Timeline for CPUs

80's: CPU and system same speed. Zero wait states.

1993: CPUs faster than the rest of the system. Rapid raise of frequency.

Late 90's to present: Multi-CPU systems, multi-core CPUs.

CPUs are still improving, but going for higher frequency is not as obvious as before.

Meanwhile, at the graphics dept

80's: Hardware sprites. Push pixels with low-level code.

1993: Textured 3D games: Wolf3D, Doom.

Early 90's: Professional 3D boards.

1996: 3dfx Voodoo1!

2001: Programmable shaders.

2006: G80, unified architecture. CUDA

2009: OpenCL.

2010: Fermi architecture

2012: Kepler architecture

	1995	2005	
CPU Frequency (GHz)	.1	3.2	32x
Memory Frequency (GHz)	.03	1.2	40x
Bus Bandwidth (GB/sec)	.1	4	40x
Hard Disk Size (GB)	.5	200	400x

	1995	2005	
CPU Frequency (GHz)	.1	3.2	32x
Memory Frequency (GHz)	.03	1.2	40x
Bus Bandwidth (GB/sec)	.1	4	40x
Hard Disk Size (GB)	.5	200	400x
Pixel Fill Rate (GPixels/sec)	.0004	3.3	8250x
Vertex Rate (GVerts/sec)	.0005	.35	700x
Graphics flops (GFlops/sec)	.001	40	40000x
Graphics Bandwidth (GB/sec)	.3	19	63x
Frame Buffer Size (MB)	2	256	128x

How about 2005-2016?

	2005	2011		2016	
CPU Frequency (GHz)	3.2	3.8	1.18x x cores?	4.0	1.25x
Memory Frequency (GHz)	1.2	2.0	1.67x	3.2	2.67x
Bus Bandwidth (GB/sec)	4	31	7.75x	?	?
Hard Disk Size (GB)	200	4000	20x	8000	40x

	2005	2011		2016	
CPU Frequency (GHz)	3.2	3.8	1.18x x cores?	4.0	1.25x
Memory Frequency (GHz)	1.2	2.0	1.67x	3.2	2.67x
Bus Bandwidth (GB/sec)	4	31	7.75x	?	?
Hard Disk Size (GB)	200	4000	20x	8000	40x
Pixel Fill Rate (GPixels/sec)	3.3	59	18x	128	38x
Vertex Rate (GVerts/sec)	.35	?	?	?	?
Graphics flops (GFlops/sec)	40	2488	62x	16380	409x
Graphics Bandwidth (GB/sec)	19	327.7	17x	512	27x
Frame Buffer Size (MB)	256	3000	12x	8000	31x

But is this a fair comparison?
Let us compare apples with apples:
GFLOPS for both!

