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

2012-2021: Kepler, Maxwell, Pascal, Turing, Ampère...

	1995	2005	
CPU frequency (GHz)	**0.1**	**3.2**	32x
Memory frequency (GHz)	**0.03**	**1.2**	40x
Bus bandwidth (GB/s)	**0.1**	**4**	40x
Hard disk size (GB)	**0.5**	**200**	400x

	1995	2005	
CPU frequency (GHz)	**0.1**	**3.2**	32x
Memory frequency (GHz)	**0.03**	**1.2**	40x
Bus bandwidth (GB/s)	**0.1**	**4**	40x
Hard disk size (GB)	**0.5**	**200**	400x
Pixel fill rate (GPixels/s)	**0.0004**	**3.3**	8250x
Graphics flops (GFLOPS)	**0.001**	**40**	40000x
Graphics bandwidth (GB/s)	**0.3**	**19**	63x
Frame buffer size	**2**	**256**	128x

How about 2005-2019?

	1995	2005	2011		2019	Since 2005
CPU frequency (GHz)	**0.1**	**3.2**	**3.8**	1.18x x cores?	**5.0**	1.56x
Memory frequency (GHz)	**0.03**	**1.2**	**2.0**	1.67x	**4.27**	3.56x
Bus bandwidth (GB/s)	**0.1**	**4**	**31**	7.75x	**128**	32x
Hard disk size (GB)	**0.5**	**200**	**4000**	20x	**16000**	80x

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Hard disk size (GB)	**0.5**	**200**	**4000**	20x	**16000**	80x
Pixel fill rate (GPixels/s)	**0.0004**	**3.3**	**59**	18x	**170**	51x
Graphics flops (GFLOPS)*	**0.001**	**40**	**2488**	62x	**16312**	408x
Graphics bandwidth (GB/s)	**0.3**	**19**	**327.7**	17x	**672**	35x
Frame buffer size	**2**	**256**	**3000**	12x	**24000**	94x

* single precision

How about 2025?

GPU (NVidia RTX 5090):

Pixel rate 423 GPixel/s (8x since 2019)
Graphics FLOPS: 105 TFLOPS (up from 34 2021)
21760 cores! (Plus 680 tensor cores, 170 RT cores)

CPU (AMD Threadripper Pro 9995WX):

26 TFLOPS in SIMD, 851 GFLOPS in multicore (MIMD)
96 cores!

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*
2021:	34000	1500
2022:	82000	1700
2025:	105000	26000 or 851

