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GPU Computing

Lesson 1: The Power of GPUs

Gauthier Lafruit & Jan Lemeire

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http://parallel.vub.ac.be/education/gpu

Course organisation

- 13/2: lessons 1 & 2
- 14/2: lessons 3 & 4
- 20/2: labo mini-project
- 27/2: labo mini-project
- 28/2: lessons 5 & 6
- 6/3: labo exercises blocks & shared memory
- 7/3: project subject: stereo matching
- 13/3: labo
- 14/3: lessons 7 (warps & coalescence)
- 20/3: labo coalescence
- 27/3: labo coalescence
- ...: project

Course evaluation

- Mini-project: 30%
- Project: 70%
  - Theory: 20%
  - Practice: 50%


ELITEGROUP
GeForce
8800 GTX
NVIDIA

versus


intel
CORE i3
inside
intel


2010
350 Million triangles/second
3 Billion transistors GPU
1995
5.000 triangles/second
800.000 transistors GPU
2016
14.000 Million triangles/second
15 Billion transistors GPU
HELMET
BULLY DOG
OGIO

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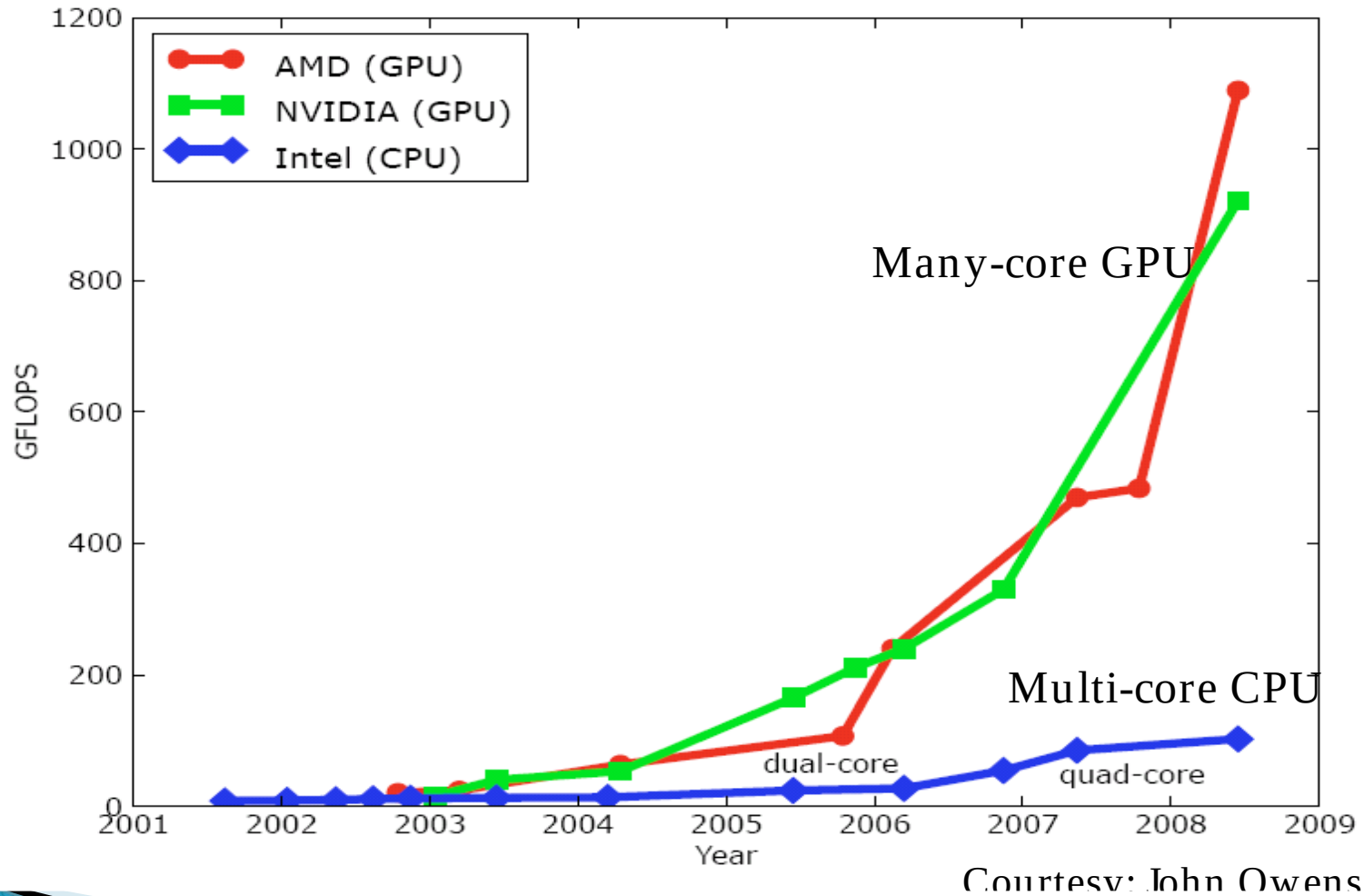
Graphical Processing Units (GPUs)



