ECE4893A/CS4803MPG: Multicore and GPU Programming for Video Games

History of Video Gaming Hardware

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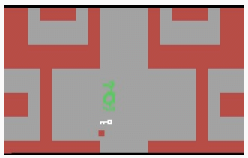
Atari 2600 VCS (1977)

- ≈ 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

Atari 2600 - hardware tricks (1)

- 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

Atari 2600 - hardware tricks (2)

- "M Network" games
  - Atari 2600 games produced by Mattel
  - Controversial decision within Mattel
  - Done by same group that designed the Intellivision: APh Technology Consulting

- Super Charger added 2K RAM
  - Originally planned as a hardware add-ons
  - Public didn't seem to like add-ons, so built in separately into each cartridge
  - BurgerTime: Cleverness beats hardware!

Info & pic from www.intellivisionlives.com/bluesky/games/credits/atari1.shtml
www.intellivisionlives.com/bluesky/games/credits/atari2.shtml

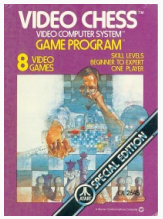
Atari 2600 - the Chess story (1)

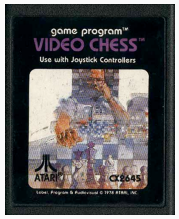
- "Atari never intended to create a Chess game for the Atari 2600"
- "the original VCS box had a chess piece on it, and Atari was ultimately sued by someone in Florida due to the lack of an actual chess game"
- "Some time later Atari's engineers began working on a version of Chess for the 2600"

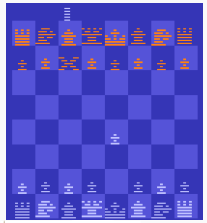
Quotes from AtariAge page on Video Chess

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

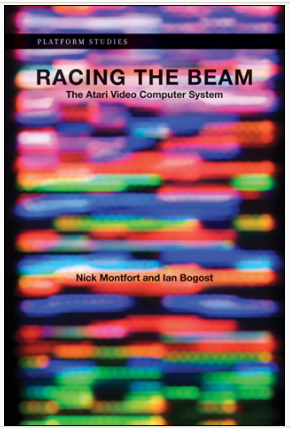
- Could change TIA registers to change colors…
  - …from scan line to scan line
  - …if you were extremely careful with your timing, you could do it in the middle of a scan line!
- Multiplex a single sprite between multiple objects
  - Flickering ghosts in Pac-Mac man
- Programmers learned to exploit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

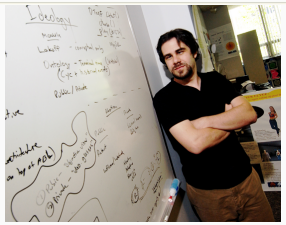
Rise of the third party developers

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

Photo and info from Wikipedia

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

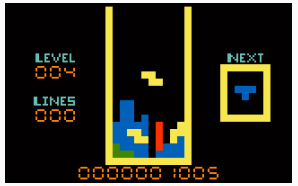
Photo and info from Wikipedia

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

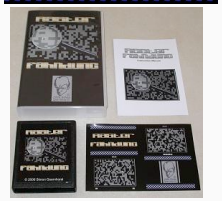
Example Intellivision code

```
            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 (LCC)



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

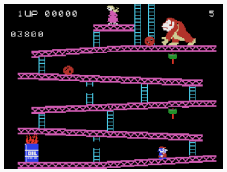
ColecoVision (1982)

- ≈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



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

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

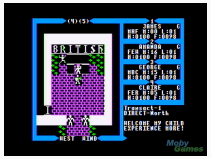
Smurf: Rescue in Gargamel's Castle

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

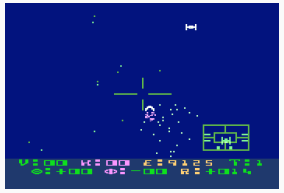


Exodus: Ultima III screenshot from Moby Games

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….



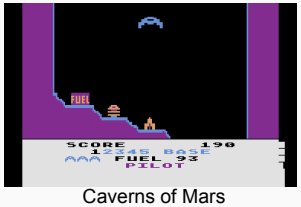
Star Raiders

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)



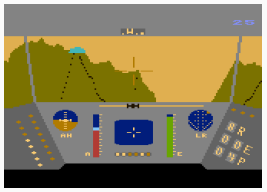
Caverns of Mars

Info from "Chris Crawford on Game Design"

Screenshots from Wikipedia

Atari 5200 (1982)

- Sort of a Atari 400/800 without a keyboard
- Not totally compatible
- Had trouble with new analog joysticks
  - Hard to center
- Atari paid more attention to 2600 line
- Discontinued in 1984



Rescue on Fractalus!

Photo and info 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 - competition

- Sega SG-1000 (1985 Japan)
- Renamed Sega Master System (1986 U.S.)
  - –Didn’t catch on in the U.S.
- Atari 7800 - last gasp, bombed

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

Nintendo Super NES

- 1990 Japan, 1991 U.S.
- 49 million sold
- Slower CPU, but nice graphics & audio chips

Info & photo from Wikipedia

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 - 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

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

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"

http://www.youtube.com/v/aRFfgdNI2F0

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

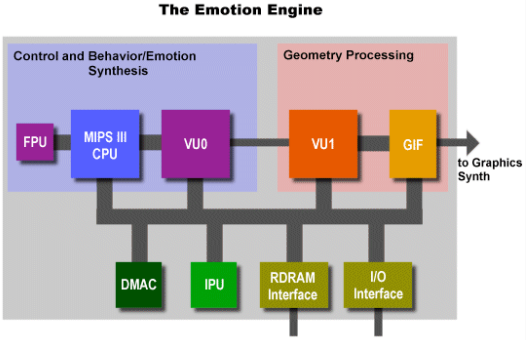


Image from J. Stokes, “Sound and Vision: A Technical Overview of the Emotion Engine,” *ars technica*, Feb. 16, 2000, arstechnica.com/reviews/hardware/ee.ars

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 currently do 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