Game Console Performance Analysis

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ABSTRACT
In this paper, I contrast the hardware and architectures of three major video game consoles in order to find out which console will best play games in each of three different video game genres.

Categories and Subject Descriptors
B.0 [**Hardware**]: General – *general hardware.*

General Terms
Documentation, Performance, Design.

Keywords
Hardware, Architecture, Game Genre, Xbox, Playstation 2, Gamecube, Role-Playing Game, First-Person Shooter, Sports Game.

1. INTRODUCTION
Game consoles are computers that are specifically designed for playing games. Three of the most popular game consoles currently on the market are Microsoft's Xbox, Sony's Playstation 2, and Nintendo's Gamecube. These consoles have specific software, hardware, and architectures that are designed for running all different types of games on them. Some of the game genres are role-playing games, first-person shooters, and sports games. Each game console has at least some games in each of these genres. So, which one of the game consoles is the best for playing games in each game genre? In this paper, the hardware and architectures of the three game consoles will be examined. Also, the hardware needs of each game genre will be discussed. Then, a comparison will be made between each console for each game genre.

2. GAME CONSOLE ARCHITECTURES
2.1 Microsoft Xbox
The first part of the comparison between game consoles will look at the hardware (CPU, memory, I/O, and graphics processing unit) and architecture (the specific organization of the hardware) inside each console. The first game console to be examined is Microsoft's Xbox. It has a lot of powerful hardware inside of it. The Xbox's CPU is a 32-bit 733MHz Pentium III. Its memory consists of 64 MB DDR SDRAM, a 128KB cache, and an 8GB hard drive. Its L2 cache is a 128 KB 8-way set associative cache. Also, it has a 16 KB L1 instruction cache and 16 KB L1 data cache. For its I/O, the Xbox has one audio/video connector, four game controllers, and one network connector. The Xbox's graphics processing unit (GPU) is the XGPU which is a 256-bit 233MHz graphics processor.

The Xbox has a strong architecture which enables its hardware to run as fast as it can to produce great looking graphics. Its Unified Memory Architecture (UMA) enables the CPU and GPU to share the same memory. UMA is used in the other consoles as well, but since the Xbox has such a fast bus clock cycle, it gives the Xbox a large amount of bandwidth. A console using a UMA is cheaper to build, but costs lower performance in some situations [1]. When the CPU and GPU access the memory at the same time, performance can be slower. This is due to RAW and WAR dependencies as well as both units trying to access the memory at the same time. By using a UMA, consoles can be made for a cheaper price so that they are more affordable to the public.

The Xbox, unlike the other two consoles, comes with 8 GB of hard drive space. Unfortunately, access times for the hard drive are extremely slow. For example, in the "Car Select" screen of the game Project Gotham Racing, models of the player's car are shown on the screen; however, these models take about two seconds to change when the player selects a different car [3]. These models could have been cached for faster access or been dealt with in some other more appropriate fashion.

As mentioned before, the Xbox's buses run at fast speed. Its memory chips run at 200 MHz each which gives it a combined memory bandwidth of 6.4 GB/s for the CPU and GPU. The CPU is limited by the speed of the front side bus (FSB) to roughly one-sixth of that total bandwidth. The rest of the system can use the remaining bandwidth for its own various uses, giving the rest of the system much more bandwidth to use than the other two entire game consoles.

Since the CPU is the central processing unit of the console, one would think that limiting its bandwidth would be a bad idea. That is not true though, since the load of the CPU can

be decreased by adding other functional units. One example of this is that the Xbox's transformation and lighting calculations are done by a deep pipeline. In the past, these calculations were done by the CPU, but the new organization used in the Xbox decreases the load on the CPU, allowing it to be the boss of other units instead of being the main processing unit.

2.2 Sony Playstation 2

The second game console to be analyzed is Sony's Playstation 2 (PS2). It has a lot of different hardware than the other consoles and it gets its processing power through a drastically different architecture. The 128-bit 295 MHz Emotion Engine (EE) is the PS2's CPU. Sony's console has less memory, though. It has 32 MB RDRAM and a 40KB cache. Its L1 cache is also a split cache consisting of a 16 KB instruction cache and a 32 KB data cache. For its I/O, it has two game controllers, two USB connections, one network connection, and one composite audio and video connection. The PS2 uses a 128-bit 137 MHz GPU with 4 MB of embedded DRAM, named the Graphics Synthesizer (GS) to do its graphics processing.

The PS2 follows a very different architecture than the one the Xbox uses. The PS2's Emotion Engine features a 128-bit MIPS processor. Also, it has 128-bit registers. In addition, the PS2 has two 64-bit integer units. An advantage of using the MIPS ISA level is that less decoding is necessary in order to simplify instructions to Reduced Instruction Set Computer (RISC) instructions [3]. Although its registers are large, the PS2 still does not have enough cache memory. This is one reason why only lower resolution textures can be used for game models.