Courtesy: John Owens

Supercomputing for free

- FASTRA at university of Antwerp (2009)

http://fastra.ua.ac.be

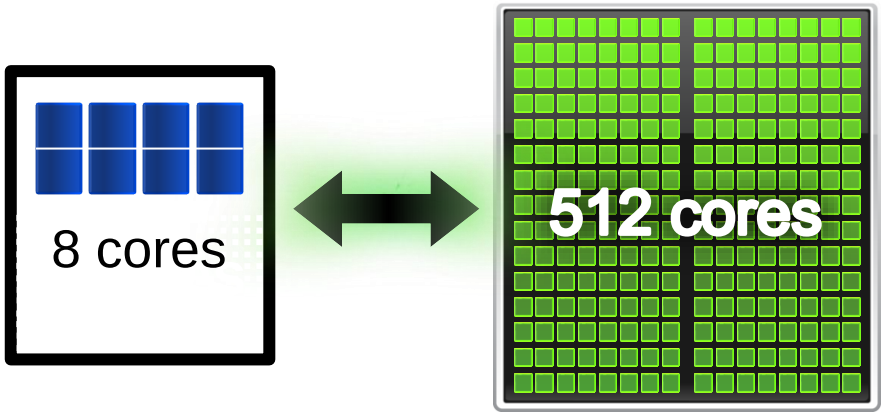
Collection of 8 graphical cards in PC

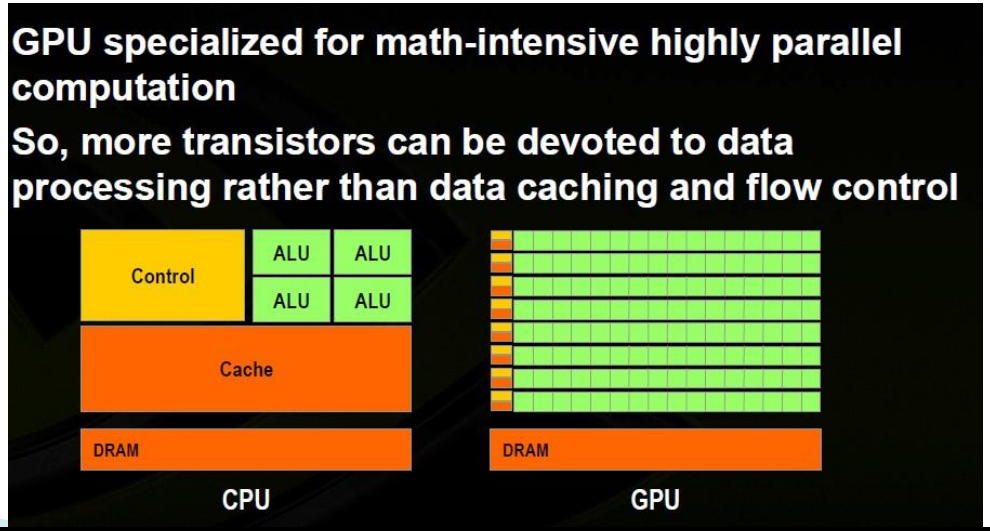
FASTRA 8 cards = 8x128 processors = 4000 euro

Similar performance as University's supercomputer (512 regular desktop PCs) that costed 3.5 million euro in 2005

"**Supercomputing in a box**": a high-end GPU cost 500 to 2500 euro and has equivalent power as 40 quadcore CPUs

Why are GPUs faster?





Both, about 12 billion transistors

No branch prediction, out-of-order execution, …

Devote transistors to… computation

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GPU vs CPU: NVIDIA 280 vs Intel i7 860

	GPU	CPU[1]
Registers	16,384 (32-bit) / multi-processor[3]	128 reservation stations
Peak memory bandwidth	141.7 Gb/sec	21 Gb/sec
Peak GFLOPs	562 (float)/ 77 (double)	50 (double)
Cores	240 (scalar processors)	4/8 (hyperthreaded)
Processor Clock (MHz)	1296	2800
Memory	1Gb	16Gb
Local/shared memory	16Kb/TPC[2]	N/A
Virtual memory	None	

[1]http://ark.intel.com/Product.aspx?id=41316
[2]TPC = Thread Processing Cluster (24 cores)
[3]30 multi-processors in a 280

Basic Architecture (more details in chapter 3)

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Processing elements

- The processing elements of GPUs are called by Nvidia:
  - Scalar Processors (SPs): single-precision floating point operations
  - CUDA cores (in the data sheets)
- The SPs are grouped into Streaming Multiprocessors (MPs or SMs):
  - Is what we would call a *core* (see later)
- The number of SPs per MP is fixed for each GPU generation
- The number of MPs varies per GPU (determines power & price)