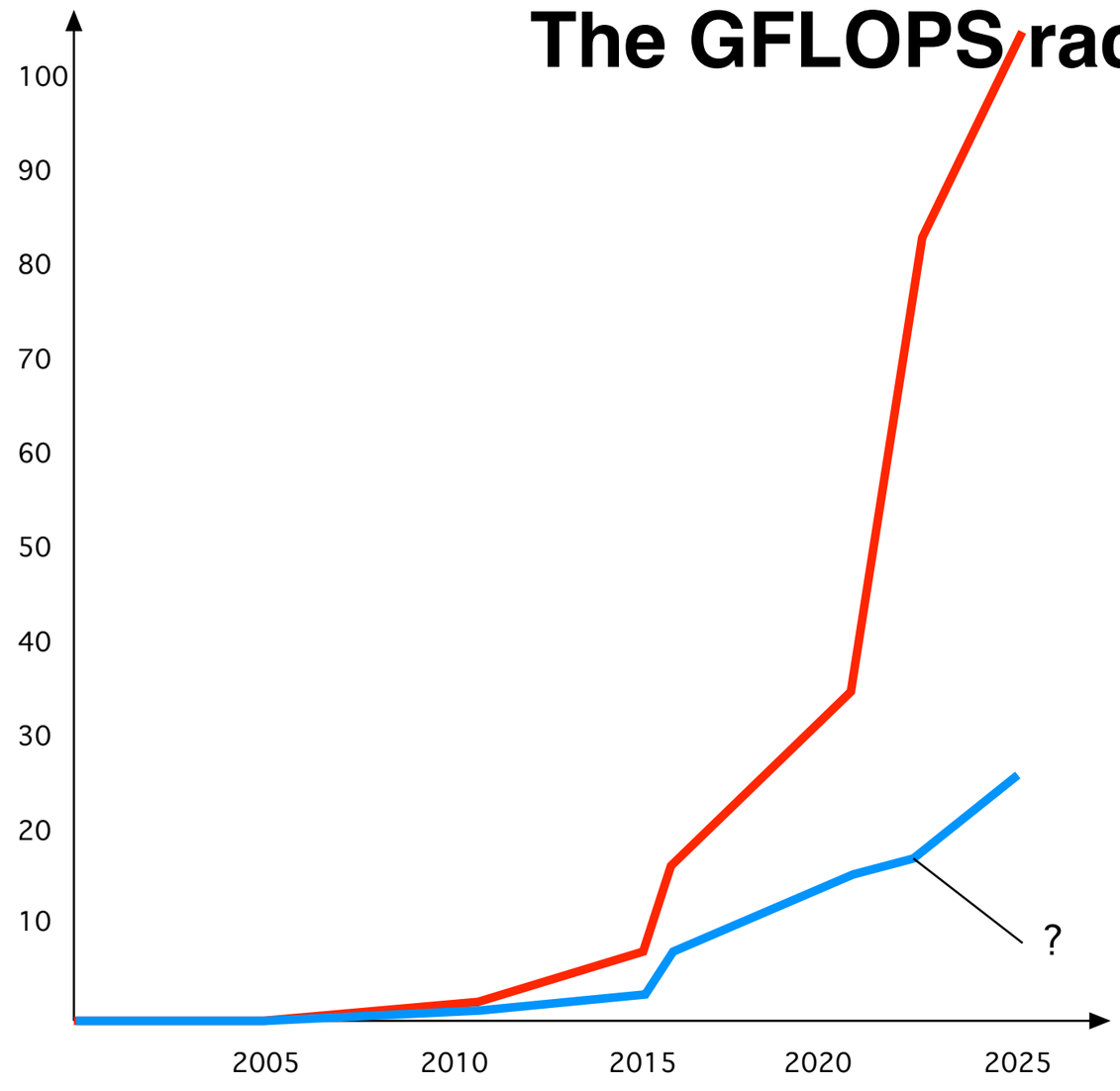
* Theoretical, 16 cores

Gets complicated here:
CUDA vs tensor 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)	
2022:	0.02 (RTX 4090)	
2023:	0.012 (AMD RX7600)	(Wikipedia)
2025:	0.003 (RTX 5080)	(Unclear source)

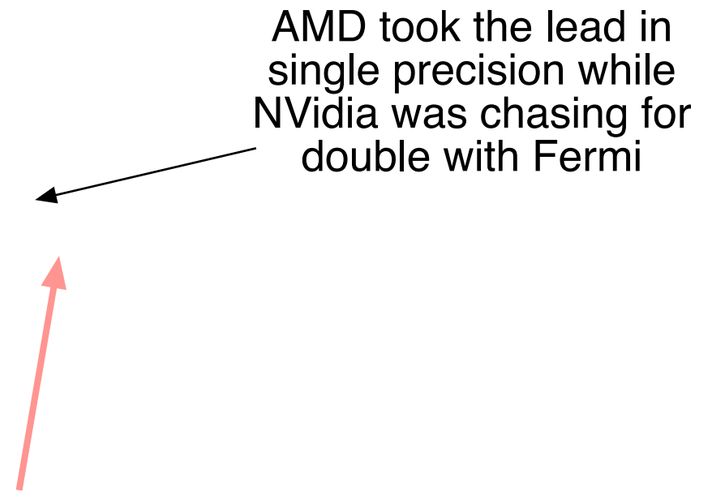


Mixed sources, no bias, gathered by me

Measure methods vary!