One main feature of the PS2 is its two Vector Units. These units are extra floating point units. They help with the transform and lighting calculations that are so often needed for many 3d games. The Vector Units were not implemented in the best possible way, though [3]. Since the Vector Units are where the PS2 gets a lot of its power, it is left lacking some processing power that it very easily could have had.

The Graphics Synthesizer (GS) is a 16-pipeline processor for rendering 3d images. In order to keep the pipelines full to take full advantage of the pipelines, instructions need to be issued as fast as possible to the GS and fast access to data needs to be granted to it. For that reason, there are 4 MB of DRAM that are embedded in the GS for storing render information. Also, a fast 32 MB RAMBUS gives the EE and GS a combined bandwidth of 3.2 GB/s. This is a lot less than the Xbox, which is another reason why only lower resolution textures can be used with the PS2.

One of the PS2's greatest features is its I/O processor which gives it backward compatibility with the old Playstation architecture. That allows PS2 owners to play all of the original Playstation games for the PS2. In some cases, the old PS games will even run with better graphics; although, with most games, they are too old and were written too long ago to take advantage of the new technologies in the PS2.

2.3 Nintendo Gamecube

The third and final game console to be looked at is Nintendo's Gamecube. It has some unique hardware coupled with a different purpose behind the creation of its architecture. The Gamecube's CPU is a 64-bit 485 MHz IBM processor named Gekko. The Gamecube also comes with a large amount of memory. It has 24 KB of RAM and a 256 KB cache. Its I/O consists of four game controllers, two serial ports, one parallel port, and a digital audio/video connection. The Gamecube's GPU is a 64-bit 162 MHz ATI graphics processor named Flipper.

As previously mentioned, Nintendo had a different purpose behind its architecture than Microsoft and Sony had for their respective consoles. Starting off by looking at its CPU, the theory behind Gekko's creation was not to create it as a processing powerhouse [4]. Gekko gives off a lot less heat than Xbox. Gamecube is less powerful than the other two consoles, but it is a lot more efficient. Also, since the Gamecube uses less die in its chips, it is able to be sold for less than the other two consoles.

Even though the Gamecube is not a powerhouse, Gekko and Flipper do have a lot of memory available to them. Gekko contains an abundance of 32-bit and 64-bit registers. Gekko has 32 general purpose registers, as opposed to Xbox's 8 registers. Its registers are for integers, floating point numbers, and general purpose uses. Another of Gekko's features is that it has a relatively short pipeline. It can keep the pipelines full with its short clock cycle so that there will not be a bottleneck in the CPU. Its performance is limited by the short pipeline and its short clock cycle, but it is still quite efficient.

One of the Gamecube's major advantages is its memory. The Gamecube uses 1T-SRAM which is like SRAM but made from one transistor. This memory is more expensive, but more efficient in that one transistor does the work of six transistors. One might notice that the Gamecube only has a 24 KB main memory, but that is all it needs because the calculations on the current graphics frame are done in embedded RAM in Flipper. This memory plus a fast bus gives the Gamecube a bandwidth of 2.4 GB/s between Gekko and Flipper. This amount is lower than the other two consoles, but less is needed since the workload is distributed among each processing unit [4].

3. VIDEO GAME GENRES

3.1 Role-Playing Games

Three different genres of console games and some of their hardware needs will be described next. The first game

genre that will be discussed is the role playing game (RPG). An RPG involves a user making decisions which control how a group of one to four characters in a party act in order to accomplish a mission. "Gameplay is usually very linear, with new areas of the world map opened as you complete quests. Vehicles play a big part in this, since some areas will only be accessible with special vehicles. Later games often have pseudo-non-linearity in the second half, where you have opened up the whole map and have a couple of quests that can be finished in any order" [2]. Characters in RPG's are static, but have many attributes that can change as the game progresses. A few examples of RPG's are Fable, Final Fantasy, and Star Wars: Knights of the Old Republic.

The characteristics of an RPG give the user many different paths for them to achieve their goal. In addition, a lot of RPG's have multiple possible endings. A lot of processing power and memory are needed to run an RPG and execute the code for the path the user decides to take. Predicting branches in the gameplay would be useful. For example, if there is a fork in the road and the user needs to choose one way to go, it would be ideal for the console to have a way to predict which path the user will take.

Also, most RPG's are games in which the models for the characters do not change much, so a lot of cache memory would be useful for displaying the characters that are on the screen most of the time. Some RPG's are in 3d (first person or third person) while some are only 2d. Depending on how many dimensions are used in the certain RPG, a powerful GPU would be useful for rendering the characters that are almost always on the screen, too. The attributes of an RPG's characters are often determined by statistics. A console that could crunch a lot of numbers very fast would help to quickly calculate the attributes of the characters. In an RPG, the attributes of the character often decide what happens next for the character, so a lot of conditional and branch statements are executed.