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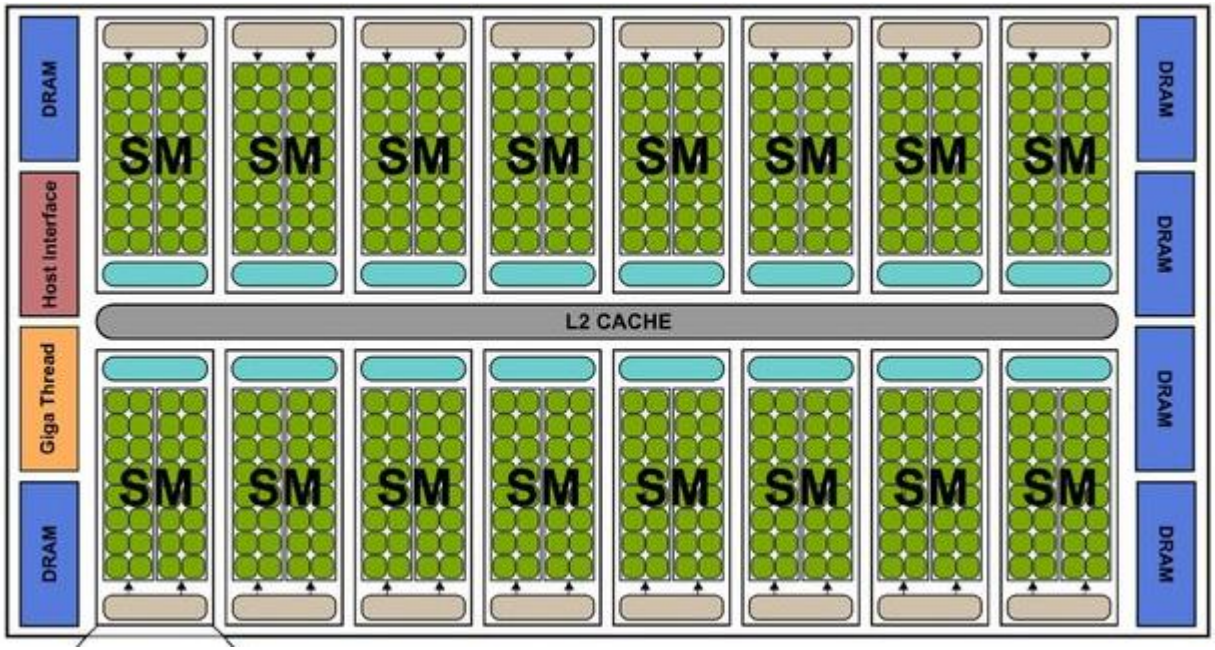
A GPU consists of Streaming Multiprocessors (SMs/MPs)



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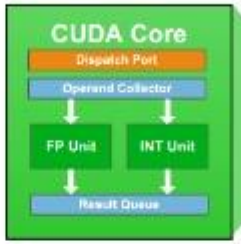
Each Multiprocessor consists of Scalar Processors (called CUDA core by Nvidia)

CS 354

Streaming Multiprocessor (SM)

- Multi-processor execution unit
  - 32 scalar processor cores
  - Warp is a unit of thread execution of up to 32 threads
- Two workloads
  - Graphics
    - Vertex shader
    - Tessellation
    - Geometry shader
    - Fragment shader
  - Compute



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Nvidia GPU generations

	Tesla		Fermi		Kepler				Maxwell				Pascal	
Architecture	**G80**	**GT200**	**GF100**	**GF104**	**GK104 (K10)**	**GK110 (K20X)**	**GK110 (K40)**	**GK210 (K80)**	**GM107 (GTX750)**	**GM204 (GTX980)**	**GM200 (Titan X)**	**GM200 (Tesla M40)**	**GP104 (GeForce GTX 1080)**	**GP100 (Tesla P100)**
Time frame	**2006 /07**	**2008 /09**	**2010**	**2011**	**2012**	**2013**	**2013 /14**	**2014**	**2014 /15**	**2014 /15**	**2016**	**2016**	**2016**	**2017**
CUDA Compute Capability	**1.0**	**1.3**	**2.0**	**2.1**	**3.0**	**3.5**	**3.5**	**3.7**	**5.0**	**5.2**	**5.3**	**5.3**	**6.0**	**6.0**
N (multiprocs.)	16	30	16	7	8	14	15	30	5	16	24	24	40	56
M (cores/multip.)	8	8	32	48	192	192	192	192	128	128	128	128	64	64
Number of cores	128	240	512	336	1536	2688	2880	5760	640	2048	3072	3072	2560	3584

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Nvidia GPU generations

Nvidia Architecture	Clock freq MHz	SPs per MP	SFUs per MP	DPs per MP	RAM band-width (GBs)	latency Λ_{SP} (cycles)
Tesla		8	?	–	141	24
Fermi	1147	32	8	–	144	18
Kepler	1032	192	32	64	86	9
Maxwell	1058	128	32			6
Pascal	1506	128	32	64	192	6
Turing		64	8	?		

