

# ***Game Consoles Vs. personal Computers***

Design, Purpose, AND Marketability Differences

TRAVIS PAYTON

## ***Abstract***

This paper presents the differences inherent in designing game consoles versus the personal computer. It also discusses the similarities and differences between processors and system designs for the last 3 generations of game consoles as compared to their desktop counterparts of the time. It also correlates this data with the market trends to provide an idea of why engineers and developers used different approaches, and to provide a preview of what might be in store for the next generation of game consoles. With the advent of smart phones, broadband internet, social networking, and a huge growth in Indie Developers, there has been a major change in not only the video game format, but also the role Game Consoles play in the market.

## ***1. Introduction***

Thirty years ago there was a stark difference between computers and video game consoles. With the invention of the microprocessor personal computers became an affordable reality instead of science fiction, albeit a reality only pursued by hobbyists and skilled electricians.<sup>[1]</sup> In contrast, the first video game console, the *Magnavox Odyssey* released by Ralph Baer in 1972<sup>[2]</sup>, did not even have a processor. Instead it used a series of transistors and diodes and removable printed circuit boards that changed the hard-wired game logic. Unlike the computers of the era, the *Magnavox Odyssey* was affordable and could easily convert

any television set into a gaming machine. Over the next twenty years game consoles evolved from simple machines that only had an extremely small library of a few, practically identical games, into specialized computers that hundreds of developers created games for. As technology advanced, and processors and memory became more affordable, the differences between game consoles and desktop computers started to disappear. The only difference is that the game console specialized in doing one thing, and doing it extremely well, so well in fact that even a child could use it.

This paper will start with the fifth generation of video game consoles released in the mid 90's, focusing on only the major and successful consoles of each generation.

## ***2. Previous Work***

Video games have become a multi-billion dollar industry surpassing Hollywood.<sup>[3]</sup> In order to survive companies are always striving to create better games and consoles. Many studies have been done regarding the history and economics of the video game industry. There are also substantial amounts of information on the hardware specifications of each console. However there are not a lot of studies that show how these differences in hardware and innovative designs changed the market, or how the market dictated the requirements for the hardware.

Studies have shown that recent trends in how video games are consumed and produced have

changed dramatically from the norm of the last 20 years. With app stores and worldwide publication services giving independent developers access to millions of consumers, the multi-million dollar video game budgets and large development teams are starting to become an outdated business model.

### 3. Fifth Gen (1994-2001)

The age of Dos games, SoundBlaster sound cards, and Warcraft and Wing Commander. Personal computers had an ever-growing amount of video games that over-shadowed the video game consoles of the time. The stark differences in graphics, gameplay, and sound quality between the current Super Nintendo's and Sega's of the time with those of their PC counterparts was the sign that the dawn of the next generation of game consoles was soon. Enter the Sega Saturn, Sony PlayStation, and the Nintendo 64. These consoles raised the bar for game quality and provided experiences that were not possible on the PC. Not only did they re-define the market place, but they introduced new gameplay mechanics brought 32-bit and 64-bit architecture to game consoles, and made 3D graphics a standard in games.

Computers on the other hand were still expensive, required technical skill, and simply getting a new game installed and running was usually a much more arduous process than blowing on a game cartridge.

Since price is such a major factor for marketing game consoles, cost is a major factor in chip design. Processors and graphics cards are designed be able to be mass produced at an affordable price, and still turn a profit.

### 3.1 Sega Saturn (1994)



The Sega Saturn had two Hitachi SuperH-2 7604 32-bit RISC CPUs clocked at 28.63 MHz, and two

custom 32-bit video display processors (VDP) clocked at 28.63 Mhz.<sup>[4]</sup> This was the first game console with multiple processors, which proved to be difficult for developers to utilize. Only the most skilled programmers could hope to see a performance increase of only one and a half times that of using a single SH-2 chip. Another hardware design choice that also made the Sega Saturn hard to develop for was the fact that the VDP units rendered quadrilaterals instead of triangles. When used correctly it would allow for a greater amount of video memory and better graphics. But the other consoles used triangles as the basic geometric primitive, making cross-console game development difficult. Not only did the Sega Saturn have non-conventional hardware, but it did not have good SDK's or libraries available for developers to utilize the dual CPUs and dual VDPs.<sup>[5]</sup> This meant programmers had to code in assembly if

