous (Information Sciences, 2011)
  - Any topology allowed
  - Any problem size
  - Large overhead (three memory swaps)

- Single-kernel asynchronous (GECCO 2011)
  - Ring topology, radius = 1
  - Limited number of particles
  - Fastest possible (no swaps)

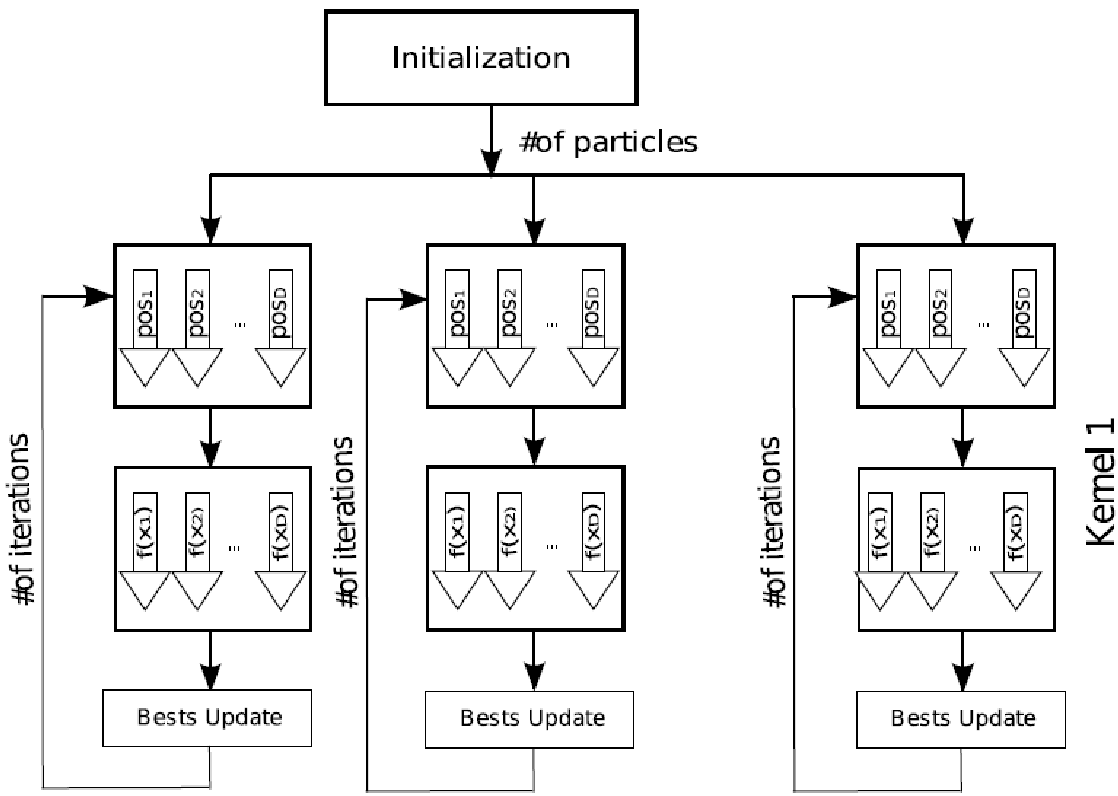
Previous work on GPU-PSO Single-kernel vs. Multi-kernel

Synchronous multi-kernel PSO



Previous work on GPU-PSO Single-kernel vs. Multi-kernel

Asynchronous single-kernel PSO (ring topology, radius=1)



Previous work on GPU-PSO Single-kernel vs. Multi-kernel

- Single-kernel (all computations in local memory)
  - \+ No (limited) need for synchronization