	GPU	CPU
1995:	0.001	0.09
2005:	40	5.6
2011:	2488	91
2015:	7000	176
2016:	16380	400-700*

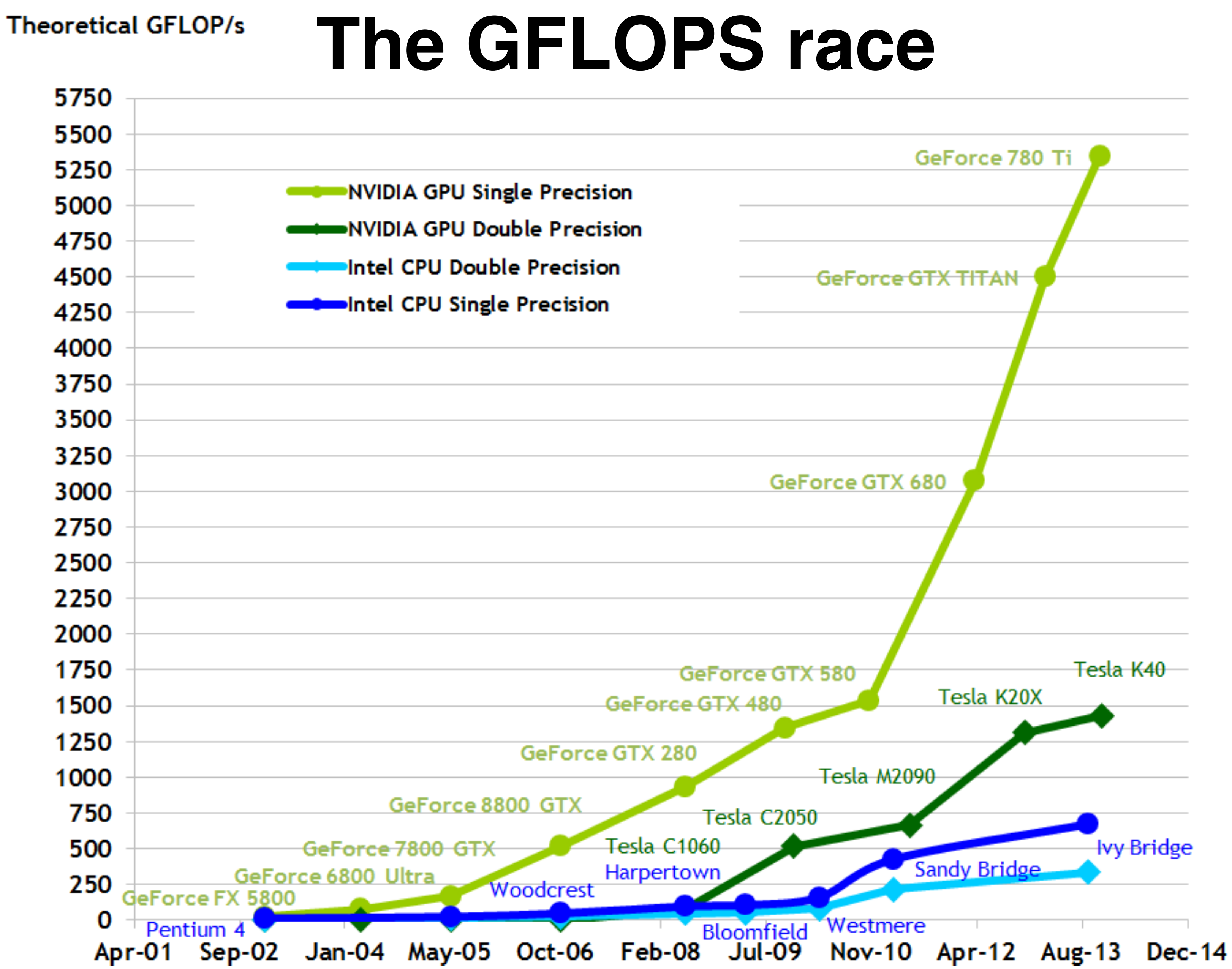
* Theoretical, 16 cores

(Various sources)

