GPU Programming for Video Games

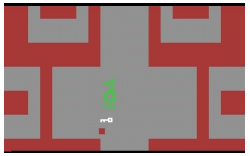
History of Video Gaming Hardware

Prof. Aaron Lanterman
School of Electrical and Computer Engineering
Georgia Institute of Technology

Georgia Institute of Technology

Atari 2600 VCS (1977)

- ≈ 1 MHz MOS 6507
  - low-cost version of 6502
- 128 bytes RAM
- First ROM cartridges 2K, later 4K
- Discontinued 1992
- Retro releases now on the market!



Adventure

Solaris

Pics & info from Wikipedia

Georgia Institute of Technology

2

Atari 2600 - hardware tricks

- Could put RAM on the cartridge
  - "Atari Super Chip"
  - 128 more bytes!
  - Jr. Pac-Man

- "Bank switching" to put more ROM on cartridge
  - Only 4K immediately addressable - game still has to operate within individual 4K chunks at a time
  - Mr. Do!'s Castle (8K), Road Runner (16K, 1989)
  - Fatal Run (only 32K game released, 1990)

Info & pics from AtariAge

Georgia Institute of Technology

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Atari 2600 - the Chess story (1)

- "Atari never intended to create a Chess game for the Atari 2600"
- "the original VCS box had a chess piece on it, and Atari was ultimately sued by someone in Florida due to the lack of an actual chess game"
- "Some time later Atari's engineers began working on a version of Chess for the 2600"

Quotes from AtariAge page on Video Chess

Georgia Institute of Technology

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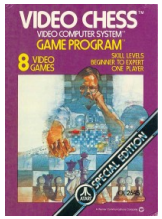
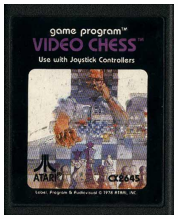
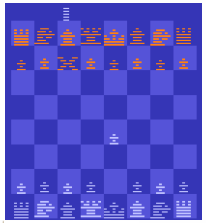
Atari 2600 - the Chess story (2)

- "Although Video Chess ended up shipping as a 4K game, earlier versions of the game were larger…This prompted Atari to invent bank-switching ROMs which would be used in later titles that needed more than 4K…"







Quotes & pics from AtariAge page on Video Chess

Atari 2600 graphics

- Custom **Television Interface Adapter** for handling graphics and sound
- No graphics buffer!
- "Playfield" scanline 40 blocks wide, two colors
- Two sprite "players": 8-"pixel" wide chunks, twice resolution of playfield, could be two colors different than playfield
- Missiles: single-bit

Info from "Chris Crawford on Game Design"
Some details from Ian Bogost

"Racing the beam"

- Atari 2600 games have intricate timing loop
- For each scanline, program has **76 cycles** to do whatever computations it needs to do to load a scanline's worth of pixels into the TIA
- Have to do most the "game logic" during the vertical blanking period

Info from "Chris Crawford on Game Design"
Some details from Ian Bogost

Atari 2600 graphics tricks

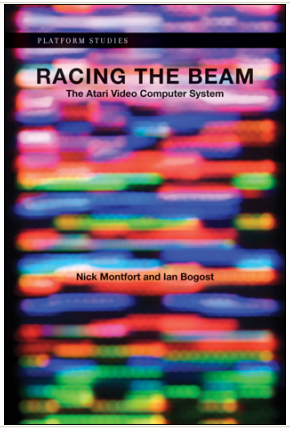
- Could change TIA registers to change colors…
  - …from scan line to scan line
  - …if you were extremely careful with your timing, you could do it in the middle of a scan line!
- Multiplex a single sprite between multiple objects
  - Flickering ghosts in Pac-Mac man
- Programmers learned to exploit "undocumented features" in the hardware

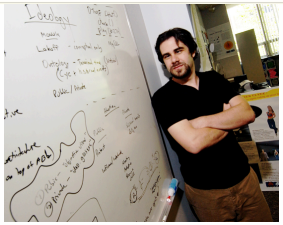
Rise of the third party developers

- Atari programmers unhappy
  - No credit! Salaried - little if any royalties
- Four top programmers split and form Activision (1979)
  - Promoted game creators along with games
  - Breakthrough product:
    Pitfall! (1982)
  - Didn't pay royalties to Atari
  - Atari sued; settled in 1982

- Mattel and Coleco made the same mistakes in handling their programmers that Atari did!