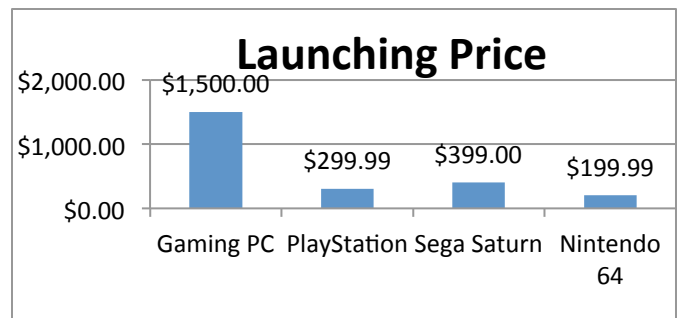
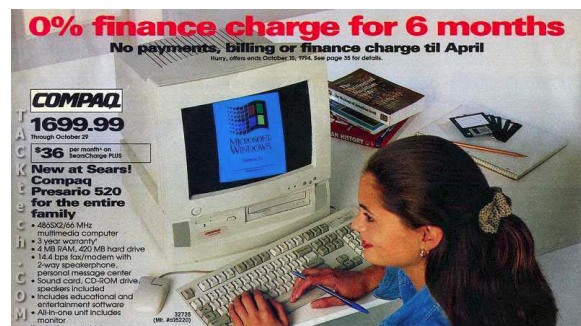


Fig 1. Left: original 1994 PC advertisement for Compaq, list price of \$1699.99. Right: Comparison of

they wanted to gain the performance benefits of dual processors.

With a custom processor for almost every function, the complex hardware made the Sega Saturn costly to produce. With the higher price tag and lack of titles due to difficult development, the console did not fair well against Sony's PlayStation.

### 3.2 Sony Playstation (1994)

The Sony PlayStation wowed the market with its capabilities when it was released in December of 1994. It was powered by a MIPS R3000A 32-bit RISC CPU clocked at 33.8688 MHz. The CPU contained a proprietary Geometry Transform Unit that was used for 3D graphics and capable of rendering 160,000 polygons per second.<sup>[6]</sup> Unlike the Sega Saturn, the hardware design of the Sony PlayStation made programming and game development a relatively easy process. It also allowed for a cheaper manufacturing process.



Due to the cheap media format, and easy development model, the PlayStation had the largest collection of games out of any of the fifth generation consoles with a library of 2,418 titles<sup>[7]</sup>. This is compared to the 387 titles for the Nintendo64, which was the second highest selling console of the generation.

With the introduction of the CD-R format, piracy started becoming a major concern for the video game industry. Pirating the previous generation cartridge-based games was practically impossible without being skilled in electronics or having specialized hardware. With the Sony PlayStation, anyone with a computer and a cd burner could make copies of games, and play them with nothing more than a little tape and some well timed disc swaps.<sup>[8]</sup>

### 3.3 Nintendo 64 (1996)



The Nintendo 64 was named after its 64-bit CPU, a NEC VR4300 clocked at 93.75 Mhz.<sup>[9]</sup> This was a cheaper version of the more powerful MIPS Technologies R4300i, but still more powerful than all of the other consoles on the market.

With the powerful tri-linear texture filtering and 128-bit data bus, the powerful 64-bit Reality Co-Processor developed by SGI made the N64 was capable of producing gorgeous 3D graphics. The system also came with 4 MB of RDRAM, expandable to 8MB with the expansion pack, making it the first console to have a unified memory subsystem.

However, despite the powerful sounding hardware, the design proved to be anything but great for developers. Nintendo helped create its biggest competition when it partnered with Sony years earlier to create the optical disc format for their Super Nintendo. However, due to licensing and media rights, Nintendo ended up scrapping the project and releasing the Super Nintendo in the familiar cartridge format. Nintendo decided to stick with this format when it released the N64 as well. This was a serious limitation as the amount of space available to developers was significantly smaller than that of a CD. This limited how many textures developers could place in a game, and the 4kb texture size hardware limitation usually meant a few small textures stretched over large polygons producing blurry textures that were even blurrier after the tri-linear filtering. Also, the development and manufacture cost of producing an N64 game was much higher due to the propriety cartridge and anti-piracy lockout chip.

Despite these limitations, the Nintendo 64 is praised by many as one of the best consoles due to the quality of games that were produced for it. The Nintendo 64 set the standard for

gameplay with the introduction of the Rumble Pak, a force-feedback controller add-on, and immersive, completely 3D games, like Mario 64.