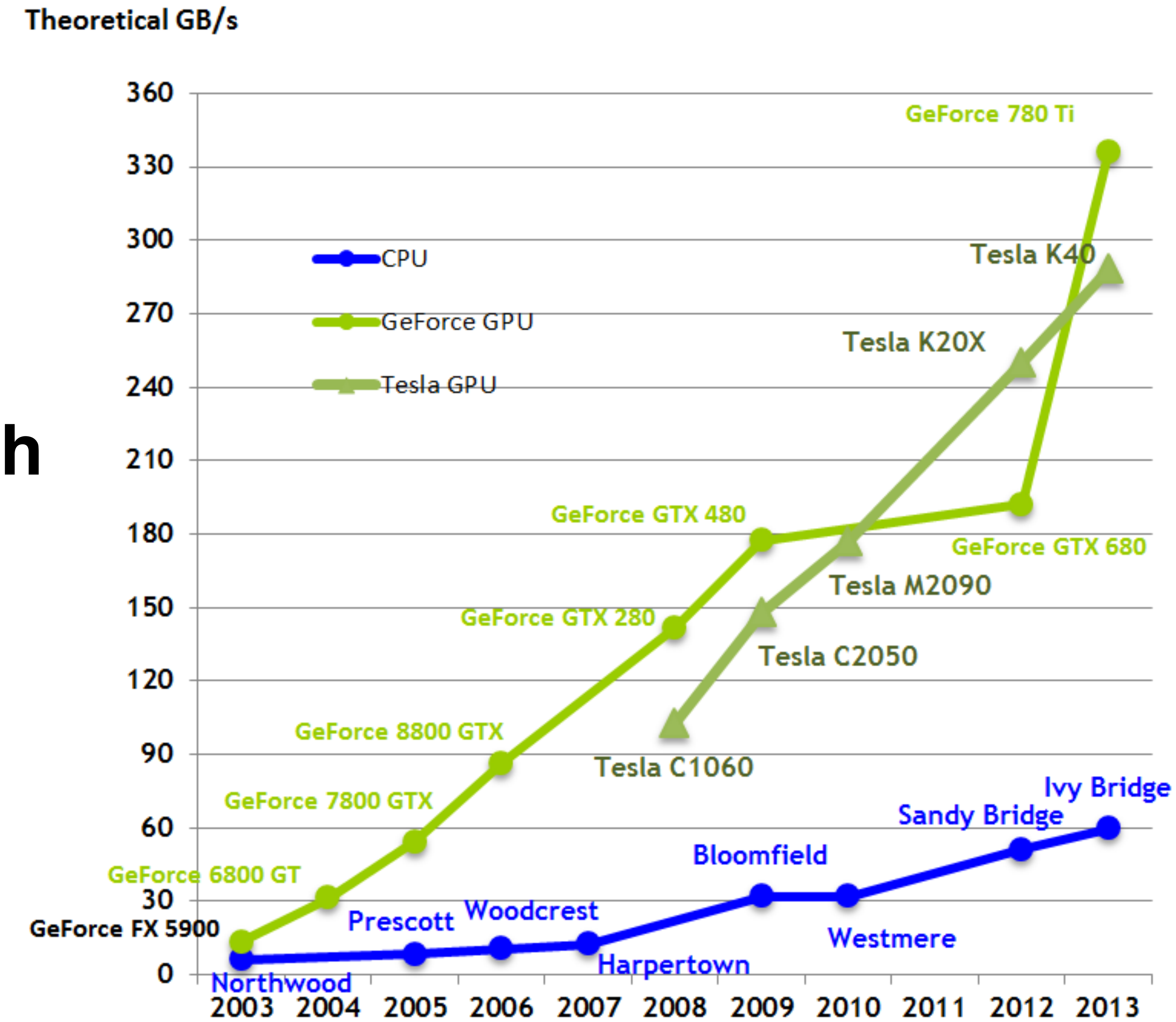
How about economy: dollar per GFLOPS?

1961:	8.3 trillion
1984:	42 million
1997:	42000 (CPU cluster)
2000:	836-1300
2007:	52
2012:	0.73 (AMD 7970)
2013:	0.22 (PS4)
2015:	0.08 (Radeon R9 295)

