Xbox 360 Hardware: Overview

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Xbox 360 is the successor to the Xbox game console from Microsoft. Xbox 360 launched in the fall of 2005. This white paper provides a brief overview of the primary hardware features of the console from a game developer's standpoint.

Basic Hardware Specifications

Xbox 360 is powered by a 3.2 GHz IBM PowerPC processor and a 500 MHz ATI graphics processor. Xbox 360 has 512 MB of unified memory. Xbox 360 runs a custom operating system based on Microsoft Windows NT, similar to the Xbox operating system. The graphics interface is a superset of Microsoft Direct3D version 9.0.

CPU

The Xbox 360 CPU is a custom processor based on PowerPC technology. The CPU includes three independent processors (cores) on a single die. Each core runs at 3.2 GHz. The Xbox 360 CPU can issue two instructions per clock cycle per core. At peak performance, Xbox 360 can issue 19.2 billion instructions per second.

The Xbox 360 CPU was customized by IBM specifically for Xbox 360, leading to a number of revolutionary additions, including a dot product instruction for extremely fast vector math and custom security features built directly into the silicon to prevent piracy and hacking.

Each core has two symmetric hardware threads (SMT), for a total of six hardware threads available to games. Not only does the Xbox 360 CPU include the standard set of PowerPC integer and floating-point registers (one set per hardware thread), the Xbox 360 CPU also includes 128 vector (VMX) registers per hardware thread. This astounding number of registers can drastically improve the speed of common mathematical operations.

Each of the three cores includes a 32-KB L1 instruction cache and a 32-KB L1 data cache. The three cores share a 1-MB L2 cache. The L2 cache can be locked down in segments to improve performance. The L2 cache also has the very unusual feature of being directly readable from the GPU, which allows the GPU to consume geometry and texture data from L2 and main memory simultaneously.

Xbox 360 CPU instructions are exposed to games through compiler intrinsics, allowing developers to access the power of the chip by using C/C++ language notation.

GPU

The Xbox 360 GPU is a custom 500 MHz graphics processor from ATI. The shader core has 48 Arithmetic Logic Units (ALUs) that can execute 64 simultaneous threads on groups of 64 vertices or pixels. ALUs are automatically and dynamically assigned to either pixel or vertex processing depending on load. The ALUs can each perform one vector and one scalar operation per clock cycle, for a total of 96 shader operations per clock cycle. Texture loads can be done in parallel to ALU operations. At peak performance, the GPU can issue 48 billion shader operations per second.

The GPU has a peak pixel fill rate of 4 gigapixels/sec (16 gigasamples/sec with 4× antialiasing). The peak vertex rate is 500 million vertices/sec. The peak triangle rate is 500 million triangles/sec. The interesting point about all of these values is that they're not just theoretical—they are attainable with nontrivial shaders.

Xbox 360 is designed for high-definition output. The GPU includes 10 MB of fast embedded dynamic RAM (EDRAM). A 720p frame buffer fits very nicely here. Larger frame buffers are also possible because of hardware-accelerated predicated tiling that has little cost other than additional vertex processing. Along with the extremely fast EDRAM, the GPU also includes hardware instructions for alpha blending, z-test, and antialiasing.

The Xbox 360 graphics architecture is a unique design that implements a superset of Direct3D version 9.0. It includes a number of important extensions, including additional compressed texture formats and a flexible tessellation engine. Xbox 360 not only supports high-level shading language (HLSL) model 3.0 for vertex and pixel shaders but also includes advanced shader features well beyond model 3.0. For instance, shaders use 32-bit IEEE floating-point math throughout. Vertex shaders can fetch from textures, and pixel shaders can fetch from vertex streams. Xbox 360 shaders also have the unique ability to directly access main memory, allowing techniques that have never before been possible. Like Xbox, Xbox 360 supports precompiled command buffers (known as "push buffers" on Xbox), but to a much greater extent than the Xbox console does.

In addition to an extremely powerful GPU, Xbox 360 also includes a very high-quality resize filter. This filter allows consumers to choose whatever output mode they desire, up to and including 1080p high-definition output. Xbox 360 automatically scales the game's output buffer to the consumer-chosen resolution.

Memory and Bandwidth

Xbox 360 has 512 MB of unified memory, equally accessible to both the GPU and CPU. The main memory controller resides on the GPU (the same as in the Xbox architecture). It has 22.4 GB/sec aggregate bandwidth to RAM, distributed between reads and writes. Aggregate means that the bandwidth may be used for all reading or all writing or any combination of the two.