### 3.4 Desktop CPUs and GPUs

Around the same time that the next Generation of game consoles were being release, so were the next generation of CPUs from Intel and AMD. The Intel Pentium launched in 1993, with clock speeds reaching 233 MHz by 1996. The Pentium was Intel's first super scalar processor, and had 8Kb L1 Cache, 4 GB of memory addressing, and was capable of over 100 million instructions per second. Later versions of the processor included MMX, the first SIMD instruction set. AMD's own K5 processor was also hitting the markets as a direct rival to Intel's Pentium Pro, and the later models of the K6 included both MMX and 3DNow, another SIMD x86 extension developed by AMD for vector math. By 1999 AMD had released its Athlon brand of processors, capable of reaching speeds of 1 GHz, and by 2001 their Athlon XP line of processors included SSE, another SIMD instruction set. Intel was also setting the bar with its release of the Pentium 4 in 2000, which included SSE2 and a standard clock of 1.4 GHz.

The inclusions of the deeper pipelines, larger branch prediction, and new SIMD capabilities improved the multimedia capabilities of the standard desktop processor dramatically. Space was also improving rapidly as hard drives were breaking out of the few hundred megabytes and into gigabytes.

Graphics cards were also improving greatly as they became capable of doing more than just 3D graphics. Cards like ATI's RAGE, or the NVidia GeForce 260 were released in the late 90's far surpassing any of the dedicated 3D hardware of the consoles. Also during this time OpenGL and DirectX emerged making 3D game development on the PC easier and better.

### 3.5 summary

The end of the fifth generation saw a shift from the 2D sprite based games of the previous generations to completely 3D games. The Sony PlayStation led the video game market selling 102 million units compared to the next highest 32.93 million of the Nintendo 64.

The success and popularity of the PlayStation was not only due to its excellent hardware design, but the freedom the optical disc format provided developers. The CD was so successful that it will become the medium of choice for all of the next generation consoles.

The other consoles of the time including the Neo Geo CD, and the Atari Jaguar, ultimately failed due to the lack of games.

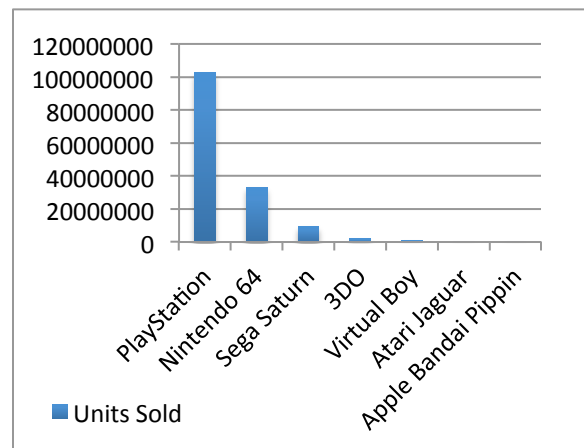


Figure 2. Graph of Console Sales during the life of the console

### 4. Sixth Gen (1998-2005)

The next generation of consoles focused almost exclusively on better graphics. Consoles were now powerful enough to have operating systems and many of them doubled as a DVD player or other multimedia machine. This was first generation of consoles that had only 4 machines.

## 4.1 SEGA DreamCast (1998)



Hoping to get a jump on the market, Sega released their next generation console far earlier than the competition. This also had a slight negative impact on their sales of the Sega Saturn as people quit purchasing the console due to rumors of its successor already in development.

The Sega Dreamcast set a new standard in graphics, far surpassing anything available on the market with its 128-bit vector graphics engine capable of 360 million instructions per second and 1.4 GFLOPS (single precision).<sup>[10]</sup> The graphics engine was on the same die as the main processor, which was a 200 MHz SH-4. The Dreamcast also had a PowerVR2 CL2X2 for dedicated graphics capable of 7 million polygons per second and tri-linear filtering. Other built-in hardware effects were gouraud shading, spatial anti-aliasing, per-pixel translucency sorting, and bump mapping.<sup>[11]</sup> This was very similar hardware to the very popular Naomi arcade cabinet, making porting of popular arcade games very simple.

The Dreamcast also brought the Internet to the console world with an integrated modem, allowing for multiplayer games. Another innovation was the concept of bringing operating systems to the console world. Sega worked with Microsoft for about 2 years to develop a customized version of Windows CE with DirectX for the console. Sega chose to implement the OS on the actual game discs so that developers could choose the OS and version; it was loaded into the console before the game could even run.