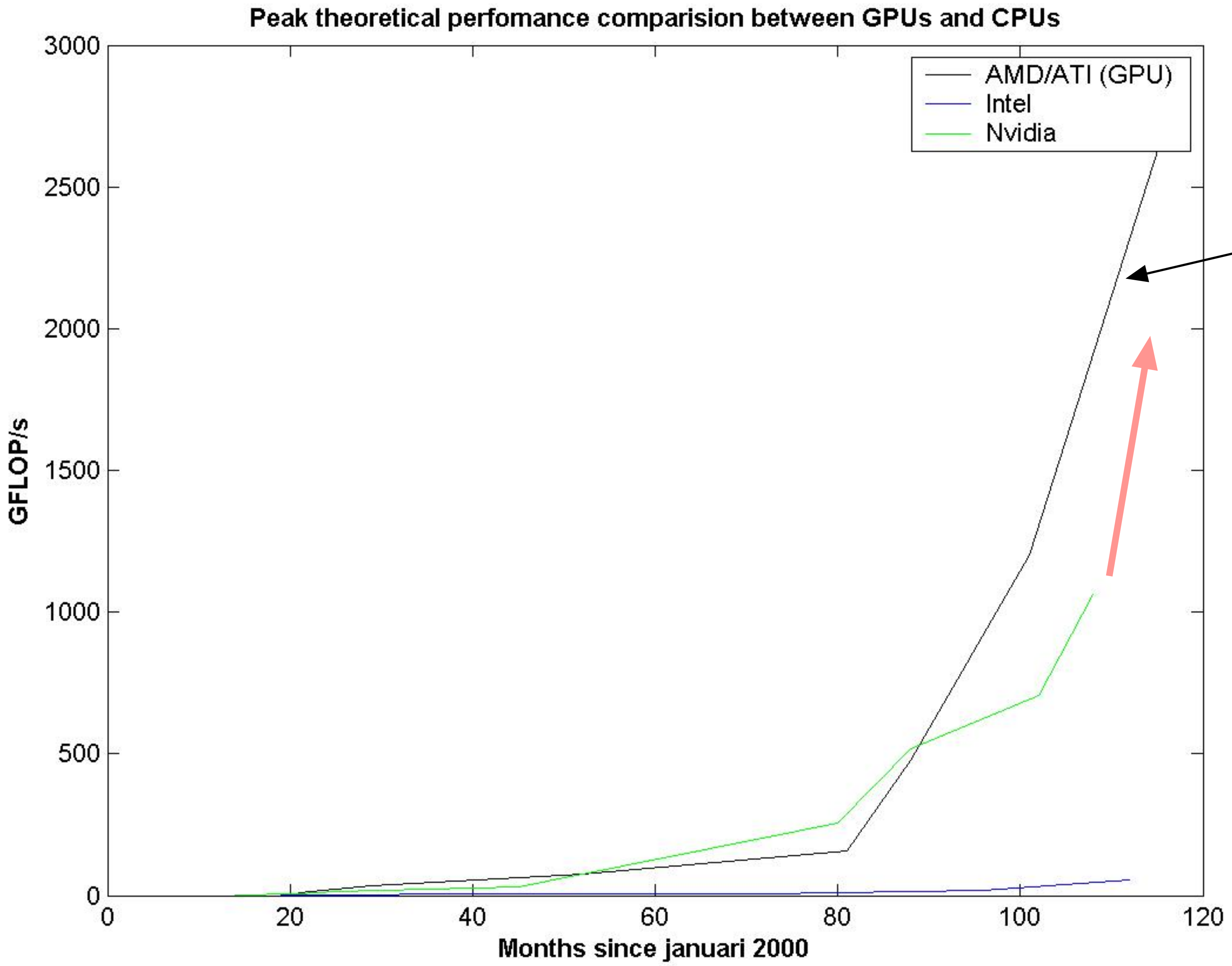
(Wikipedia)


Theoretical GFLOP/s
The GFLOPS race
NVIDIA GPU Single Precision
NVIDIA GPU Double Precision
Intel CPU Double Precision
Intel CPU Single Precision
5750
5500
5250
5000
4750
4500
4250
4000
3750
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
Apr-01
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Nov-10
Apr-12
Aug-13
Dec-14
GeForce 780 Ti
GeForce GTX TITAN
GeForce GTX 680
GeForce GTX 580
GeForce GTX 480
GeForce GTX 280
GeForce 8800 GTX
GeForce 7800 GTX
GeForce 6800 Ultra
GeForce FX 5800
Tesla K40
Tesla K20X
Tesla M2090
Tesla C2050
Tesla C1060
Harpertown
Woodcrest
Pentium 4
Bloomfield
Westmere
Sandy Bridge
Ivy Bridge