PE: single-precision floating-point or integer
SFU: special function unit (cos, sin, …)
DP: double-precision unit (not present in old GPUs)

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GPU Peak Performance

- GPUs consist of or Streaming MultiProcessors (MPs) grouping a number of Scalar Processors (SPs)
- Nvidia GTX 280 (Tesla architecture):
  - 30MPs x 8 SPs/MP x 2FLOPs/instr/SP x 1 instr/clock x 1.3 GHz (clocks per second)

  = **624 GFlops**
- Nvidia Tesla C2050 (Fermi architecture):
  - 14 MPs x 32 SPs/MP x 2FLOPs/instr/SP x 1 instr/clock x 1.15 GHz = **1030 Gflops**
- Nvidia GTX 1080 (Pascal architecture):
  - 40 MPs x 64 SPs/MP x 2FLOPs/instr/SP x 1 instr/clock x 1.733 GHz = **8872 Gflops**

Memory bandwidth

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Other limit: bandwidth

- Nvidia GTX 280:
  - 1.1 GHz memory clock
  - 141 GB/s
- Nvidia Tesla C2050:
  - 1.5 GHz memory clock
  - 144 GB/s
- Nvidia GTX 1080
  - 2.5 GHz memory clock
  - 320 GB/s

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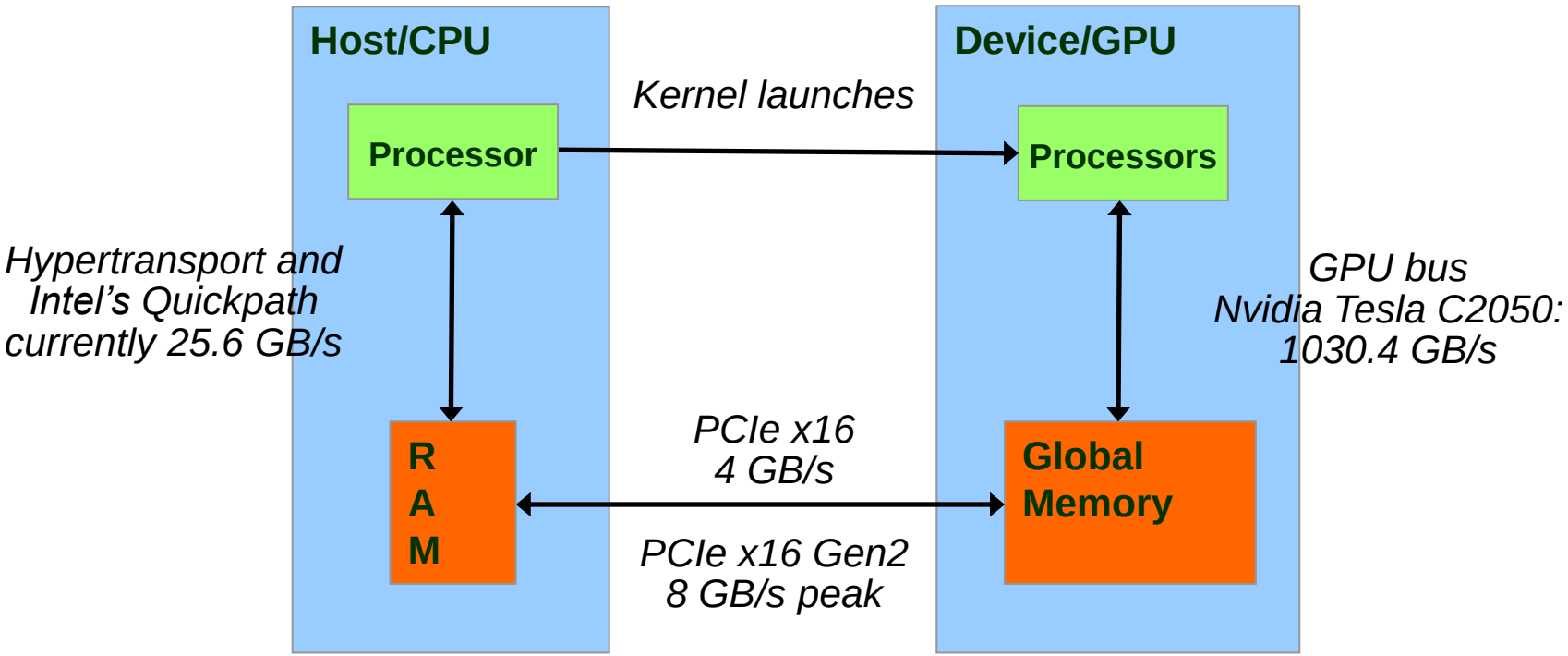
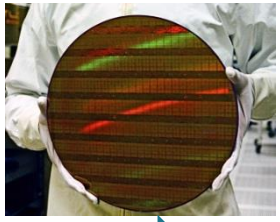
Host (CPU) – Device (GPU)