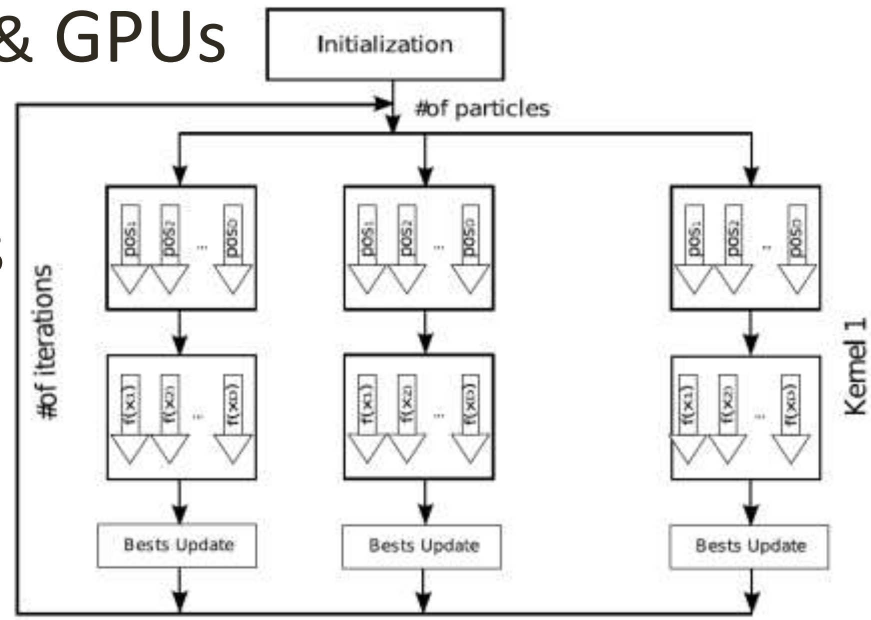
    No data exchange between GPU and CPU
  - − Limited local resources

    Small maximum number of particles in a swarm
- Multi-kernel (need for 3 data swaps)
  - \+ Virtually no resource-related limitation

    Any swarm size possible (up to several hundreds)
  - − Large memory overhead due to the need for synchronization after each kernel is run

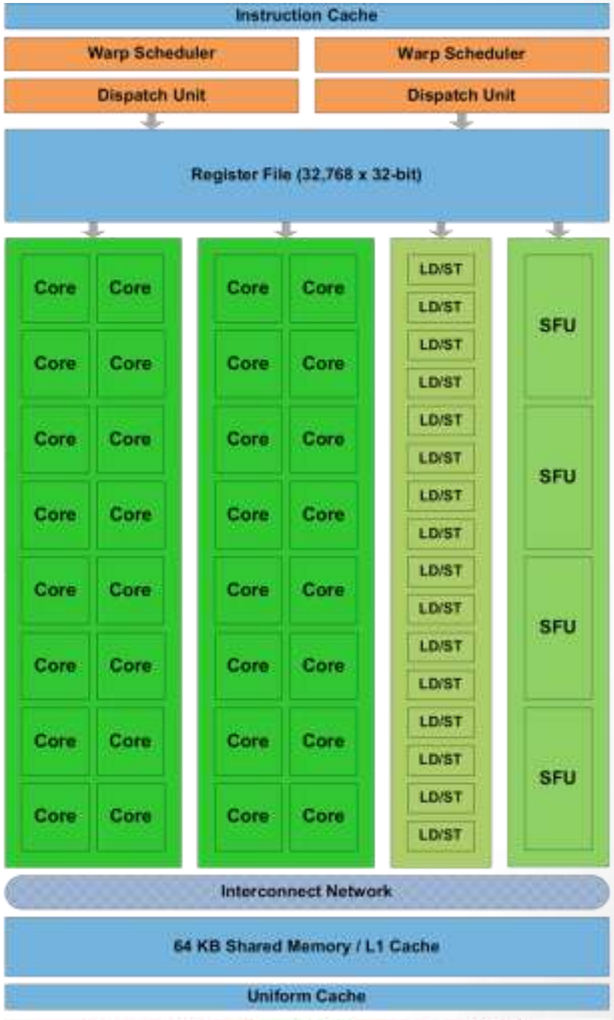
New implementation

- Single kernel
- Synchronization at the end of each cycle
  - One can schedule as many threads as necessary
- Suitable for both CPUs & GPUs
- Virtually no limits to the number of particles
- Smaller memory overhead wrt the multi-kernel version