Although production of the Dreamcast was discontinued in 2002, it is still a very popular console, with many small communities still actively developing for it in 2012. This would be Sega's last home game console, as the new Chair of Sega wanted to focus on software<sup>[12]</sup>.

## 4.2 Sony PlayStation 2 (2000)



The PlayStation 2 is the best selling game console of all time, reaching 154.4 million units sold as of November 21, 2011<sup>[13]</sup>. New games continue to be developed and released for this console, with the latest being FIFA 2013 and Pro Evolution Soccer 2013 released in September 2012. Sony has stated that there are 10,828 titles for the PS2 with 1.52 billion games sold since launch<sup>[14]</sup>.

The success of the PS2 is not only on account of its expansive library of games, but also the physical capabilities of the console. It was the first console to introduce DVD-ROM formatted games, giving developers over 8 times more space than they had on conventional CD-ROM discs. The PS2 is driven by Sony's own Emotion Engine that it developed with Toshiba. The Emotion Engine is a set of 8 individual parts that are on a single die. These include a CPU core, two vector processing units (VPU), a graphics interface (GIF), a 10 channel DMA unit, a memory controller, an Image Processing Unit (IPU) and an input output interface.<sup>[15]</sup> Unlike a standard CPU, the emotion engine is built from the ground up to perform extremely well at 3D games. It was capable of clocking 6.2 GFLOPS between the FPU and two vector units, handling 150 million polygons per second, and had a pixel fill rate of 2.4 gigapixels per second.

The PS2 also came with an operating system built in capable of playing DVD's and doing system maintenance tasks such as memory card management. The PS2 was also internet capable with an Ethernet port on the back. The PS2 was also the first console to have 5.1-channel audio through a Toslink optical connection in the back, making it a complete DVD player as well as an immersive gaming experience.

The PlayStation was also the first console to be backwards compatible with its previous version. Meaning customers who owned a PlayStation

could by the new console and still play all of their favorite games on a new, better system. This would prove to be a tactic that the next generation of consoles would mimic.

### 4.3 Nintendo GameCube (2001)



Nintendo still refused to conform to the status quo by going with a custom MiniDVD form factor for its new media format. This would be Nintendo's first optical drive console; however the GameCube was unable to play DVDs or CDs like the PS2 or Xbox. The GameCube also had the ability to add network connectivity via an add-on, although only a very few games supported it.

The GameCube was an under appreciated powerhouse as far as hardware. It came with a 486 Mhz IBM PowerPC "Gekko" CPU, capable of 1.9 GFLOPS. For graphics it had a 162MHz "Flipper" LSI GPU that Nintendo co-developed with ArtX who was acquired by ATI. The GPU was capable of 8 GFLOPS, and included 4 pixel pipelines with 1 texture unit each.<sup>[16]</sup>

The main problem encountered by developers was again the limited size available due to the castrated size of the MiniDVD format the GameCube used for media.

Nintendo was still pursuing innovation as every console supported native stereoscopic graphics. However, this was never released in the mainstream as 3D televisions were not readily available to the public.<sup>[17]</sup> The strong line-up of titles for the GameCube boosted sales, however many of the older gamers complained that there were not enough mature games for the system, especially when compared to the PS2.

### 4.4 Microsoft Xbox (2001)



Microsoft decided to dive into the realm of home consoles in

November 2001 when it released the XBOX. However, Microsoft was not new to games or 3D graphics as it already had a very successful game studio as well as its own graphics API, DirectX. Four engineers from Microsoft's DirectX Team created the XBOX, and the console name was derived from the name DirectX Box.

The XBOX would be the first American video game console since the Atari Jaguar stopped sales in 1996. This would prove difficult for gaining momentum and generating sales in Japan and other Asian countries.

The XBOX was also large and bulky compared to the other consoles, being built on standard PC hardware. It featured a custom 733 MHz 32-bit Intel Pentium III Coppermine-based CPU with SSE and MMX, dual-channel 64 MB DDR SDRAM shared memory subsystem, and a 233MHz NV2A ASIC co-developed by Microsoft and NVidia for its graphics. The standard hardware setup made it easy to develop for the console.<sup>[18]</sup> Games could also be easily ported to the Windows OS on the PC, allowing Microsoft to ship more copies of its Windows Operating system.