The bandwidth race

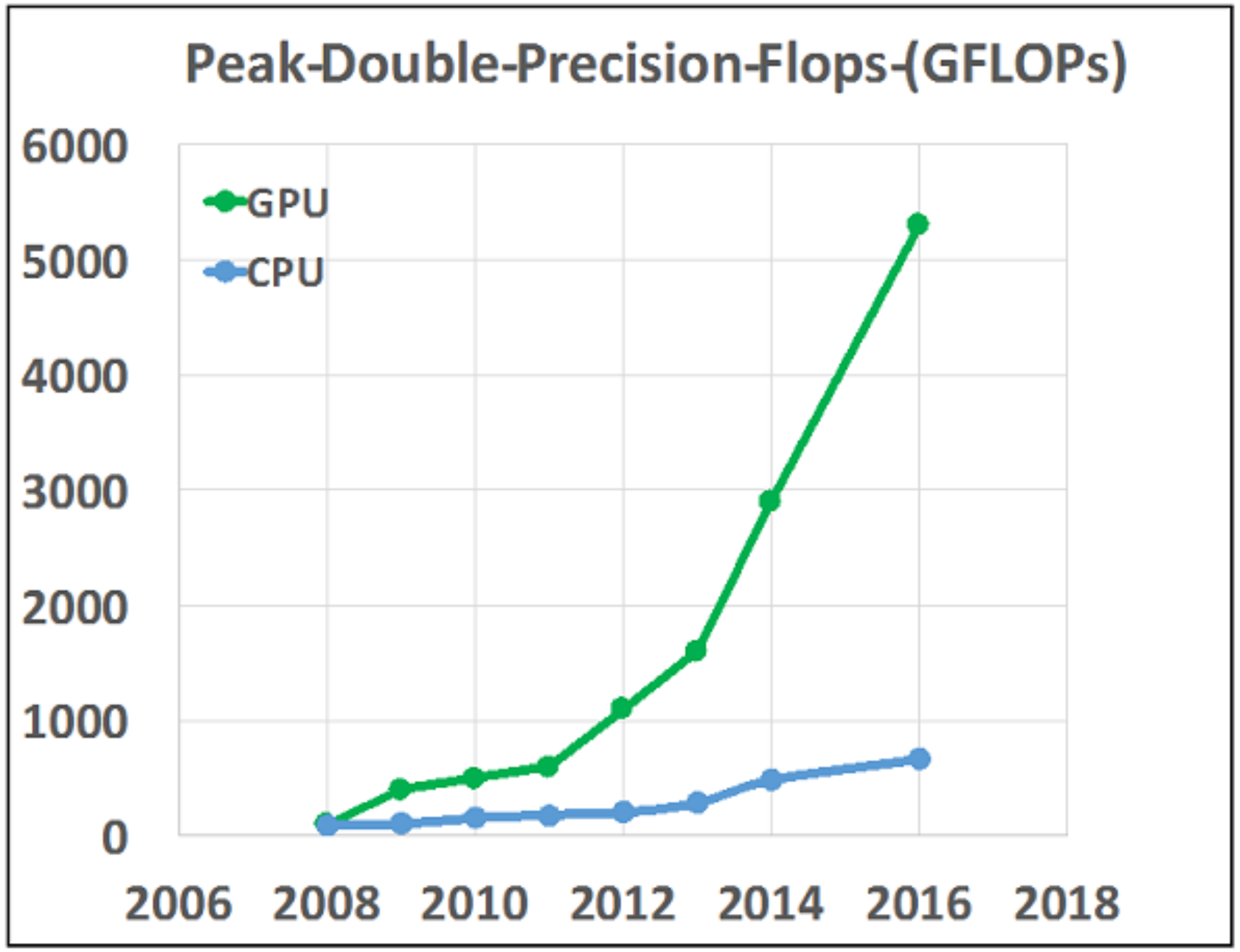


Another graph, including ATI/AMD



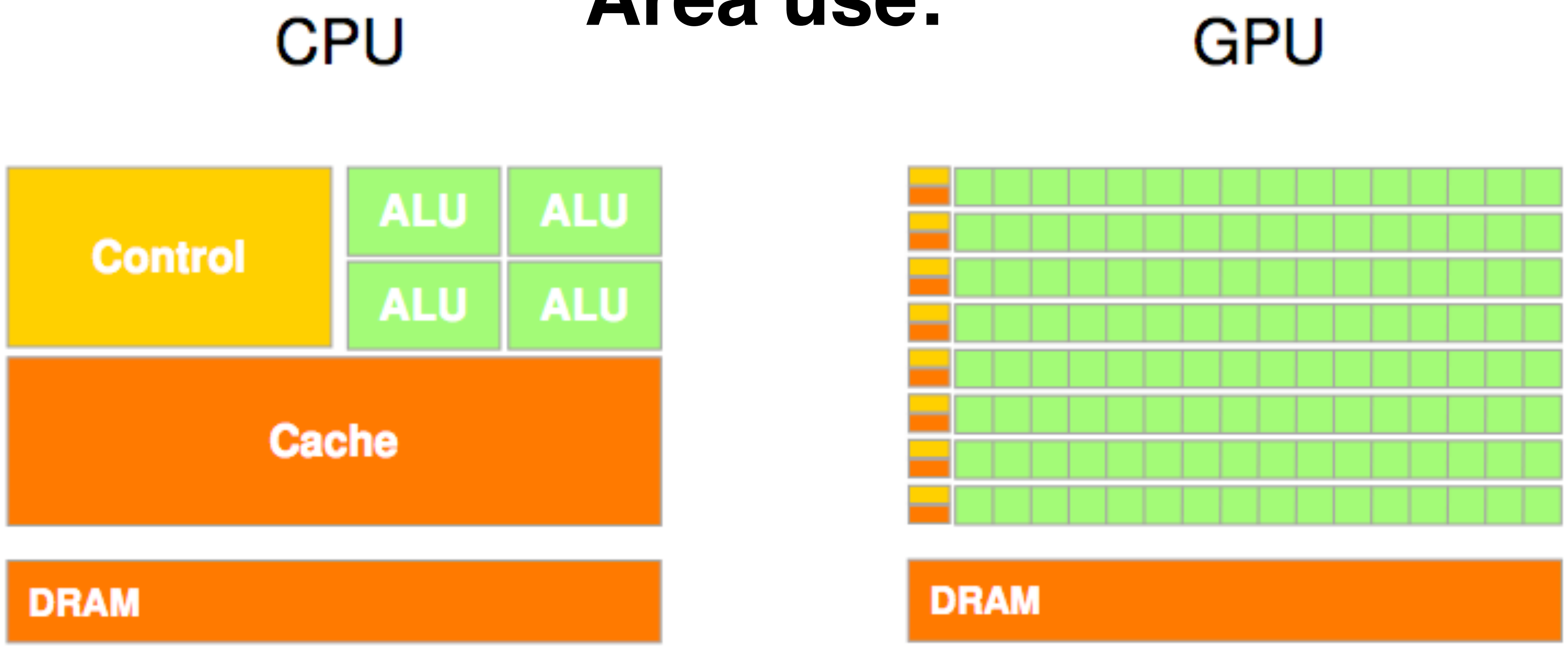
AMD took the lead in single precision while NVidia was chasing for double with Fermi

...up to today.


Peak-Double-Precision-Flops-(GFLOPs)
6000
5000
4000
3000
2000
1000
0
2006
2008
2010
2012
2014
2016
2018
GPU
CPU

How is this possible?

Area use:



But in particular: SIMD architecture

Flynn's taxonomy

SISD Single instruction, single data Old single-core systems	**MISD** Multiple instruction, single data Multiple for redundance
SIMD Single instruction, multiple data GPUs, vector processors	**MIMD** Multiple instruction, multiple data Multi-core CPUs

Plus SIMT, single instruction, multiple threads

SIMD

Single instruction, multiple data

Simplifies instruction handling. All cores get the same instruction.

Excellent for operations where one operation must be made on many data elements.

Is that so common? Yes!

Data best in stored arrays.