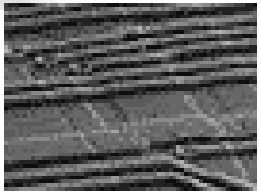


Example: real-time image processing

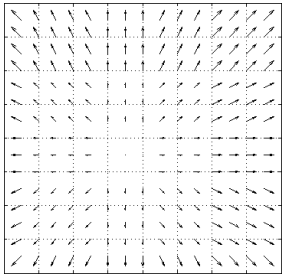
KLA-Tencor
Accelerating Yield



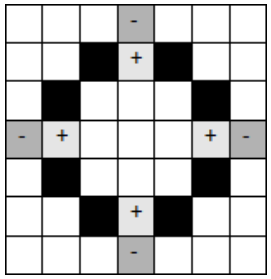
Images of 20MegaPixels



Pixel rescaling



lens correction



pattern detection

CPU gives only 4 fps
next generation machines need 50 fps
GPUs deliver 70 fps

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Example: pixel transformation (FPN)

```
byte transform(byte pixel, byte gain, byte gain_divide, byte
offset)
{
    int x = (pixel * gain / gain_divide) + offset;
    if (x < 0)
        x = 0;
    if (x > 255)
        x = 255;
    return x;
 }
```

Pixel transformation

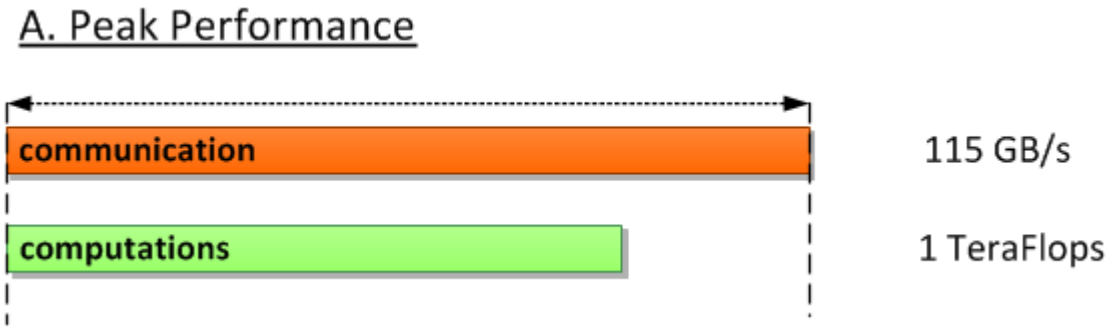
- Performance on Tesla C2050
- 1 pixel is represented by 1 byte [0-255]
  - Per pixel: read 4 bytes (pixel & gain & divide & offset) and write 1 byte
- Integer operations: performance is half of floating point operations
- **Pixel transformation**: around 6 operations (1 index calculation, 3 integer calculations and 2 comparisons)

P_{mem} *(bytes/s)*	115 GB/s	P_{ops} *(ops/s)*	500 Gops/s	
bytes/pixel	5	*Ops/pix*	6	CI=1,2
P_{mem}xCI *(pix/s)*	**23 Gpix/s**	**Pix/s**	**83 Gpix/s**	

Memory-bound (minimum of both)

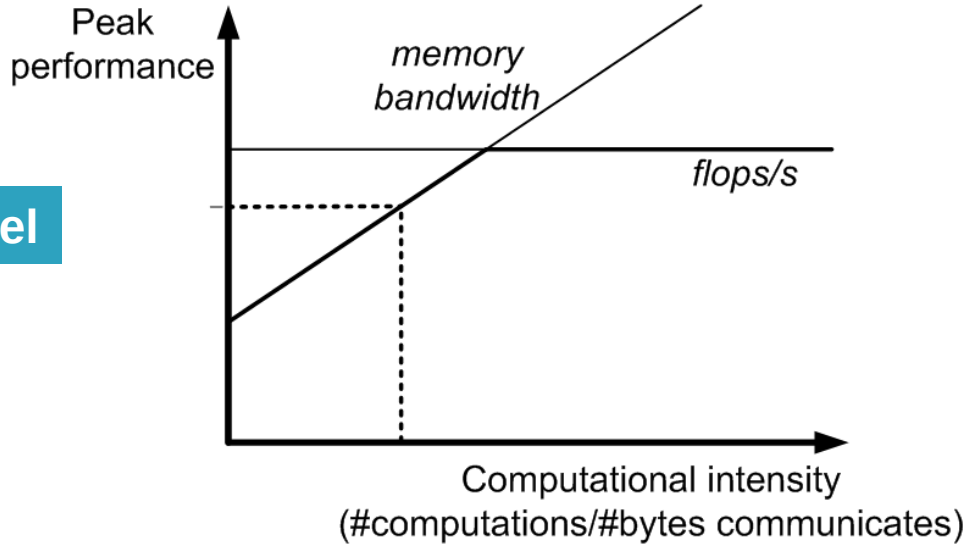
CI = Computational Intensity

What is taking longer: memory transfer or the computations?