3.2 First-Person Shooter Games

The second game genre to be described is the first-person shooter (FPS). An FPS gives a user a first person view of a 3d world. Games in this genre are meant to be fast-paced and exciting. The games often have many special effects, graphics, and 3d models. These games have realistic physics for shooting bullets and moving objects around in the game's world. Some examples of games in this genre are Half-Life 2, Doom III, and Halo 2.

The fast-paced, action-filled characteristics of an FPS often require a lot of fast processing power and memory from a game console. The user is constantly in a 3d world; therefore, a fast graphics processor that can transmit a lot of data is needed. A separate graphics processor from the main CPU allows the console to do many of the calculations to create the world and display it to the user. Additional video memory can be used to store graphics and player models so that the main memory does not get tied up. FPS games also require realistic, precise calculations for the physics within the game's world. A large amount of mathematical checks need to be performed to see if any players in the game were hit by bullets and to make sure that no players are able to walk through walls. A lot of physics need to be calculated for the movements of the individual players and any other objects in the world that can be moved. The nature of FPS games requires a fast processor in order to calculate the translations, rotations, and perspective of the 3d world to create a first person perspective.

3.3 Sports Games

The third and final game genre to be described is the sports game. Sports console games let a user control a sports team in a practice session, single game, or even a whole season. Sports games have a lot of saved models, statistics, graphics, and other data. Player and team data are crucial to the gameplay. The player models are used for every player on the team, but with different features in order to simulate different people. In more recent versions of sports games, players in the games have begun to look increasingly more realistic and more similar to the athletes that they were meant to represent. Also, newer versions of the games have increasingly more realistic gameplay such as improved AI. Sports games include football, baseball, basketball, hockey, tennis, golf, and more. Examples of some games in the sports genre are Madden NFL 2006, MLB Slugfest 2004, and NBA Live 2006.

4. GAME GENRES ON GAME CONSOLES

4.1 Microsoft Xbox

4.1.1 Role-Playing Games

Finally, how well each game genre runs on each game console will be discussed. RPG's are well suited for Microsoft's Xbox. A major benefit of the Xbox relating to an RPG is the 8-way set-associative cache. Since so many branches are taken in RPG's, it is necessary to store common data that come from possibly large differences in offsets in memory. An 8-way set-associative cache would allow eight cache entries with the same tag field to be in one cache line. Since the Xbox has so much speed in its CPU and buses, the time needed to check the cache for a hit or miss among eight entries would pose no significant delays.

The other advantage to running RPG's on an Xbox involves the Unified Memory Architecture (UMA). Since the CPU and GPU share the same memory, the CPU can execute the RPG's conditional statements quickly and then have the GPU take control of the data to render the correct scene in the game based upon the outcome of the test. A UMA is a good choice for an RPG since the data the CPU processes

will be closely linked to which graphics need to appear on the screen.

4.1.2 First-Person Shooter Games

An FPS is very well-suited for the Xbox. Support for Dolby Digital 5.1 Surround Sound helps the Xbox to give a great first person experience. Console games involve 3d graphics, but the sounds within games are important, too. Support for the surround sound, which the other two consoles do not offer, puts the Xbox above the rest of the competition in the sound category.

In addition, the Xbox has a fast CPU and GPU as well as double the amount of bandwidth of the other two consoles. The large amount of bandwidth allows the Xbox to use a decentralized architecture since it can quickly transfer large amounts of data between components. The registers may only be 64 bits, but the fast CPU can process the data in the registers twice as fast, therefore producing a large amount of throughput.

4.1.3 Sports Games

Sports games are well-suited for the Xbox, too. The Xbox has a strong CPU that is good for more than just graphics calculations. Sports games require a lot of AI in order to determine the computer team's next positions and the positions for the rest of the players on the user's team. Sports games usually require the teamwork of a group of individuals, and since the user can only control one person at a time, the console will need algorithms to determine the next positions for the rest of the players.

Also, the Xbox's ability to use high resolution textures is an advantage of using this console for a sports game. In order to make the players on the sports team look as realistic as possible, crisp, high resolution textures need to be mapped to the player models. Running the sports game in a high resolution will also create a quality picture. Since the Xbox has so much bandwidth, the Xbox can run its games in some nice looking resolutions. The Xbox is also the only console that has High Definition TV support for its games. The HDTV support makes its game's graphics look even clearer.