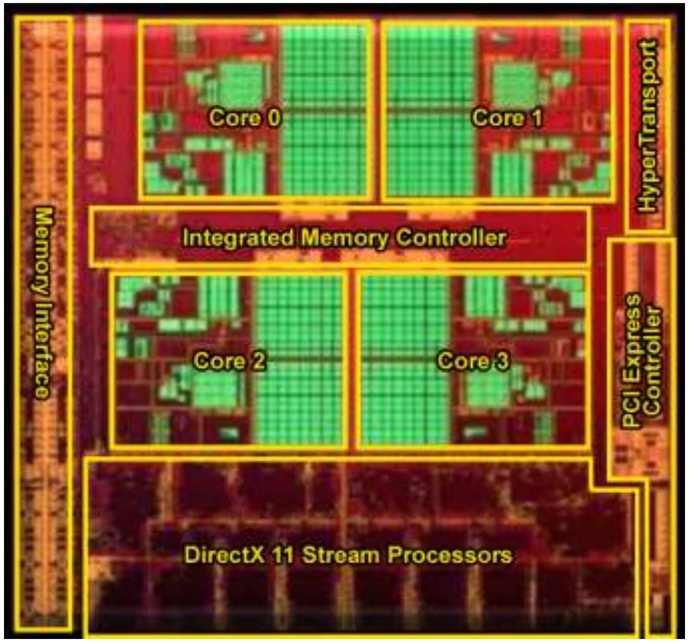
GPU

- Massively parallel architecture
  - Hundreds or thousands of simple cores
  - Simple instruction set
    - Synchronization primitives
- Deep memory hierarchy
  - Private, local, global, constant memory
  - Each one has a different role



Fermi Streaming Multiprocessor (SM)

Multi-core CPU



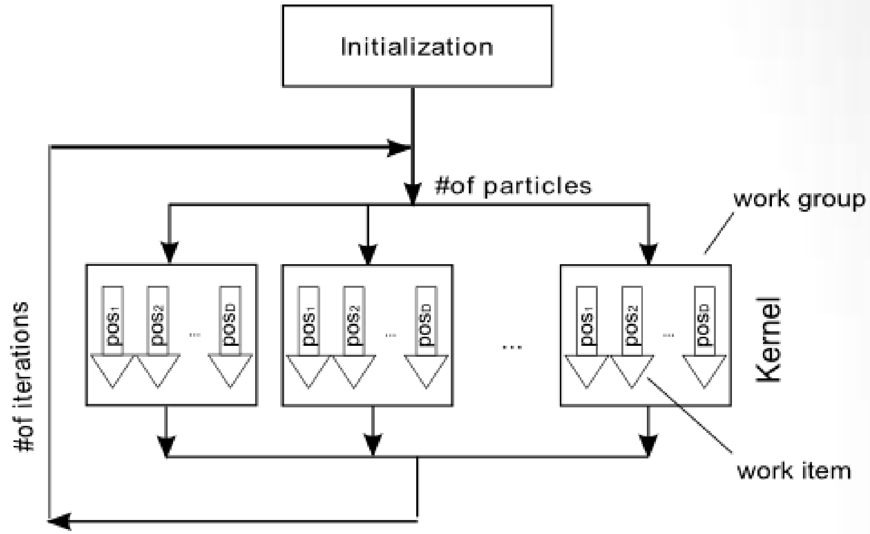
- Parallel architecture
  - 2 to 12 cores
  - Complex instruction set
    - Vectorized instructions (SSE, AVX)
- Shallow memory hierarchy
  - Global and local memory share the same chips