Data Oriented Programming

DOP optimizes for performance.

Data structures selected to fit the computations, instead of the programmer!

Optimize for the end user instead for the programmer!

Popular in the game industry - why not elsewhere?

SIMT - Single Instruction, Multiple Thread

A variant of SIMD.

Parallelism expressed as threads.

A programming model, but also demands that the hardware can handle threads very fast.

Threads dependent - executed in a SIMD processor!

So, why does SIMT fit a graphics processor so well?

Why did GPUs get so much performance?

Early problem with large amounts of data. (Complex geometry, millions of output pixels.)

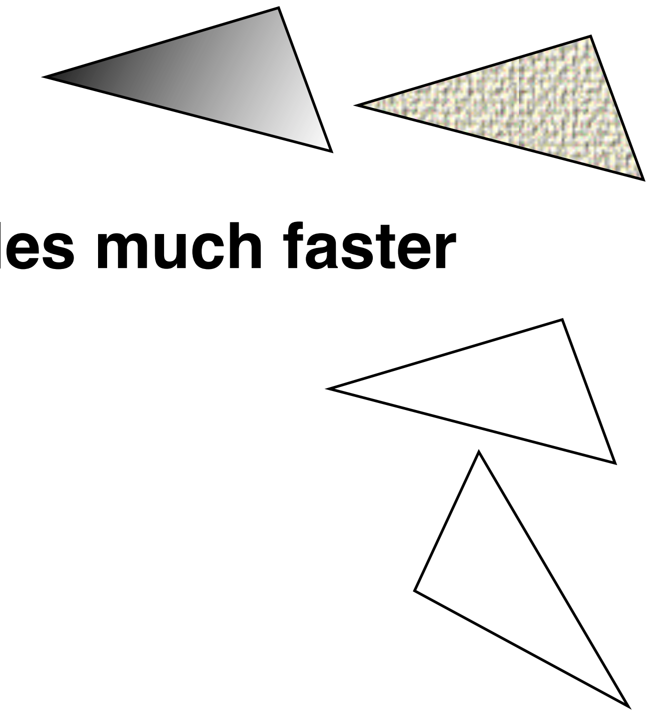
Graphics pipeline designed for parallelism!

Hiding memory latency by parallelism

Volume. 3D graphics boards central component in game industry. Everybody wants one!

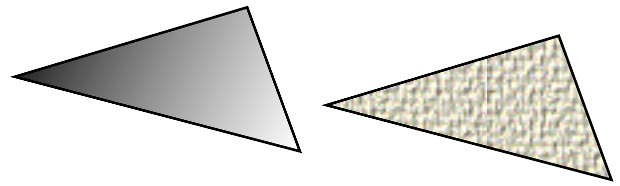
New games need new impressive features. Many important advancements started as game features.

Must process many pixels fast!



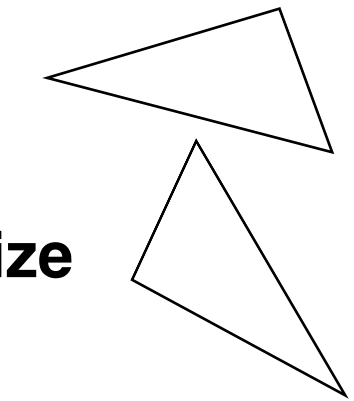
Early GPUs could draw textured, shaded triangles much faster than the CPU.

Must process many pixels fast!

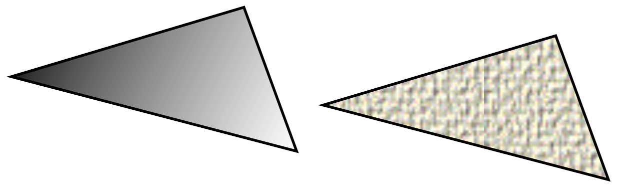


Early GPUs could draw textured, shaded triangles much faster than the CPU.

Must do matrix multiplication and divisions fast.