4.2 Sony Playstation 2

4.2.1 Role-Playing Games

The PS2 is somewhat well-suited for RPG's. RPG's are less about graphics and more focused on the strategy and gameplay. The lack of nice looking graphics is less accentuated in RPG's. There is a lot of branching in an RPG based on the attributes of the player's character. The PS2 architecture uses a slower clock speed for the CPU; therefore, it can operate on fewer instructions per cycle and pay a smaller price for an incorrectly predicted branch in an RPG.

Since the flow of an RPG often comes from the values of the attributes of the character, it is important that the console can transfer data easily from one unit to the other. The scratchpad RAM that connects some units in the PS2 is an ideal spot for holding data to do a quick calculation on it before passing it on to the next unit. Also, the PS2 uses many 128-bit buses to directly send data between important units so that the console is not slowed down by the front bus speed.

4.2.2 First-Person Shooter Games

The FPS is not well-suited for the PS2; however, the power of the PS2's two Vector Units is well used for FPS games. In order to generate the first person view, many floating point and vector calculations need to be performed. Having two units work specifically on the floating point operations allows the other units to do their jobs better. The CPU can calculate physics, check for collisions of objects in the 3d world, and determine the enemy's new position while the Graphics Synthesizer renders the graphics image.

Unfortunately, even with the Vector Units, the PS2 is still lacking power in its architecture. The PS2 is lacking cache memory, a hard drive, bandwidth, CPU speed, and main memory. The PS2 does not have enough power to generate outstanding, high resolution 3d graphics that simulate a first person situation well.

4.2.3 Sports Games

Sports games are very well-suited for the PS2. The PS2's backward compatibility is the key to making it the best for sports games. Sports games are often created every year with updated team rosters, new team statistics, and updated graphics. Since the PS2's architecture is backward compatible with the old Playstation, it will have twice the available number of games than the other two consoles. The PS2 will have great graphics for newer versions of sports games and great gameplay for older versions of sports games.

Although the PS2 does not have the large bandwidth to support high resolution textures, it can still produce some nice 3d graphics. The large graphics pipeline architecture of the Graphics Synthesizer (GS) is ideal for sports games. The GS can do operations such as loading the models, loading the textures, mapping the textures to the models, generating the 3d environment, and mapping the textures to the environment in a quick, assembly line fashion. The deep pipeline of the GS has a small amount of latency at the beginning, but once the pipeline is full, it can operate very fast to generate a large amount of throughput.

4.3 Nintendo Gamecube

4.3.1 Role-Playing Games

The RPG is very well-suited for the Gamecube. Nintendo has been making RPG's since the company began work on Mario for its Nintendo Entertainment System. The reason for Nintendo's success at the RPG is its efficiency. Even though most of its hardware specifications are lower than

that of the other two consoles, the Gamecube gets the most out of its hardware while the other consoles might get hung up in one unit. Since the slow main memory access is often the source of a hang-ups in the system, the Gamecube comes with fast 1T-SRAM and plenty of other local memory. The fast access to the data allows the Gamecube to run smoothly and keep the slower-running CPU instruction queue full.

4.3.2 First-Person Shooter Games

The FPS is not well-suited for the Gamecube. Although the Gamecube is efficient, an FPS needs a console that has a lot of power. The Gamecube was designed for efficiency, a target size and shape, a lower budget, and a target audience of people who enjoyed games such as Super Mario. If the Gamecube were meant to excel at running FPS games, a stronger CPU and faster buses would have been added to it.

The one thing that the Gamecube does have in its favor is high resolution texture support. Even with its lack of bandwidth, the Gamecube is able to create crisp, clean, high resolution graphics. Its work is distributed among many slow units working as hard as they can.

4.3.3 Sports Games

The Gamecube is well-suited for sports games. The Gamecube does not have as much bandwidth as the other two consoles, but it has enough to allow it to use high resolution textures. As mentioned before, the calculations done on the current frame are done in Flipper's embedded RAM, so its lack of bandwidth is deceiving. The bandwidth is used on the rest of the frames to give the user realistic-looking players with high resolution textures. It may not be as powerful, but the processing power that the Gamecube has is used efficiently.

One advantage to using the Gamecube for sports games is that it can be easily programmed for. Many people have said that the Gamecube is easier to program for than the other two consoles [5]. Since newer versions of sports games come out every year, a console is needed that has a simple enough architecture that it can be easily programmed for, yet still produce great-looking graphics.

5. CONCLUSIONS

The hardware and architectures of each game console have been analyzed, and the hardware requirements of each game genre have been described. In conclusion, the Gamecube is the best console for a role-playing game, the Xbox is the best console for a first-person shooter, and the Playstation 2 is the best console to play a sports game. Each of the game consoles were more specialized than a computer by the fact that they were fine-tuned to play video games, but in the end, it turns out that each console is more specialized than the others because its design produced the best result for a certain genre of games.

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