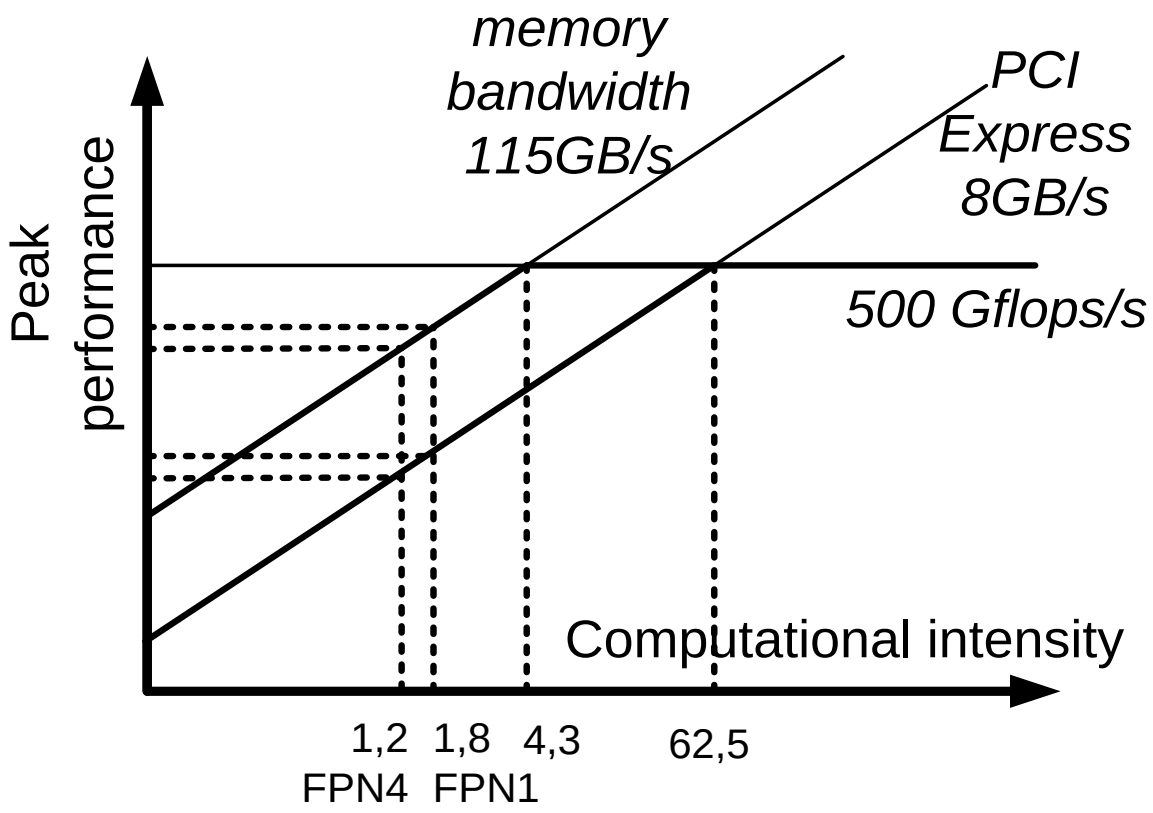
Depends on Computational Intensity (CI)