Typical older graph

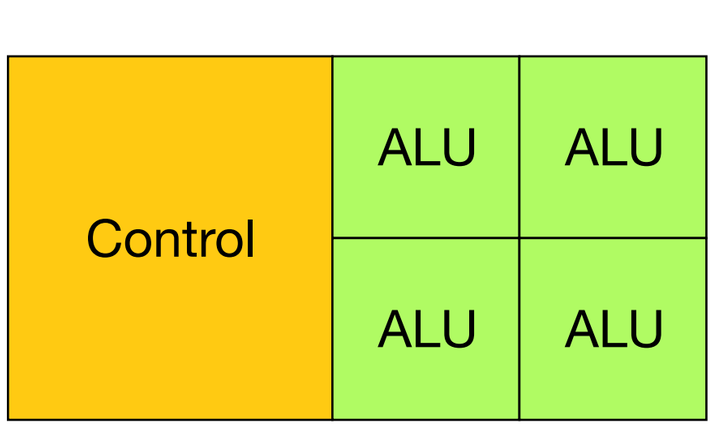
Another graph, including AMD



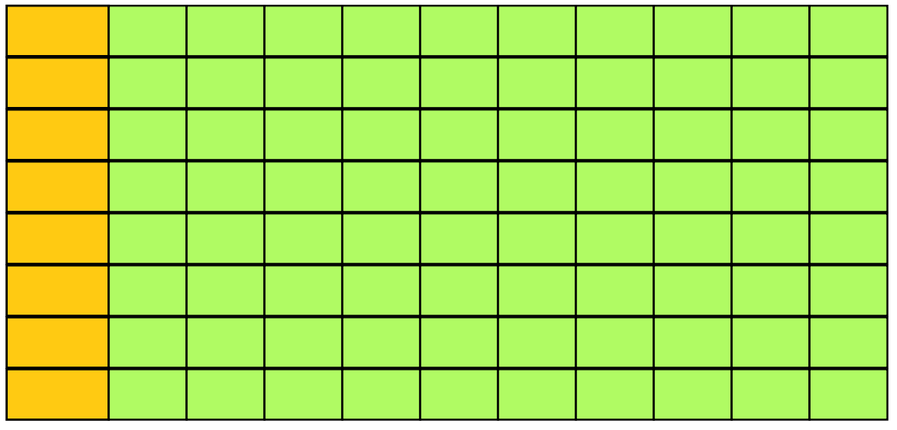
How is this possible?

Area use:

CPU



GPU



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

SIMT, single instruction, multiple threads ≈ SIMD

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?

Is this important?

- Extra hardware needed
- Different programming
- Only benefits big problems with good parallellization possibilities

but

+ Great for all image processing problems
+ Good for many other problems (sorting, FFT...)
+ Key component in the current deep learning revolution!

Deep learning

Learning systems based on very large neural networks.

Good problem for GPUs!

Remarkable results! Big trend in computer vision and other fields.

GPUs opened the door!

Why did GPUs get so much performance?

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

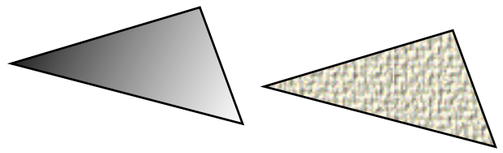
Graphics pipeline designed for parallelism!

Hiding memory latency by parallelism

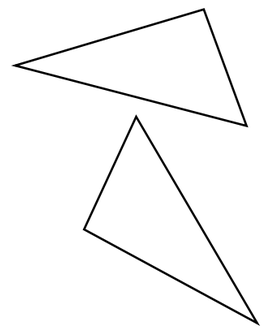
Volume. 3D graphics boards central component in game industry. Everybody wants one!

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.



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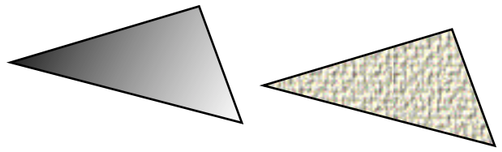
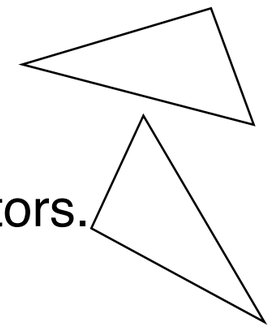


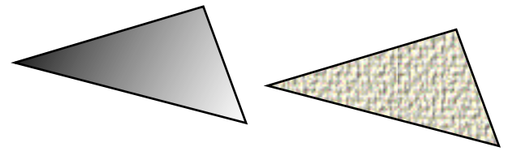
Early GPUs could draw textured, shaded triangles much faster than the CPU.

Must do matrix multiplication and divisions fast.



Next generation could transform vertices and normalize vectors.

Must process many pixels fast!



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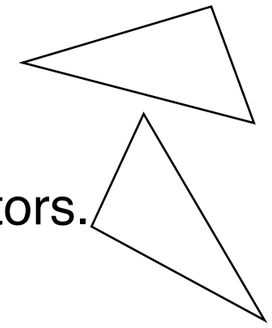
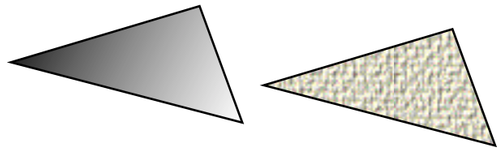


Next generation could transform vertices and normalize vectors.

Must have programmable parts.

This was added to make Phong shading and bump mapping.

Must process many pixels fast!



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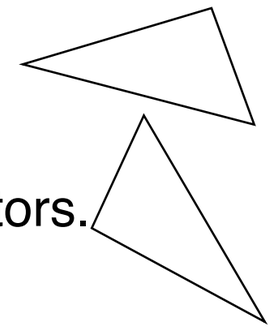

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Must have programmable parts.

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

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