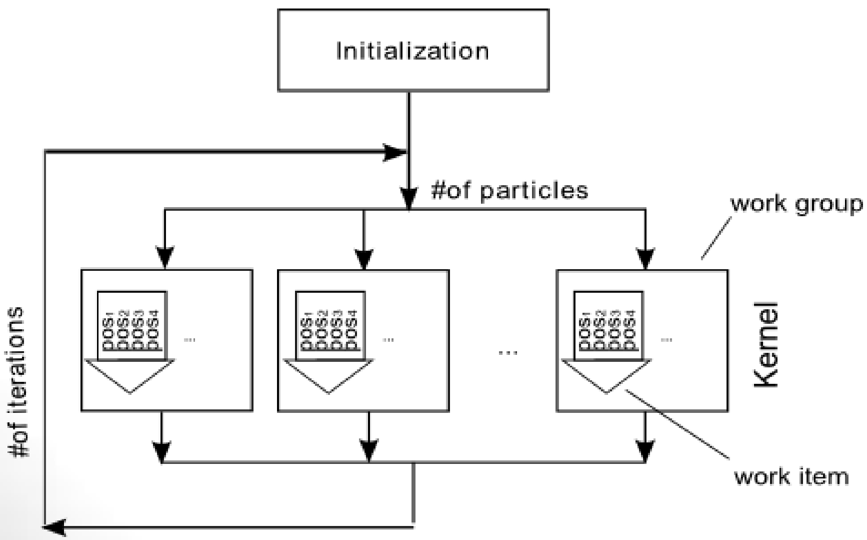
Vectorization instructions

- A single instruction operates on multiple data
- OpenCL natively supports vector data types
  - The OpenCL compiler has auto-vectorization capabilities, but manually optimized vectorization still offers better results
- GPU/CPU comparison:
  - Intel i7, with 8 cores and AVX SIMD instructions, can process 64 floats in parallel
  - Nvidia Geforce GTX560 Ti can process 384 floats in parallel
    - 6 times as many as the CPU

Vectorization

- Non-vectorized
  One thread per dimension
  128 particles on a 128-D problem = 16384 threads
- **Better for GPUs**





- Vectorized
  - 8 dimensions per thread
  - 128 particles on a 128-D problem = 2048 threads
- **Better for CPUs**

Tests

- A set of 5 commonly (ab)used functions was used as benchmark:
  - Sphere $[-100, +100]^N$
  - Elliptic $[-100, +100]^N$
  - Rastrigin $[-5.12, +5.12]^N$
  - Rosenbrock $[-30, +30]^N$
  - Griewank $[-600, +600]^N$
- Our goal was to compare execution speed
  - Algorithm equivalence was also checked

Tests

- 2 multi-core CPUs:
  - Intel i7 2630M (high-end laptops)
  - Intel i7 2600K (medium/high-end desktops)