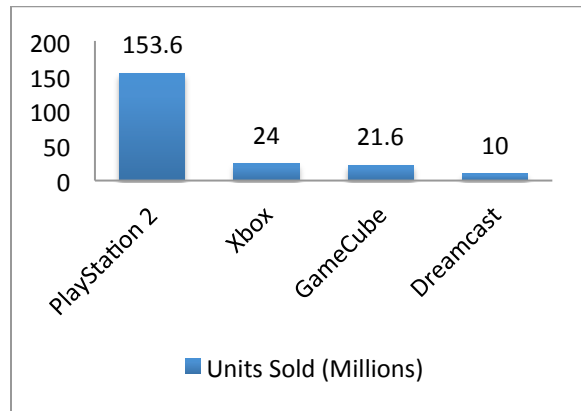
The XBOX was also the first console to have an included hard drive for saving of online content and game saves. The main difference between the XBOX and the other consoles was that the XBOX focused on online multiplayer with a subscription based Xbox live service.

### 4.5 Summary

The sixth generation of game consoles brought amazing graphics and online multiplayer. The market also started converging as major developers started adopting a cross-platform release strategy. This meant that PC gamers could also experience the same games without having to own a console.

Many of the major game companies also started merging, for example Square and Enix, Microsoft and Rare Studios, and Namco and Bandai.

Sony again was the market leader with over 153.6 million units sold. Graph correlating graphics and titles available with the number of units sold.



## 5. Seventh Gen (2005-2013)

Only three major players remain in the market for Game Consoles, and the trends of the last few years have set the stage for the next generation of consoles.

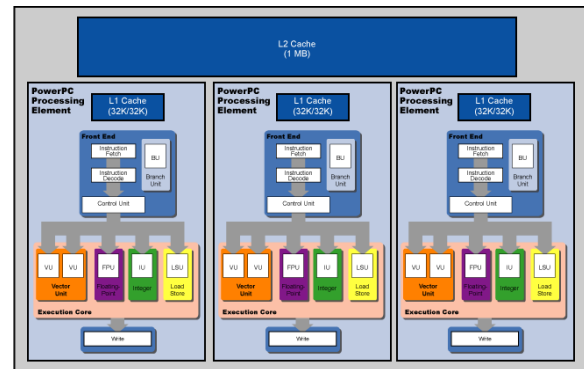
There has been a major increase in online Multiplayer Games and social networking. Technology has also advanced substantially in the field of computer graphics and parallelism.

PCI express dramatically increased the amount of data that can be transferred per second between graphics hardware, and Nvidia and ATI have introduced multi GPU computing and rendering with their SLi and Crossfire technologies. Again, the personal computer has surpassed the game console relatively quickly. Its time again for a new set of consoles, and this time a major design goal is making one that will last by creating new technologies.

## 5.1 Microsoft Xbox 360 (2005)



The Xbox 360 is powered by a XENON processor, a PowerPC IBM processor with 3 symmetrical cores clocked at 3.2 GHz. This would be the first console to have a CPU clocked in the GHz range. For SIMD it used VMX-128, with two 128x128 register files for each core, capable of doing 9.6 billion dot products per second.<sup>[19]</sup>



Architecture of the Xenon Processor

The GPU is a custom 500 MHz Xenos GPU developed by ATI capable of 240 GFLOPS, and rendering 6 billion vertices per second. The Xbox360 was the first HD capable console with native resolution of 1920x1080 pixels, it also included HDMI out, and is capable of 3D stereo graphics with select games.

Microsoft also included backwards compatibility with most Xbox games. There is also an online store where complete games and add-ons can be purchased and downloaded to the console. The hard drive is also removable for easy expansion. Other changes included wireless controllers that used Microsoft's own custom signal standard.

With the popularity of the Nintendo Wii, Microsoft released the Kinect. A 3D camera and mic array capable of tracking objects in 3D space enabling games to be played without the use of controllers. Microsoft also released the SDK for the Kinect to software developers and

made drivers available for windows allowing the accessory to be used on any windows machine.

Microsoft made developing for the console as easy as possible with a free XNA Game Studio that allows the same code to be compiled for Xbox360, Windows, and Windows Phone. This opened up development to independent developers that do not have a large budget for creating games. These games are then sold on Xbox Live, Microsoft's own online server for the Xbox360.

Microsoft also integrated social networking into the console's OS. There is integration for twitter, Facebook, and YouTube, as well as video and text chat via Microsoft's own windows live service.

