Challenges in the Architecture of Electronic Games

Ricardo Alexandre G. C. Martins

Departamento de Informática, Universidade do Minho
4710-057 Braga, Portugal
ricardo@poupetempo.com.br

Abstract. This communication presents topics about the videogames consoles from the past to the present. A reference is made to show each evolution in some aspects - video, graphics, performance - and gives a glimpse of what the future will bring..

1 Introduction

Some things in this world never stop amazing us, for example the videogame: financially the videogame has developed enormously, however it has not yet received the proper cultural esteem.

Statistics, taking in mind their credibility, show us that the average age of players is increasing steadily. But the reactions are double-hearted: on the one hand people smile grimly whenever the subject is brought up, but on the other hand the sales figures of the last adventures of Lara Croft or the Playstation 2 are quite astounding.

Nevertheless, the evolution of this medium should not be underestimated. The roughly designed spaceships and the dots swallowing yellow balls belong to the past. The graphical and narrative aspects nowadays can really be considered as works of art. No wonder that celebrities of the cinema and literary world are interested in this new discipline. There are remarkable structural resemblances between the videogame and the cinema. And it is so different when all started. The simple graphics from the Atari is an example for this evolution, when compared with Quake for Playstation, for example. Other example is the software media and their speed access: today the speed is around 33Mhz (and there are consoles that are faster) processing and the first videogame had a processing speed of the 1.19Mhz. In the Atari's time, the games were stored in cartridges. Now the standard is the CD.

Briefly, there is a new resource in the popular culture, and it is worthwhile exploring it. There is a triple evolution that lies at the basis of the development of the videogame. The digital revolution, which occurred in the mid nineties, the development of a new generation of machines, resulted in a wider use of the medium. Suddenly, it became possible to design games applying images in three dimensions. The possibility to use different perspectives and depth of field admitted to express the most fantastic scenarios ever. Obviously the CD-ROM, with it's enormous memory capacity, made it possible to stock the digital weight of more complicated games.

When the information technology was at its peak, the first generation players matured. This did not influence their urge to play but they became much more demanding. The characters had to be more outlined, the story more complicated, the images nicer en the sound more realistic. The producers accepted the challenge and their continuing research efforts resulted in a rapid acceleration in the development of the videogame.

2 CPU

The heart of any electronic machine is the processor. With the videogames is not different. Each processor has their characteristics and includes ways to resolve their functions.

Processor	System Interface	Speed	Number of Transistors	Instructions per second
6507	8 bits	1.19 MHz	4000	Few thousand
65816	16 bits	3.58 MHz	300 thousand	1 million
R3000A	32 bits	33.8688 MHz	3.6 million	30 million
R4300i	64 bits	93.75 MHz	Over 4 million	500 million

As can be seen, the processor of Nintendo 64 is more powerful than the others, due to a higher clock frequency and to the capacity to make calculations in 64 bits. It helps in the calculations of the polygons, so, in the Nintendo 64 is easier have more polygons with a texture quality much superior than the other consoles.

2.1 Atari

In the Atari videogame, the 8-bit main processor is the 6507 chip. This microchip is identical to the standard 6502 except that it only has 13 external address lines and no interrupt inputs. With a clock speed working at 1.19 Mhz, the processor works with availability less then 50 % and can only address 8K.

2.2 Super NES

The Super NES runs on a 65816 processor with a 3.58 Mhz clock speed. This is similar to the 6502, but many new instructions are available.

The 65816 is a 16 bit processor that does 24 bit addressing. You can load and store 16 bit numbers, as well as 8 bit. The addressing is different than the 6502 in that it includes a bank.

2.3 Playstation

The heart of the Playstation is a slightly modified R3000A CPU. This is a 32 bit Reduced Instruction Set Controller (RISC) processor that clocks at 33.8688 MHz. It has an operating performance of 30 million instructions per second. In addition, it has an Internal instruction cache of 4 KB, a data cache of 1 KB and has a bus transfer rate of 132 MB/sec. It has internally one Arithmetic/Logic unit (ALU), One shifter, and totally lacks an FPU or floating-point unit. The R3000A is configured for little-endian byte order and defines a word as 32-bits, a half-word, as 16-bits, and a byte as 8-bits.

2.4 Nintendo 64

The Nintendo 64's main power is the NEC MIPS R4300i processor. This is a low-cost chip based on the workstation-class MIPS 4400. The processor is able to operate in either a

32bit or 64bit mode and includes both a 64bit integer data execution unit and a 64bit floating point unit.
The chip has a single issue, five stage instruction pipeline that handles both the integer and floating point instructions.
The R4300i used in the Nintendo 64 is internally clocked at 93.75Mhz which is slower than the original 100Mhz design specification, but is still faster than any other currently available console. Externally, the R4300i uses a 32bit system interface.