Sales pitch





Intellivision vs. Atari

- Plimpton Sports
  - http://www.youtube.com/v/IDza6eTXGEY
- Major League Baseball
  - http://www.youtube.com/v/Y0KTjpaG3cg
- Star Strike
  - http://www.youtube.com/v/VPB3H_a234s

Mattel Intellivision (1979)

- ≈1 MHz General Instrument CP1610 (16-bit!)
- 1352 bytes RAM:
  - 240x8 scratchpad memory
  - 352x16 system memory
    - 240 words for character buffer – what characters are where and what color
  - 512x8 graphics memory
    - Character patterns
- 7168 bytes ROM
  - 4096x10 (5120) executive ROM
  - 2048x8 graphics ROM

Photo and info from Wikipedia

Mattel Intellivision graphics

- 160x196, 16 colors
- 8 sprites
  - 8x8 or 8x16
  - Stretching: horizontal (1x, 2x) or vertical (1x, 2x, 4x, 8x)
  - Mirroring: horizontal and vertical
  - Collision detection: sprite to sprite, sprite to background, sprite to screen border
  - Priority: in front of or behind background

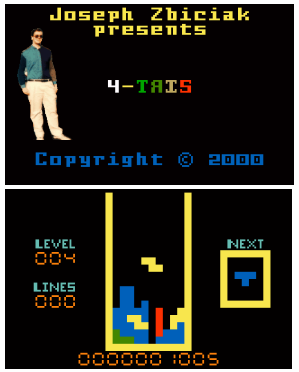
Photo and info from Wikipedia

Mattel Intellivision retro revival

Mattel Intellivision homebrew scene

spatula-city.org/~im14u2c/intv

sdk-1600.spatula-city.org



spatula-city.org/~im14u2c/intv/4-tris

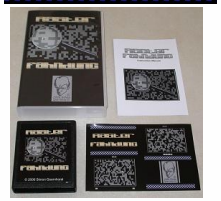
Example Intellivision code

```
CALL    RSGGB               ; Reset good guy bullets.

CALL    FILLZERO.lp         ; \
DECLE   25                  ;  |- nuke any remaining bad guys
DECLE   BGMPTBL             ; /

CALL    FILLZERO.lp         ; \
DECLE   10                  ;  |- and their sprites
DECLE   SPAT                ; /


;; ------------------------------------------------------------ ;;
;;  Draw the crater strip in selected color scheme.             ;;
;; ------------------------------------------------------------ ;;
MVI     COURSE,     R1      ; \
ANDI    #7,         R1
SLR     R1,         1       ;  |_ Adjust color for course
ADDI    #CRATCLR,   R1      ;  |
ADD@    R1,         R0      ; /
MOVR    R0,         R2      ;
ADDI    #7*8,       R2      ; City/crater ending card #
```

Source code for Space Patrol
From spatula-city.org/~im14u2c/intv/spteaser

Atari homebrew scene

Ian Bogost (LMC)



From www.bogost.com and www.quernhorst.de/atari/rf.html

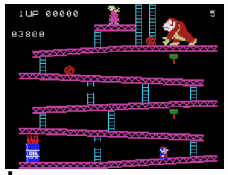
ColecoVision (1982)

- ≈3.6 MHz Zilog Z-80A (8-bit)
- 1KB scratch RAM
- 16 KB of separate VRAM (not directly CPU addressable)
- Cartridges 8/16/24/32K
- Expansion Module #1 allowed user to play Atari 2600 games
  - Atari sued, but lost since EM #1 used off-the-shelf hardware

Info from Wikipedia

ColecoVision

- Bundled with Donkey Kong - "killer app"
- 6 million sold
- Discontinued 1984
- Coleco also produced games for Atari 2600 and Intellivision



Info from Wikipedia

ColecoVision - graphics

- Video Processor: Texas Instruments TMS9928A
  - Variants used in MSX, Texas Instruments TI-99/4A
- 256x192, 15 colors
- 32 sprites (but only 4 per line)
- First console that could seriously compete with stand-alone arcade machines

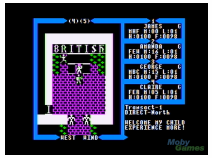
Smurf: Rescue in Gargamel's Castle

War Room

Info & screenshots from Wikipedia

Apple][series (1977)