## 5.2 Sony PlayStation 3 (2006)



Sony boasted the capabilities of its PS3 when it launched in 2006. Equipped with a proprietary CELL Broadband Processor, co-developed by Sony, IBM, and Toshiba. The CELL processor improved speed by offering an extremely wide and parallel instruction set. With one PPC based Power Processing Element (PPE), and eight Synergistic Processing Units, the processor is capable of a theoretical maximum of 230.4 GFLOPS.

The RSX 'Reality Synthesiser' GPU was co-developed by Sony and Nvidia, and capable of 400.4 GFLOPS and has a texel fill rate of 13.2 GigaTexels per second.<sup>[20]</sup>

This hardware made the PS3 the most powerful console, and the graphics are still setting the standard today. Sony also used another new media format, the Blu-ray Disc, capable of holding up to 128 GB of data in the triple layer discs. This also meant that the PS3 could play the now popular Blu-Ray video format.

Sony originally launched the PS3 with an onboard Emotion Engine for backwards compatibility with PlayStation and PS2 games, but discontinued that option due to cost. The OS on the console does include an online store as well as multiplayer functionality, and built in web browser.

In response to the Wii's success, Sony released the PlayStation Move add-on for the PS3 that enabled gesture based controls for the console. The Move was more precise, but less popular than the Kinect or the Wii.

In 2010, the United States Air Force Research Laboratory built a super computer out of 1,760 PS3s which was capable of over 570 TFLOPS.<sup>[21]</sup>

## 5.3 NINTENDO Wii (2006)



Nintendo took a dramatically different route compared to Sony and Microsoft with its next generation console. Instead of focusing on processing power, and taunting its graphical prowess, Nintendo focused on game play mechanics and creating a new experience.

The game changing hardware of the Wii was the infrared-camera and accelerometer equipped controllers that allowed players to interact with games by moving the controllers around in 3D space.

The novelty and availability of games to the casual gamer made the Wii the fastest selling console of all time. It currently leads the market share for current generation consoles out-selling both the xbox360 and the PS3 every month since launch.

The less powerful hardware also made the console the least expensive. It is powered by a 32-bit PowerPC-based "Broadway" CPU developed by IBM capable of 2.9 GFLOPS. The



“Hollywood” GPU developed by ATI is basically a higher clocked “Fipper” GPU from the GameCube with added modules for handling other I/O operations. The similarity in hardware between the Wii and GameCube makes backwards compatibility with the GameCube very affordable and simple. Even the GameCube controllers could be used with the Wii.

The Wii also had an OS with built in Internet connectivity and a unique social aspect achieved with personalized avatars or Miis.

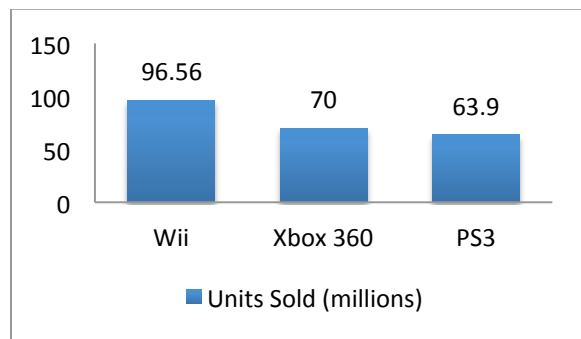
Nintendo drastically changed the video game market and proved that nothing is more powerful than originality and creativity.

## 5.6 Summary

Nintendo changed the video game market by its focus on original and novel game play. Other companies tried to follow suit by introducing add-ons to their systems that all but copied the gesture based gaming of the Wii.

Meanwhile mobile phones are becoming more and more powerful, with integrated chips such as the Tegra3, console quality graphics are now achievable on a smart phone.

The creation of Microsoft’s XNA studio, Apple App Store, Google Play, Steam, and many other outlets for independent developers to create and sell games to consumers, there is a huge increase in original content.



## 6. Conclusion

The current generation of consoles are starting to show their age. The previous generations of consoles had average release cycles of 4 years. The current consoles have been out for almost twice that and the only known next generation console is the Wii U that will be launched sometime in the 4th quarter of 2012.

The next generation of consoles will have greater computing power, but they will also need something unique about the gameplay in order for them to compete with personal computers, smart phones, and other portable devices.