3 Audio / Video

The Audio processor is a chip that performs phase and harmonic compensation on audio signals to accurately reproduce the “rise” section of audio signals that determines the characteristics of the sound, and thus reproduce the original recording as naturally as possible.

Computer animation is often depicted as stop motion animation in which an object is drawn somewhere in a buffer out of view and then placed on the display to be seen. With this process repeated very rapidly in real-time the effect of motion is achieved [1].

3.1 Atari Audio and Video

The responsible chip for the Audio / Video processing in the Atari is Stella. This chip makes all the video displays in a resolution of 40 x 24 bits and sounds for the 2600 VCS.

The Stella chip incorporated two audio circuits that could be programmed independently. The sound output was controlled via three registers:

- AUDC0, a 4-bit register that could be loaded with the values 0..15 resulting in 16 different basic sounds, ranging from flute-like, pure tones to explosive noises.
- AUDF0, a 5-bit register, was used to divide a basic frequency of 30kHz by 1.32
- AUDV0, another a 4-bit register, affected the volume of the sound in 16 steps.

3.2 Super NES Audio and Video

The Graphics chip is a custom chip made for the sole purpose of this console. It can do many things, such as rotation of the background, scaling, transparency, and "Mode 7." It can display 256 colours at the same time, out of a palette of 32,768. It has only 128K of VRAM for displaying the color information. It also has a maximum resolution of 512x384, but this resolution needs a monitor to display clearly. Most to all games use its default 256x256.

The Super NES has a custom chip called the SPC700 (12-bit), manufactured in-house by Sony. It can handle 44KHz sound, but only can access 64K (hint, the slow CPU can only access 64K at a time). Most games render the sound at 22KHz or 11KHz to save memory. This chip also has the first wave table synthesis to ever appear on a console. It uses 16 voices and has a stock set of General MIDI instruments.

3.3 Playstation Audio and Video

The video unit of the Playstation utilizes a 1 MB frame buffer, and provides a screen resolution of up to 1024x512. The display can be set up for 15- or 24-bit color. The Playstation does not contain a floating-point unit. Instead, another co-processor, termed Cop2 and named the Geometry Transformation Engine, maintains all 3D calculations and performs matrix operations, color operations, vector operations, and other sorts of calculations. The speed of this processor is much greater than the R3000A core processor for these types of operations. Additionally the GTE requires no address space.

The sound-processing unit can handle 24 voices and features a 512KB sound buffer. Data is stored in compressed blocks of 16 bytes, which contain packed sample bytes to output as well as start and looping time information. The 512KB buffer can be subdivided into a series of memory ranges, providing areas for CD audio left, CD audio right, two voice regions of memory, system, sound data, and reverb work area regions. Registers are provided with each voice sample for various effects and volume control. The SPU itself features internal registers controlling the master volume, main volume left, main volume right, reverberation left and right, output phases, and other channel and buffering information. [2]

3.4 Nintendo 64 Audio and Video

In the Nintendo 64 is the custom chip - the Reality Co-Processor (RCP). This is a 62.5Mhz chip that interfaces directly to the CPU. The Reality Co-Processor is designed to handle most of the audio and graphics processing. In addition to this, the chip also contains DMA logic, audio and video outputs, and a joystick input. The chip also supports timing and signals for the game cartridges.

There are two processors inside the Reality Co-Processor: the Reality Signal Processor and the Reality Drawing Processor.

The Reality Signal Processor performs all 3D manipulations and audio functions. A special feature is that this processor is configurable via microcode allowing the system to be optimised over time.

The Reality Drawing Processor is a pixel drawing processor. This unit performs all pixel-level operations including texture mapping, anti-aliasing, tri-linear interpolation, MIP mapping and z-buffering. The Reality Drawing Processor operates on a display list to provide its graphics output meaning the Reality Drawing Processor is essentially an Object List Processor.

Sound and Graphic Interface claims that the Reality Co-Processor contains a vector processor (probably the Reality Signal Processor) that can perform over half a billion arithmetic operations per second - approximately 10 times the raw compute power of a low end Pentium. Internally the Reality Co-Processor performs 128bit processing, although this could be “split" between the Reality Signal Processor and Reality Drawing Processor.

Both the R4300i and the Reality Co-Processor generate the audio, presumably using the CPU to provide the music data, while the Reality Co-Processor performs the actual sound generation. It is possible to produce 16bit stereo sound at up to 48Khz (greater than CD at 44.1Khz). The number of sound channels is not defined in hardware. The total number of simultaneous voices depends on the software, although 64 channels is apparently possible.