- ≈1 MHz MOS 6502
- 16K to 48K of RAM (64K with “Language Card”)
- Expansion slots
- VisiCalc (first spreadsheet) - killer app
- Spurred IBM to make the IBM PC
- Hi-res graphics: 280x192, 5 colors (sort of)
  - Page flipping, Pre-shifted shapes



Exodus: Ultima III screenshot from Moby Games
Other pics and info from Wikipedia

Atari HCS 400/800 (1979)

- ≈1 MHz MOS 6502
- 16K to 48K of RAM
- Star Raiders - “killer app”
  - Created by engineer who designed POKEY (the I/O and sound chip)
  - Written to show off the machine’s capabilities
  - 3-D math!!! Remember, no divide instructions….

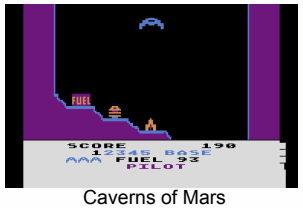
Star Raiders

Pics and info from Wikipedia

Atari HCS 400/800 - graphics

- Extremely flexible graphics system
- Amenable to all kinds of 2600-style tricks, although now with a much more powerful basic capabilities
  - Reprogramming color table for each scan line
  - Vertical smooth scrolling easy
  - Smooth scrolling horizontally via custom character set patterns

Eastern Front (1941)



Caverns of Mars

Info from “Chris Crawford on Game Design”
Screenshots from Wikipedia

Commodore 64 (1982)

- ≈1 MHz MOS 6510 (close relative of 6502)
- 64K RAM
- Discontinued 1984
  - Followed up by many variations
- Classic sound chip: SID
- Launch price: $595

Photo and info from Wikipedia

Commodore 64 - graphics

- MOS VIC-II graphics chip
- 16 colors
- Display modes:
  - 320x200 (2 unique colors in each 8x8 pixel block)
  - 160x200 (3 unique colors + 1 common color in each 4x8 pixel block)
- 8 sprites, 24x21 pixels (12x21 in multicolor mode)
- Smooth scrolling
- Raster interrupts

Info from Wikipedia

The Video Game Crash of 1984 (1)

- E.T. rushed to market in only 5 weeks to hit stores in time for holiday season
- Widely considered Worst Game Ever
- Atari paid $20-25 million for the rights
- 1.5 million sold
- 8th best selling Atari cartridge of all time
- 4 million manufactured

http://www.youtube.com/v/VakiwDmJ-II

Screenshot and info from Wikipedia

The Video Game Crash of 1984 (2)

- Rushed, weak port of Pac-Man
- 12 million manufactured…
- …but only 10 million Ataris in homes at the time!
- Only 7 million sold
- Ms. Pac-Man port & homebrew Pac-Mans are better

Photo and info from Wikipedia

The Video Game Crash of 1984 (3)

Millions of cartridges of E.T. and Pac-Man encased in concrete and secretly dumped in landfill

Photo from Wikipedia

The Video Game Crash of 1984 (4)

- In 1982, Atari CEO Ray Kassar sells off 5,000 of his Warner (Atari's parent company) stock…
- …just before a low earnings report drops Warner stock by 40%

Photo from www.absoluteastronomy.com/topics/Ray_Kassar
Info from Wikipedia

The Video Game Crash of 1984 (5)

- SEC investigated for insider trading
- Settled, returned profits
- Later cleared by SEC
- Forced to resign in 1983

Photo from www.absoluteastronomy.com/topics/Ray_Kassar
Info from Wikipedia

Nintendo NES (1985 U.S. release)

- ≈1.8 MHz 6502 core
- On-die DMA controller and sound hardware (Ricoh)
- Called "Famicom" in most of Asia (1983 in Japan)
- Bundled with Super Mario Bros. - "killer app"
- Launch price: $200; final bundle: $50
- Discontinued in 1995
- 62 million sold

Pics and info from Wikipedia

Nintendo NES – graphics

- Ricoh-made "Picture Processing Unit"
  - ≈5.4 MHz, RP2C02
- 256x240 resolution
- 64 sprites (8x8 or 8x16 for all), 8 per scanline
- Tile patterns
- 25 colors per scanline:
  - 1 background
  - 4 sets of 3 tile colors
  - 4 sets of 3 sprite colors

