# 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: Textures 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 2005-2011?

| | 2005 | 2011 | |
|---|---|---|---|
| CPU Frequency (GHz) | 3.2 | 3.8 | 1.18x |
| Memory Frequency (GHz) | 1.2 | 2.0 | 1.67x |
| Bus Bandwidth (GB/sec) | 4 | 31 | 7.75x |
| Hard Disk Size (GB) | 200 | 4000 | 20x |

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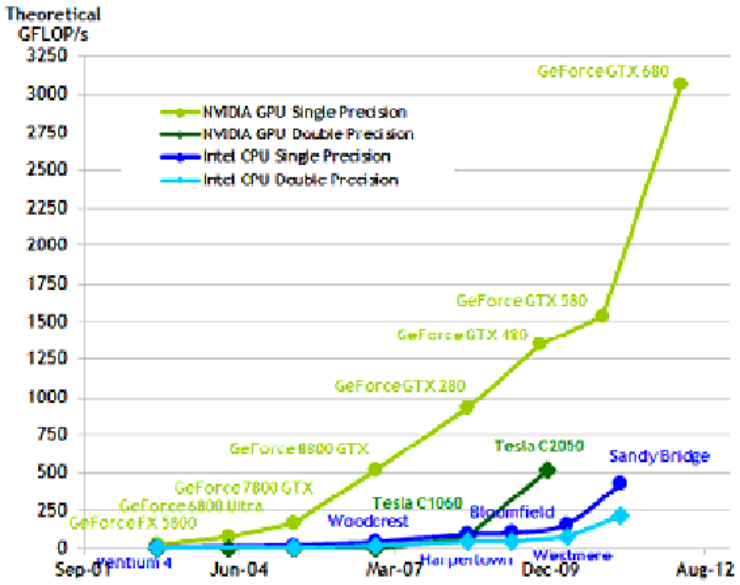
| | 2005 | 2011 | | |
|---|---|---|---|---|
| CPU Frequency (GHz) | 3.2 | 3.8 | 1.18x | x cores? |
| Memory Frequency (GHz) | 1.2 | 2.0 | 1.67x | |
| Bus Bandwidth (GB/sec) | 4 | 31 | 7.75x | |
| Hard Disk Size (GB) | 200 | 4000 | 20x | |
| Pixel Fill Rate (GPixels/sec) | 3.3 | 59 | 18x | |
| Vertex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

# The GFLOPS race




Floating-Point Operations per Second - NVIDIA CUDA C Programming Guide
Version 4.2 - 4/5/2012 - copyright NVIDIA Corporation 2012