Roofline model



Equation of Memory line: peak performance = CI * BW

Roofline model applied to pixel transformation



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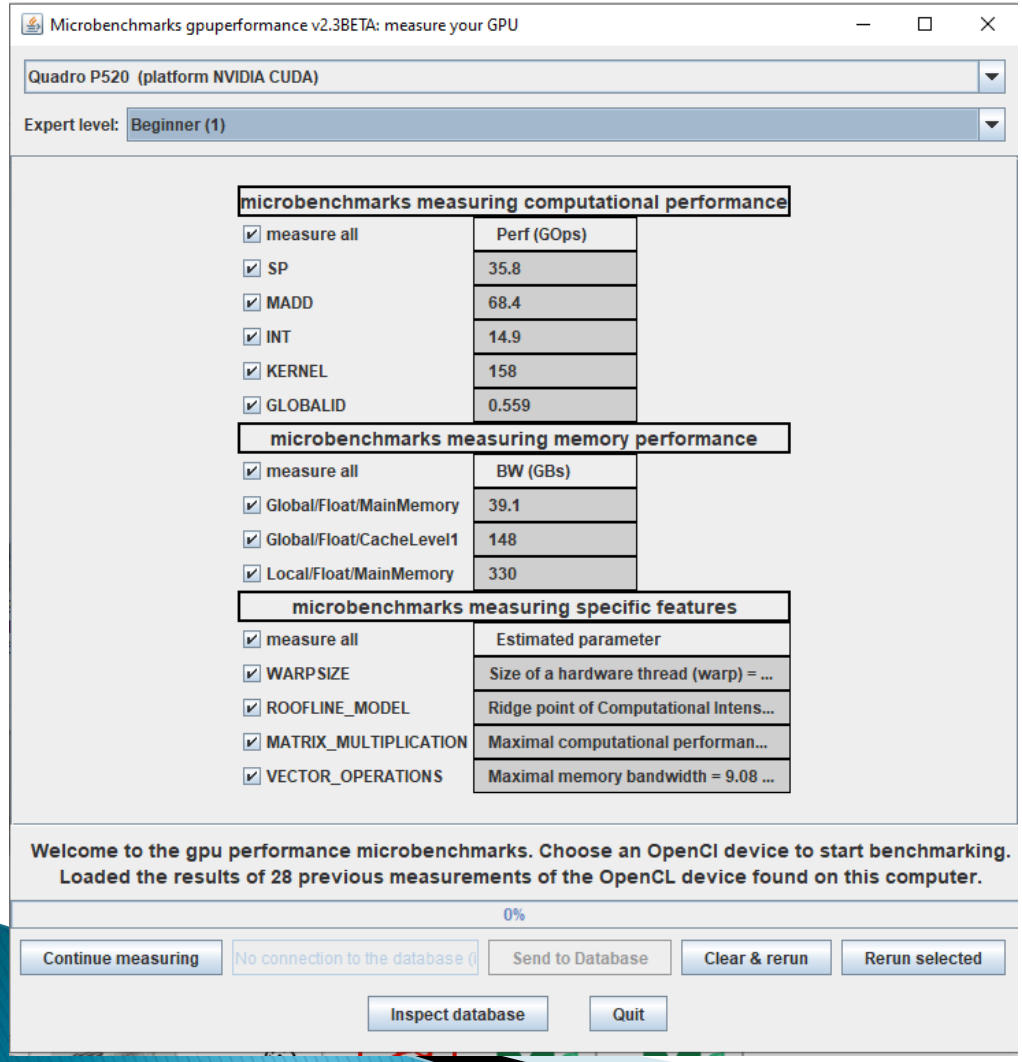
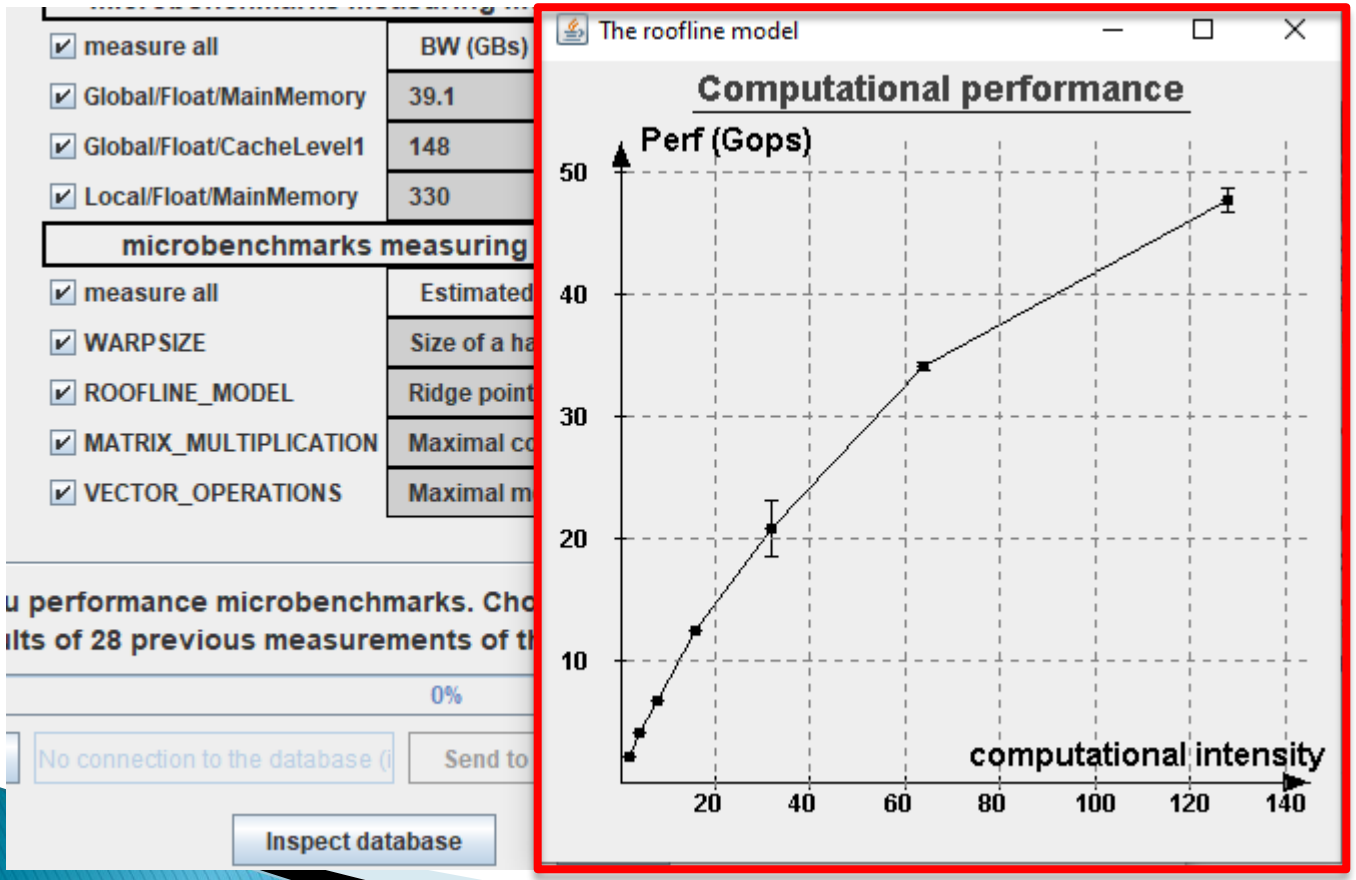
Measure your GPU's performance