Photo and info from wikipedia

Sega vs. Nintendo

- Blast Processing
  - http://www.youtube.com/v/K03fQKkN7VI
- Genesis Does what Nintendon't
  - http://www.youtube.com/v/k7nsBoqJ6s8

Sega Genesis (1989)

- ≈7 MHz Motorola 68000
- ≈3.5 MHz Zilog Z80
  - Sound coprocessor
  - Backward compatibility with Sega Master System
- 64K main RAM for 68000
- 64K video RAM (not directly accessible)
- 8K secondary RAM for Z80
- 8K audio RAM
- ROM cartridges up to 4M
  - Can use bank switching for larger games
- Released as "Sega Mega Drive" in Japan (1988)
- 29 million sold

Photo and info from Wikipedia

Sega Genesis - graphics

- "Video Display Processor"
- Descendent of the TMS9928 family used in Colecovision (but not designed by TI)
- 320x224 resolution (complicated)
- 4 planes (2 scrolling playfields, 1 sprite plane, 1 'window' plane)
- Up to 64 sprites
- 61 on-screen colors

Most info from Wikipedia
TMS9928 note from Joe Zbiciak

IBM PC compatibles

- Original IBM PC (1981)
  - ≈4.8 MHz 8088
  - 16K to 640K
  - CGA (640x200 B&W, 320x200 4-color, 160x100 16-color w/tricks)
- IBM PC AT (1984)
  - 6 MHz 80286, later 8 MHz
  - 256K to 16M
  - EGA (640x350 16-color from a palette of 64)
- VGA (1987)
  - Palette of 262,18 colors
  - 640x480, 16-colors
  - 320x200, 64-colors (Wolfenstein 3-D)
  - 320x240, 64-colors (Doom)
- Killer app: Lotus 123

Photo and info from Wikipedia
Some details by Joe Zbiciak

Doom (1993)

- Followed in footsteps of of Wolfenstein 3-D (1992)
- Released as shareware!
  - Downloaded by 10 million people in two years
- Cleverness over hardware

John Carmack

Images and info from Wikipedia

Sega Saturn (1995)

- **Two** ≈29 MHz Hitachi SuperH-2 7604 32-bit
- Hitachi SuperH-1 - controller for CD-ROM
- 11.3 MHz Motorola 68EC000 sound controller
- 22.6 MHz Yamaha FH1 DSP sound processor
- 1 MB SDRAM, 1 MB DRAM
- 1.5 MB VRAM
- 4 KB VDP2 on-chip color RAM
- 512 KB audio RAM
- 512 KB CD-ROM cache
- 32 KB nonvolatile RAM
- Initial launch price $400
  - Not initially sold at a loss
- 10 million sold

Photo and info from Wikipedia

Sega Saturn - graphics

- ≈7.1590 MHz “VDP 1” 32-bit Video Display Processor
- ≈7.1590 MHz “VDP 2” 32-bit
- Quadrilaterals - not triangles!
- No hardware decompression

Quote from Wikipedia

Sega Saturn - complexity

“One very fast central processor would be preferable.

I don't think all programmers have the ability to program two CPUs — most can only get about one-and-a-half times the speed you can get from one SH-2.

I think that only one in 100 programmers are good enough to get this kind of speed [nearly double] out of the Saturn.”

- Yu Suzuki, on Saturn Virtua Fighter development

Quote from Wikipedia

Sony Playstation (1995)

- ≈34 MHz MIPS R3000A-type (R3051) 32 bit
- 2M main RAM
- 1M video RAM
- 512K sound RAM
- 32K CD-ROM Buffer
- 512K OS ROM
- 128K Memory cards
- $300 at launch
- 102 million sold

Pics & info from Wikipedia & www.insomniacgames.com

Sony Playstation – graphics (1)

- 24-bit color, 256x224 to 640x480 resolution
- "Geometry Transformation Engine"
  - Built into same chip with MIPS R3000A CPU
  - 66 MIPS
  - 360,000 flat-shaded polygons per second
  - 180,000 texture mapped, Gouraud shaded polygons per second

Photo and info from Wikipedia

Sony Playstation – graphics (2)

- "Data Decompression Engine"
  - 16x16 Inverse Discrete Cosine Transforms (ICDT)
  - DMA transfer of uncompressed images to GPU

Photo and info from Wikipedia

Full motion cheese

Insomniac's "Disruptor" (1996)