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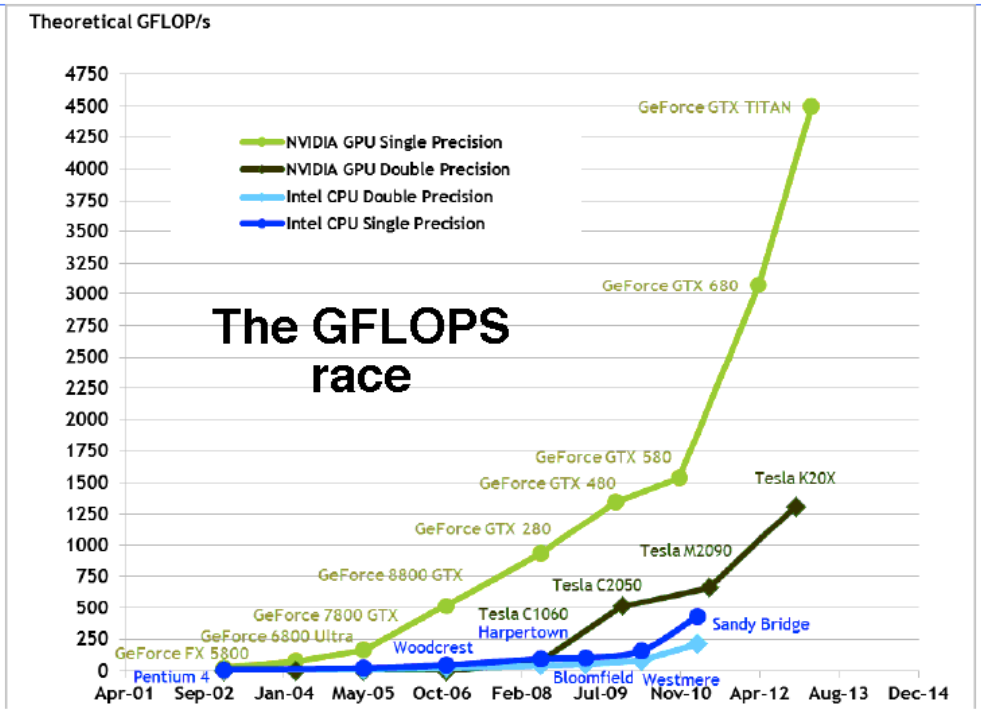
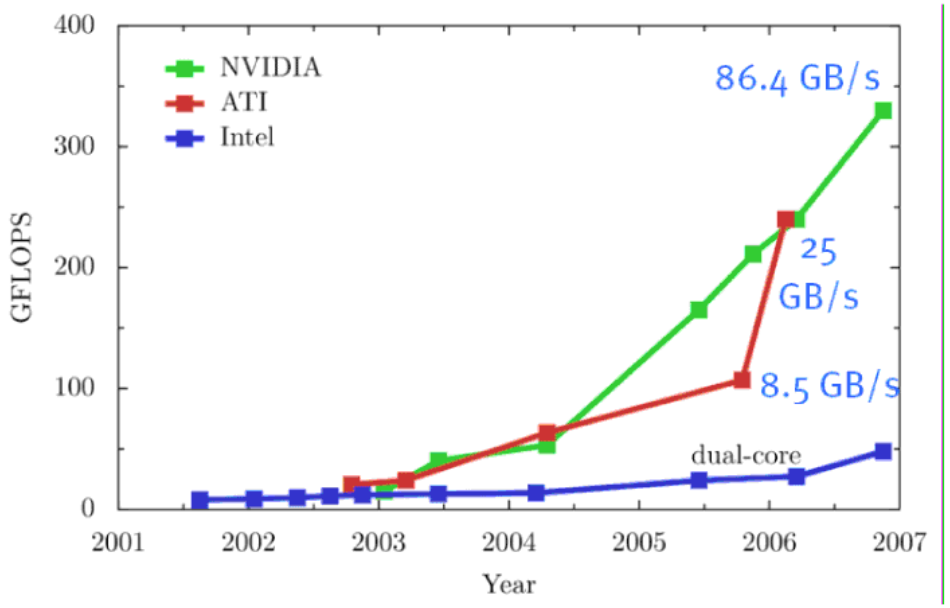