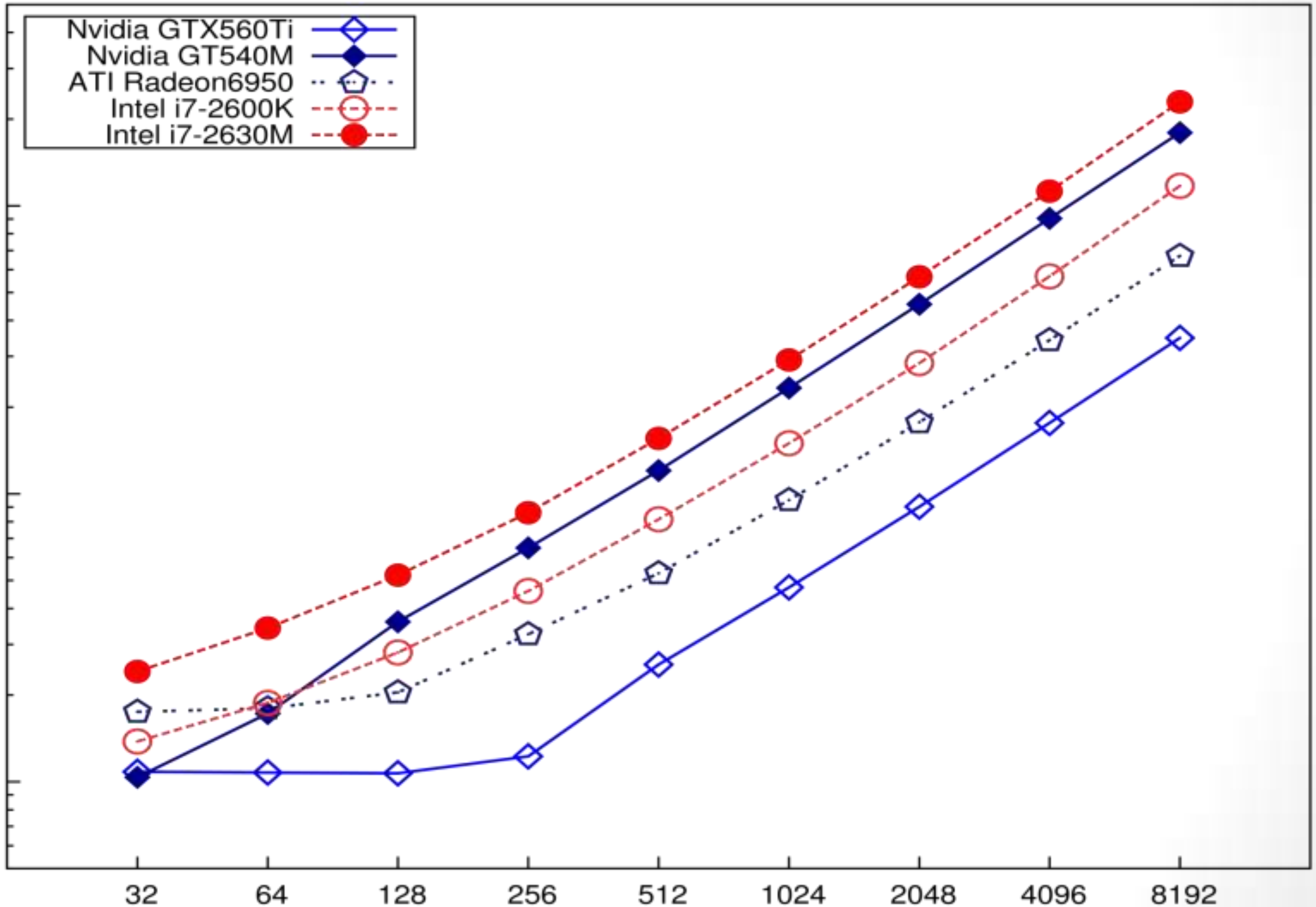
were compared to 3 GPUs:

- nVidia GT540M (medium/high-end laptops)
- nVidia GT560Ti (medium/high-end desktops)
- ATI Radeon HD6950 (medium-end laptops)

Tests

- We tested the scaling properties of our GPU-based and CPU-based implementations
  - With respect to problem size
    - 32, 64, 128 dimensions
  - With respect to swarm size:
    - 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192 particles
- Other PSO parameters
  - C1=C2=1.19315
  - ω=0.72134

Results: 64D Griewank

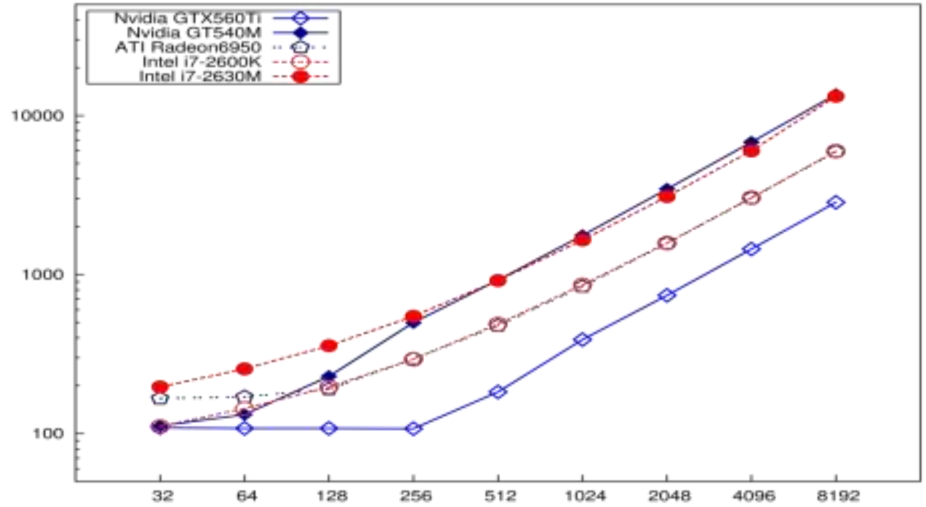


Time (ms)