Excellent gameplay, but badly acted live action cutscenes

Gameplay: http://www.youtube.com/v/VdfV7BtYVFs
Cutscene: http://www.youtube.com/v/eahGUCcj6uM

Increasing trend: in-engine cutscenes

Konami's "Metal Gear Solid" (1998)

http://www.youtube.com/v/5sny3RfMYMU

Pictures from Wikipedia

Nintendo 64 (1996)

- ≈94 MHz MIPS R4300i-type
  - 64 bit registers, instructions, internal data path
  - 32 bit external data path
- 4M RAM - unified address space
- 32K colors, 256x224 to 640x480 resolution
- $200 at launch
- 32 million sold
- SGI CPU/GPU combo design
  - SGI bought out MIPS
  - Originally for Sega, but deal fell through

Photo and info from Wikipedia

Nintendo 64 - graphics

- ≈65 MHz SGI-designed "Reality Coprocessor" (RCP)
- "Reality Signal Processor" (RSP)
  - MIPS R4000-based 8-bit integer vector processor
  - Programmable through microcode
  - Geometry transforms, clipping, lighting
  - SGI Fast3D microcode: ~100,000 polygons per second
  - Can also handle some sound duties
  - Presages some of the programmability of modern GPUs
- "Reality Drawing Processor" (RDP)
  - Rasterizer (turns triangles into pixels)

Photo and info from Wikipedia

Nintendo 64's Killer App: Rare's "Goldeneye 007"

- 4-way split screen multiplayer
  - http://www.youtube.com/v/7cf5kkoYexI

Picture from Wikipedia

Nintendo 64 - last console to use cartridges

- 4 MB to 64 MB (Resident Evil 2)
- Some cartridges have nonvolitale RAM for saved games
- Pros
  - More piracy resistant than CDs
  - Faster loading time (CD-ROMs slow at the time)
  - No lengthy load screens like on Playstation
  - More durable (important for children)
- Cons
  - Small capacity compared to CD
  - Higher manufacturing costs and lead times - turned off third-party vendors, ate into profit margins

Info from Wikipedia

Sega Dreamcast (1999)

- 200 MHz Hitachi SuperH
  - 32-bit instruction set, 128-bit FPU functions
- 16M main ram, 8M video RAM, 2M sound RAM
- Launch price: $200
- 10.6 million sold

Photo and info from Wikipedia

Sega Dreamcast - graphics

- Imagination Technologies PowerVR2
  - PowerVR series competed with Voodoo series by 3dfx
  - Both companies eventually killed by ATI & NVIDIA
- Over 5 million polygons/second (7 million peak)
- Hardware gouraud shading, z-buffering, anti-aliasing and bump mapping

Info from Wikipedia

Sega Dreamcast - Namco's "Soul Calibur"

Screenshot from Wikipedia

Microsoft Xbox (2001)

- Sony's success with PS1 worried Microsoft
- 32-bit 733 MHz Pentium III-based Celeron
- 64 MB main RAM
- Development very much like developing Windows PC games
  - DirectX API
  - Easy to make PC and Xbox versions
- $300 at launch
- Killer app - Halo: Combat Evolved

Photo and info from Wikipedia

Microsoft Xbox - graphics

- 233 MHz NVIDIA "NV2A" GPU
- Similar to GeForce 3 and GeForce 4
- 485,416 triangles per frame at 60fps
- 970,833 triangles per frame at 30fps
- Bilinear, trilinear, and anisotropic texture filtering
- Texture compression
- Full scene anti-aliasing

Photo and info from Wikipedia

Nintendo Gamecube (2001)

- "Gekko" - 485 MHz PowerPC 750CXe-based core
- Nonstandard, small optical disk
  - Can't be used as a standard DVD player
  - Some protection from piracy
  - Avoid DVD Consortium licensing fees
- 24M main RAM
- 1M texture buffer
- 2M frame buffer
- 21 million sold (as of June 2007)
- $200. Nov. 2001; $150, May 2002; $100, Sept 2003

Photo and info from Wikipedia

Nintendo Gamecube - graphics

- 24-bit color, 640x480 interlaced or progressive scan
- "Flipper" - 162 MHz, co-designed by Nintendo and ArtX
- TEV "Texture EnVironment" engine
  - Similar to "pixel shader"
- Fixed-function hardware transform and lighting
  - 12+ million polygons/second
- Bilinear, trilinear, and anisotropic texture filtering
- Bump mapping, reflection mapping