# Another graph, including ATI/AMD

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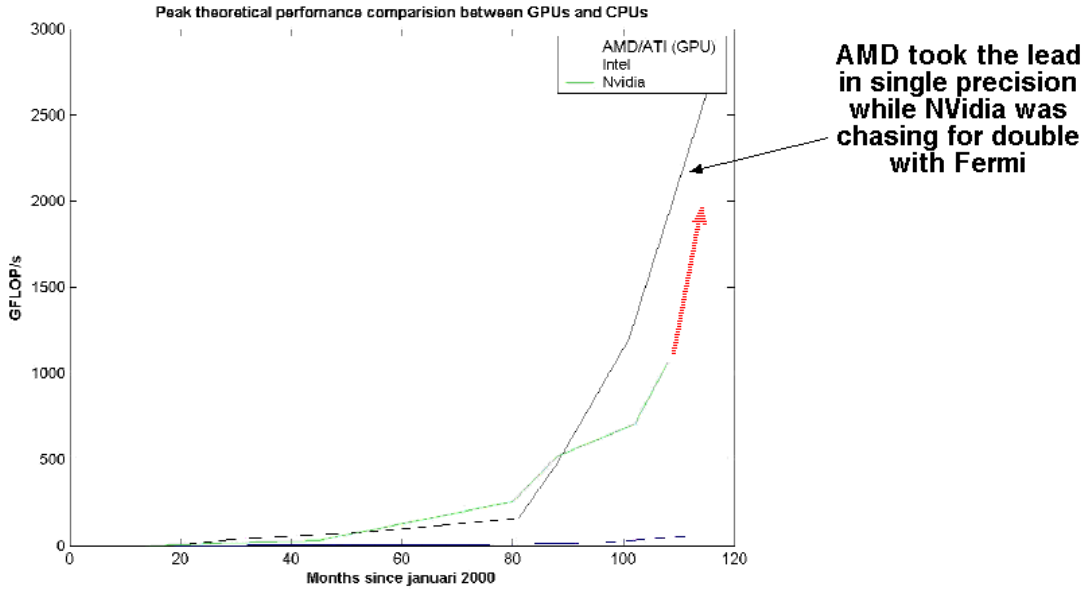
# Another graph, including ATI/AMD

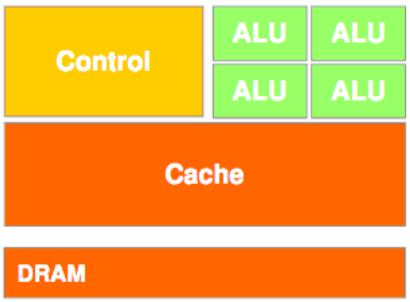



AMD took the lead in single precision while NVidia was chasing for double with Fermi

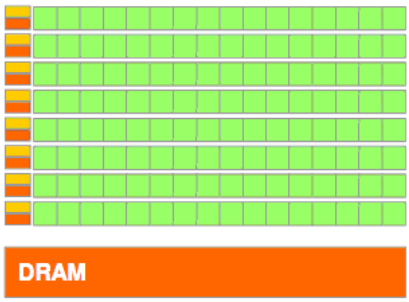
## How is this possible?

### Area use:

CPU




GPU




## But in particular: SIMD architecture

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## Flynn's taxonomy

| | |
|---|---|
| **SISD**<br>Since instruction, single data<br>Old single-core | **MISD**<br>Mupltiple instructions, single data<br>Multiple computations for redundancy |
| **SIMD**<br>Since instruction, multiple data<br>GPUs, vector processors | **MIMD**<br>Muliple instructions, multiple data.<br>Multi-core CPUs |

## SIMT = single instruction, multiple thread

# Important implications of SIMD/SIMT

SIMD: ”if” statements - all or none

SIMT: Thread focused. Fast thread switching. Hides memory latency!



# Why did GPUs get so much performance?

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

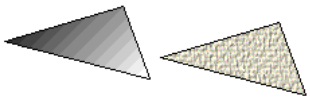
Graphics pipeline designed for parallelism!

Hiding memory latency by parallelism

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

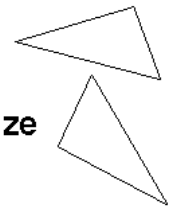
New games need new impressive features. Many important advancements started as game features.

*Must process many pixels fast!*



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

*Must 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 work in floating-point!*

This was for light effects, HDR.

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## 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

Shader threads calculate one pixel or one vertex

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

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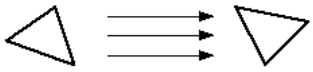
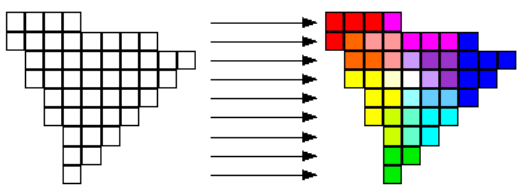
## The main tasks in rendering graphics:

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



CUDA and OpenCL generalize this to any kind of data, and possibility to access any part of memory.

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