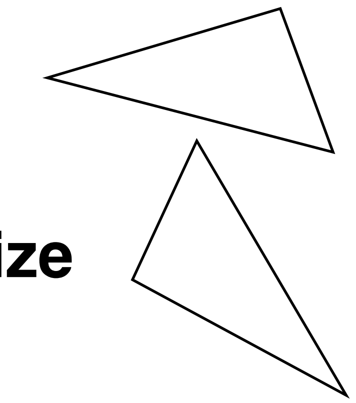


Next generation could transform vertices and normalize vectors.



Must process many pixels fast!

Early GPUs could draw textured, shaded triangles much faster than the CPU.



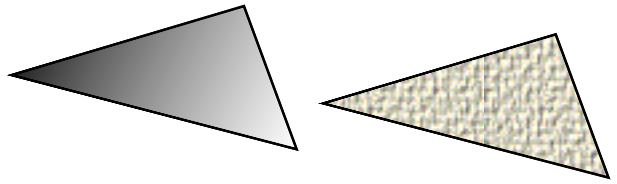
Must do matrix multiplication and divisions fast.

Next generation could transform vertices and normalize vectors.

Must have programmable parts.

This was added to make Phong shading and bump mapping.

Must process many pixels fast!



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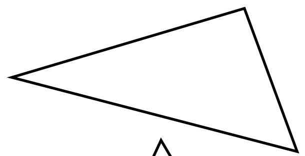

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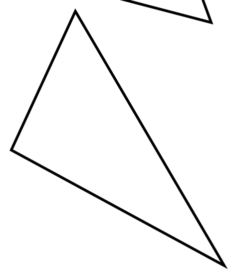


Next generation could transform vertices and normalize vectors.

Must have programmable parts.

This was added to make Phong shading and bump mapping.

Must work in floating-point!

This was for light effects, HDR.

So a GPU should

- **process vertices, many in parallel, applying the same transformations on each**

- **process pixels (fragments) in parallel, applying the same color/light/texture calculations on each**

SIMD friendly problem!

Less control, control many calculations instead of one

A different kind of threads

SIMD threads, all run the same program

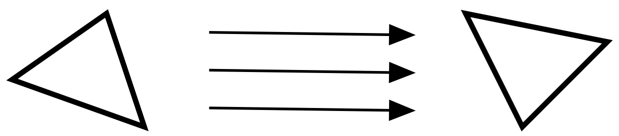
Group-wise, they execute in parallel, SIMD-style

Made for graphics operations: Shader threads calculate one pixel or one vertex

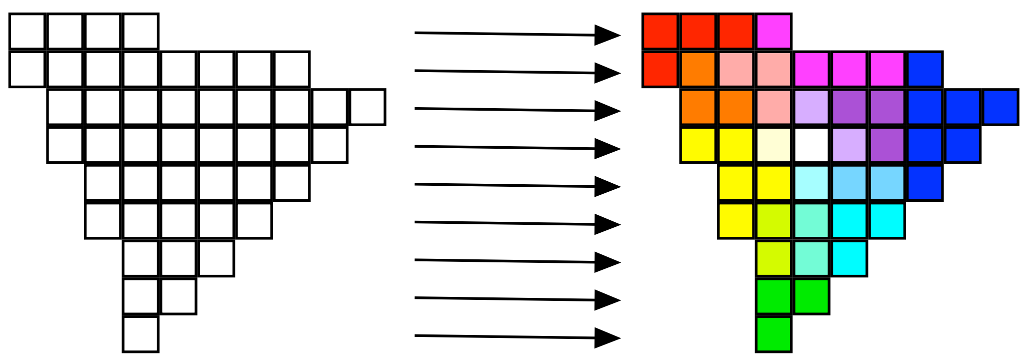
CUDA/OpenCL threads may calculate anything, but typically one part of the output - in order

The main tasks in rendering graphics:

One thread per vertex
Same operations, same kernel, different data



One thread per pixel (fragment)
Same operations, same kernel, different data



The 3D pipeline in the GPU

Low-level operations from vertices to pixel data