Photo and info from Wikipedia

Sony Playstation 2

- 140 million sold as of mid-2008
- Emotion Engine:
  - 300 MHz
  - MIPS III core
  - Two "Vector Units"
  - Graphics Interface (GIF) for talking to Graphics Synthesizer (GS)
  - Image Processing Unit
    - MPEG2 decoder
    - Macroblock decoding
    - Vector quantization

Photo and info from Wikipedia

Emotion Engine

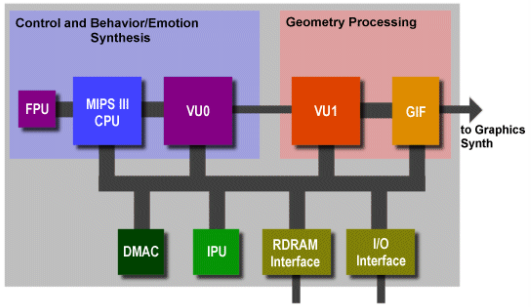


Image from J. Stokes, "Sound and Vision: A Technical Overview of the Emotion Engine," *ars technica*, Feb. 16, 2000, arstechnica.com/reviews/hardware/ee.ars

Vector Processing Units

- VPU0: intended for "thought simulation and physical simulation"
- VPU1: intended for graphics pipeline
  - Geometry transformation
  - Vertex lighting
  - Outputs triangles (display list) to Graphic Synthesizer

VPU capabilities

- 16, 16-bit integer registers
- 32, 128-bit floating point registers
  - Split into 32 bit words (x,y,z,w)
- Four FMACs in one clock cycle
- Two sets of drawing environments (internal contexts)
  - GS knows which instructions came from VPU0 and VPU1
  - Merges sequences

Microsoft XBox 360 (2005)

- 3.2 GHz "Xenon" triple-core PowerPC
  - 2 hardware threads per processor
- 256 MB main RAM
- 500 MHz ATI "Xenos" GPU
- Xbox Live online service
  - "Live arcade" game distribution
- HD-DVD drive available as ad-on (lost the war)
- Launch price: $399 premium, $299 core (kind of useless)
- Power Mac G5 early devkits?

Photo and info from Wikipedia

Sony Playstation 3 (2006)

- IBM/Toshiba/Sony Cell processor
  - PowerPC Processing Element (PPE)
  - 8 Synergistic Processing Elements (SPE)
- 256M main RAM, 256M graphics RAM
- Blu-Ray drive
  - Part of Sony's strategy of establishing Blu-Ray movie format
- Launch price: $500 (crippled), $600 ("real" version)
- Sold at an estimated loss of around $250

Photo and info from Wikipedia

Sony Playstation 3 - graphics

- 550 MHz NVIDIA RSX
- Closely related to NVIDIA 7800
- Sadly, Linux users did not have access to the accelerated graphics
  - Stuck using frame buffer mode

Photo and info from Wikipedia

Nintendo Wii (2006)

- Not a lot of info publically released
- "Broadway" - 729 MHz PowerPC core
- 243 MHz ATI "Hollywood" GPU
- 88 MB main RAM
- 24 MB RAM in GPU
- 64 MB external video RAM
- Regular sized DVDs
  - But original Wii won't play DVD movies
- Bundled with Wii Sports - "killer app"

Photo and info from Wikipedia

Historical trends

- With each generation, the differences between different consoles and desktop computer brands has become less. The differences between:
  - Atari 2600 and Intellivision were huge
  - Nintendo 64 and Playstation 1 were more subtle
  - Playstation 4 and Xbox One are negligible
- Different consoles and computers no longer have distinct "looks" dictated by the hardware

Latest trends

- Hardware has become boring – it's just "there"
- Little difference between underlying computing hardware of Playstation 4 and Xbox One
  - "Off-the-shelf" CPU and GPU cores
  - Custom efforts like the Cell not worth it anymore
- Developers no longer have to "rebuild the camera" with every technological advance
- Computers get faster, but the way programmers interface with the hardware has stabilized
  - Standard desktop OSes: Windows, Mac, Linux
  - Standard mobile OSes: iOS, Android, Windows Phone
  - Standard GPU APIs: OpenGL and DirectX