4 Memory

According to games programmers, the RAM memory is a so important factor, as much as the speed of the processor. How much bigger the available memory, more detailed and worked well will be the game and the textures that compose it.

4.1 Atari Memory

The RIOT is the chip in the Atari that contains the only 128 bytes RAM in the system and a general-purpose timer. The RAM is mapped to the high end of both page 0 and page 1. This means that it acts as both page 0 fast access memory and the 6502 stack.

4.2 Super NES Memory

The Super NES has a 128K RAM and uses a FastROM that can execute at 3.58Mhz and a SlowROM that can only execute 2.68Mhz.

The Super NES lets access ROM through memory bank $00 onwards and memory bank $80 onwards such that locations $00:8000 and $80:8000 are congruent, (they access the same locations.)

When accessing memory bank $00 onwards the 65816 runs at 2.68Mhz. However, when accessing memory bank $80 onwards the 65816 can run at 2.68Mhz or 3.58Mhz depending on how you set bit 0.

4.3 Playstation Memory

Physically, the Playstation comes equipped with four 512KB 60ns SRAM chips for 2MB of system memory. A separate processor, termed the System Control Processor, employs a virtual memory system in order to manage memory. The Playstation virtual memory creates three addressable segments of memory, termed Kuseg, Kuseg0, and Kuseg1. Within each of these 2MB virtual segments, the following elements are present: 64K kernel, 64K dedicated to the parallel port, a 1024-byte “scratch pad”, 8K of hardware registers, the remaining 1.9MB of user-programmable memory. [2]

4.4 Nintendo 64 Memory

The Nintendo 64 uses 36Mbits of RAMBUS 9bit DRAM. In more common terms this equates to 4 megabytes. The extra bit is presumably used for parity. The chips use a fast 8bit channel running at approximately 500Mhz. This yields a bandwidth of 520.5MB/sec or 4,500M bit/sec (exact benchmarks vary). The high speed of the memory, coupled with a 256k cache for both the R4300i and Reality Co-Processor, allow the system to make full use of the UMA.

5 Quick View about the Consoles

The following table resumes the basic features of the game consoles presented above, namely the processor identification, the clock frequency, the memory size and the screen resolution.

	Atari	Super NES	Playstation	Nintendo 64
CPU Processor	6507	65816	R3000A	R4300i
Clock Speed	1.19 Mhz	3.58 Mhz	33.8688 Mhz	93.75 Mhz
Memory	128 bytes	128 k	2 Mb	36 Mb
Resolution	320 x 192 pixels	512 x 488 pixels	640 x 480 pixels	256 x 224 ~ 640 x 480 pixels
Colors	16	32768	16.7 million	32 bits
Sound	2 audio channel	8 audio channel using compressed wave samples	24 audio channel	Up to 100 PCM channel

6 Conclusion

As can be seen, the evolution of the videogames was not restricted only in a few aspects. Since the first videogame (Atari), many features were included like a processor only for the sound, more memory and fast access to it, and graphics resolution. Who could think in 15 years ago, that the videogames now can print more than 1 million colours, work with 3-dimension games and have a processor that is superior of the computers nowadays (the processor architecture of a common Pentium is 32 bits, and we have today videogames processors that works with 128 bits)?

And the future, what will it goes?

Probably, everything will converge in a common platform, where Sega, Nintendo, Windows, and all others will work together… And we will not wait so much time…

The Sony's Playstation 2 has Internet access, like the Windows Xbox. The next stage is a game be played for users from different consoles…

References

[1] Byrd, Barry: Computers and Animation, White Paper, http://www.iit.edu/~byrdbar/paper.html

[2] Brown, J. B., Playstation and Playstation 2 Hardware Architecture, White Paper, http://uenics.evansville.edu/~brownie/pscompare.htm

[3] Rubin, Owen R., Memories of a Vector World, ACM SysGraph, Vol 32 No. 2 May 1998 http://www.siggraph.org/publications/newsletter/v32n2/contributions/rubin.html

[4] MIPS Technologies, Silicon Graphics unveils Reality Immersion technology for Nintendo 64 at U.S. debut, Press Release, May, 15, 1996, http://www.mips.com/press-Releases/050996C.html

[5] Carnegie Mellon University, Superscalar Processing, Class Notes, September, 25-27, 2000, http://www-2.cs.cmu.edu/afs/cs.cmu.edu/academic/class/15740-f00/public/lectures/lect06-07.ppt

[6] Blah, Fabíola, Emulador dá vida aos antigos videogames, Jornal do Commercio, January, 20, 1999, http://www2.uol.com.br/JC/_1999/2401/if2001a.htm