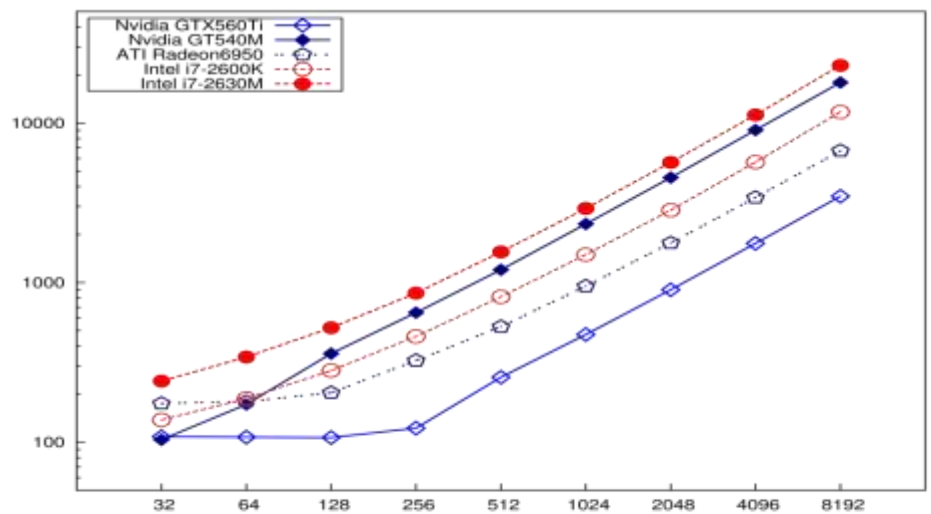
Swarm size

Results: 32D, 128D Griewank

Time (ms)



Time (ms)



Swarm size

Results: general remarks

- Scaling properties are not surprising:
  - Initial ‘flat’ segment, followed by linear increase after maximum degree of parallelism is reached
- Peculiarities:
  - nVidia GT540M is sometimes the fastest for small sizes and problem dimensions, for its slightly higher clock frequency
  - The gap between i7 and i7M narrows as problem complexity and swarm size increase: no explanation related to code or processor; possibly caused by other hardware components.

Results: GPU/CPU comparison

- GPUs are generally faster than multi-core CPUs, however:
  - Not necessarily for small swarm sizes (32-64 particles are enough for most real-world problems)
  - PSO is highly parallelizable, as are highly parallelizable the fitness functions we have used in our tests
  - Tests were generated up to huge swarm sizes, much larger than usually necessary in typical real-world applications

Results: GPU/CPU comparison

- The spread is larger for high-dimensional problems
- For larger dimensions even a cheap GPU as the GT540M has similar performances as a high-end Intel i7 processor
- In any case GPUs were never more than 6 times faster than CPUs

Results: GPU/CPU comparison

- Taking development costs into consideration:
  - Writing parallel code is more expensive, and may take more time than it saves
  - If the cost of parallelization is acceptable AND the algorithm is intrinsically parallel, then GPUs are preferable
  - Results obtained by multi-core CPUs can be close to GPUs' when GPUs cannot be used (e.g., if the graphics card must also do its traditional job…)

Some publicly-available GPU code developed at the IBIS Lab

- CUDA-PSO (ftp://ftp.ce.unipr.it/pub/cagnoni/CUDA-PSO/index.html)
  - Three-kernel implementation and some benchmark functions
- libCUDAOptimize (http://sourceforge.net/projects/libcudaoptimize/)
  - PSO, DE, Scatter Search plus benchmark functions and utilities (not yet online but coming soon)
- libCUDANN (http://sourceforge.net/projects/libcudann/)
  - Multi-layer perceptron training (BP algorithm)
- OpenCL PSO probably also available soon.

Thank you