Current computers are capable of running 3 monitors simultaneously in 3D with a dedicated graphics card, creating a truly immersive experience. Social games have become incredibly popular with simple web-based games generating large revenue for companies. This universal increase in bandwidth not only allows for greater experiences on-line, but also allows for playing games in real-time via a streaming connection to a cloud computer gaming service. Services like OnLive allow users to play the most demanding games on any hardware that can connect to their servers where the software is actually ran.

Console sales are beginning to stagnate, meaning that in order to continue making money from selling consoles, the companies need to release a new generation.

The architecture of the video game consoles is very specific, focusing on only a few tasks. This allows for less expensive hardware and incredible performance in the specific areas. Regular desktop architecture is focused more on general computing, and needs to be able to handle anything quickly.

## References

1. See the first computers manufactured or sold as kits for the Intel 8080 microprocessor. Altair 8800, or the SOL-20.
2. "[Article: Ralph Baer: Recovering the History of the Video Game :: Smithsonian Lemelson Center](#)". Invention.smithsonian.org. 1966-09-01. Retrieved 10 October 2012.
3. [Factbox: A look at the \\$65 billion video games industry](#)". Reuters. 6 June 2011. Retrieved 11 October 2012.
4. Saturn Overview Manual (temporary version 1), SEGA, June 6, 1994. Doc #ST-103-R1-040194. Retrieved from <http://koti.kapsi.fi/~antime/sega/docs.html> 11 October 2012.
5. Sega Saturn." [Next Generation](#) magazine, February 1995: 43.
6. [PlayStation \(console\) Wikipedia article](#) retrieved 11 October 2012.
7. List of Official PlayStation games, retrieved from [http://en.wikipedia.org/wiki/List\\_of\\_PlayStation\\_games](http://en.wikipedia.org/wiki/List_of_PlayStation_games)
8. As demonstrated by youtube user Timothy Westwood in PSX – Disc Swap Trick Tutorial <http://youtu.be/IW3cFEOLNWA>
9. [Nintendo 64 Hardware Specifications](#), retrieved October 23, 2012
10. [Dreamcast Technical Pages](#), Hardware Specs, retrieved October 23, 2012
11. [Dreamcast Hardware](#), retrieved October 23, 2012
12. Krell, Bobby. "[Q&A: Former Sega president on Dreamcast's failure, pranks](#)
13. [PLAYSTATION2 sales reach 150 million units worldwide](#)". Sony Computer Entertainment. February 14, 2011. Retrieved October 23, 2012.
14. Makuch, Eddie (February 15, 2011). "[150 million PS2 units shipped worldwide – News at GameSpot](#)". Asia.gamespot.com. Retrieved October 23, 2012.
15. Jon Stokes, Sound and Vision: A Technical Overview of the Emotion, Feb 16, 200. Retrieved from <http://arstechnica.com/gadgets/2000/02/ee/> October 23, 2012
16. Nintendo GameCube Technical Specs retrieved from [http://en.wikipedia.org/wiki/Nintendo\\_GameCube](http://en.wikipedia.org/wiki/Nintendo_GameCube) October 23, 2012
17. [Iwata Asks: Nintendo 3DS](#)". p. 3. Retrieved 2011-01-11. "Iwata: To go back a little further, the Nintendo GameCube system actually had 3D-compatible circuitry built in [...] Itoi: Nintendo GameCube did? And all the Nintendo GameCube systems around the world? Iwata: Yeah. If you fit it with a certain accessory, it could display 3D images."
18. [Anandtech Microsoft's Xbox](#)". Anandtech.com. Retrieved October 23, 2012.
19. Jon Stokes, Inside the Xbox 360 II: The Xenon CPU, June 1, 2005. Retrieved from <http://arstechnica.com/features/2005/06/xbox360-2/4/> on October 23, 2012.
20. J. A. Kahle, M. N. Day, H. P. Hofstee, C. R. Johns, T. R. Maeurer, D. Shippy, Introduction to the Cell multiprocessor, IBM J. RES. & DEV. VOL. 49 NO. 4/5 JULY/SEPTEMBER 2005, retrieved from <http://users.ece.utexas.edu/~adnan/grad-vlsi-05/cell-ibm-journal.pdf> on October 23, 2012
21. [AFRL to hold ribbon cutting for Condor supercomputer](#)". [www.wpafb.af.mil](http://www.wpafb.af.mil). The Official Web Site of Wright-Patterson Air Force Base. 17 November 2010, updated 29 November 2010. Retrieved October 23, 2012.