- www.gpuperformance.org
- Java app
- Uses OpenCL, so can be used for every GPU
- The GPUs are automatically identified
- Uses small programs (microbenchmarks) to experimentally measure performance
- Computational and memory performance.

Experimental Roofline Model

- Double click on dark gray fields to see the data



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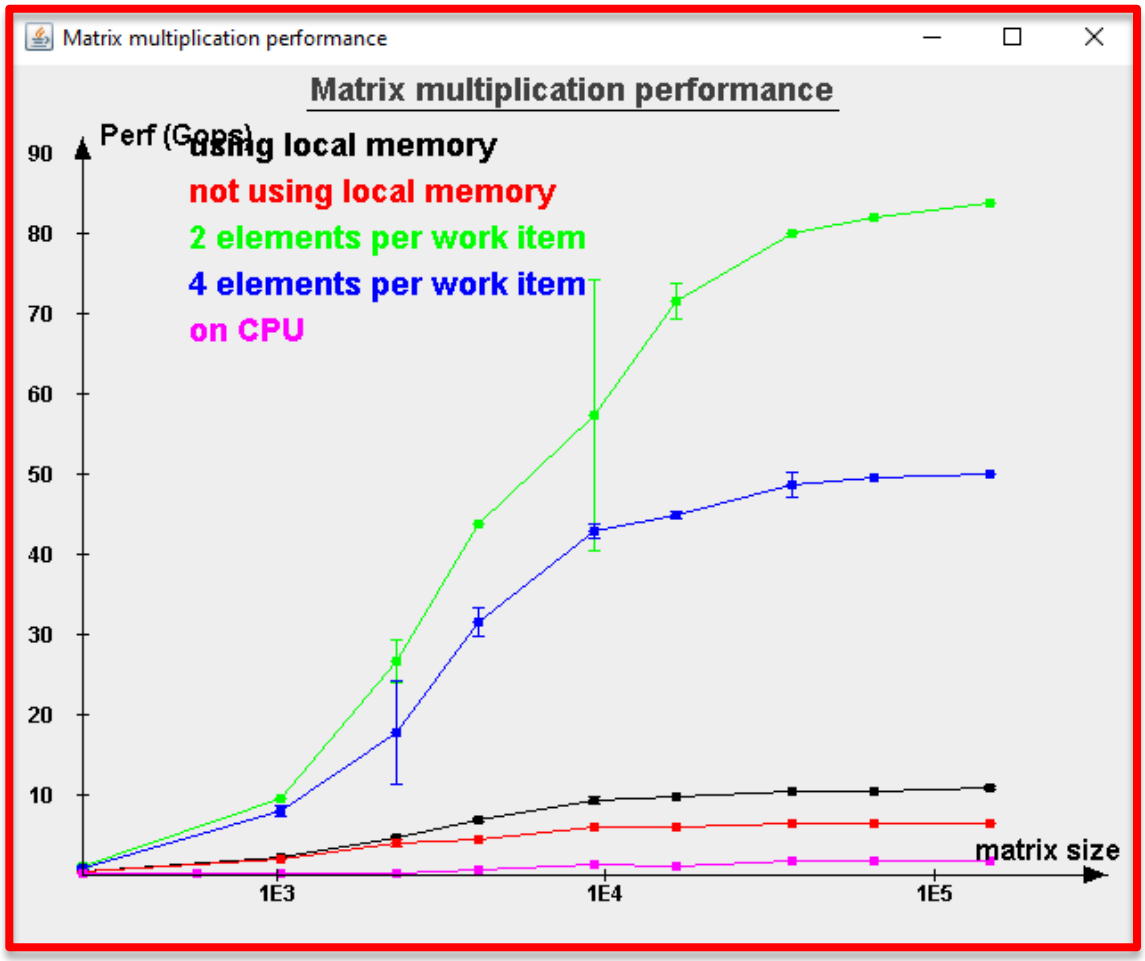
Matrix Multiplication



- Optimal version reaches peak performance of 83Gflops!