The front side bus (FSB) bandwidth peak is 10.8 GB/sec for reads and 10.8 GB/sec for writes, over 20 times faster than for Xbox. Note that the 22.4 GB/sec main memory bandwidth is shared between the CPU and GPU. If, for example, the CPU is using 2 GB/sec for reading and 1 GB/sec for writing on the FSB, the GPU has 19.4 GB/sec available for accessing RAM.

Eight pixels (where each pixel is color plus z = 8 bytes/pixel) can be sent to the EDRAM every GPU clock cycle, for an EDRAM write bandwidth of 32 GB/sec. Each of these pixels can be expanded through multisampling to 4 samples, for up to 32 multisampled pixel samples per clock cycle. With alpha blending, z-test, and z-write enabled, this is equivalent to having 256 GB/sec of effective bandwidth! The important thing is that frame buffer bandwidth will never slow down the Xbox 360 GPU.

Audio

The Xbox 360 CPU is a superb processor for audio, particularly with its massive mathematical horsepower and vector register set. The Xbox 360 CPU can process and encode hundreds of audio channels with sophisticated per-voice and global effects, all while using a fraction of the power of a single CPU core.

The Xbox 360 system south bridge also contains a key hardware component for audio—XMA decompression. XMA is the native Xbox 360 compressed audio format, based on the WMA Pro architecture. XMA provides sound quality higher than ADPCM at even better compression ratios, typically 6:1–12:1. The south bridge contains a full silicon implementation of the XMA decompression algorithm, including support for multichannel XMA sources. XMA is processed by the south bridge into standard PCM format in RAM. All other sound processing (sample rate conversion, filtering, effects, mixing, and multispeaker encoding) happens on the Xbox 360 CPU.

The lowest-level Xbox 360 audio software layer is XAudio, a new API designed for optimal digital signal processing. The Xbox Audio Creation Tool (XACT) API from Xbox and Windows is also supported, along with new features such as conditional events, improved parameter control, and a more flexible 3D audio model.

Input/Output

As with Xbox, Xbox 360 is designed to be a multiplayer console. It has built-in networking support, including an Ethernet 10/100-BaseT port. It supports up to four controllers. Controllers can be wired or wireless; there are two controller ports on the console. From an audio/video standpoint, Xbox 360 supports all the same formats as Xbox, including multiple high-definition formats up through 1080p, plus VGA output.

Storage

The Xbox 360 console is designed around a larger world view of storage than Xbox was. Games have access to a variety of storage devices, including connected devices (memory units, USB storage) and remote devices (networked computers, Xbox Live). Xbox 360 supports an attached hard drive, which is widely available as an integrated add-on component. The hard drive has a minimum sustained data rate of 17 MB/s, with an average seek time of 13 ms. As on Xbox, the hard drive supports multiple cache partitions. Each cache partition is 2 GB. The remainder of the hard drive is available for saved games, downloaded content, and so forth.

Xbox 360 supports up to two attached memory units (MUs). MUs are connected directly to the console, not to controllers as on Xbox. The initial size of the MUs is 64 MB, although

larger MUs will be available in the future. MU throughput is 8 MB/sec for reads and 2.5 MB/sec for writes.

The Xbox 360 game disc drive is a 12× DVD, with an available outer edge throughput of 15 MB/sec. Average seek time is 115 ms. The media format is similar to the Xbox media format, with approximately 7 GB of usable space on the disc, with media being stored on a single side in two layers. The maximum size for a single file on the game disc is 3.4 GB. The Xbox 360 development kit includes accurate DVD emulation technology. This allows developers to gauge the effects of the retail console disc drive very precisely.

Controller

The standard Xbox 360 controller is similar to the Xbox controller S. The primary changes are the removal of the **Black** and **White** buttons and the addition of shoulder buttons. The triggers, sticks, D-pad, and primary buttons are essentially unchanged. The controller supports vibration.

Xbox 360 Development Kit

The Xbox 360 development environment follows the same model as for Xbox. Game development occurs on the development computer. The resulting executable image is loaded by the Xbox 360 development kit and remotely debugged on the development computer. Microsoft Visual Studio is the development environment for Xbox 360.

In addition to the regular Xbox 360 development kit, there is another, known as the *Xbox 360-GB development kit*. This development kit has a second bank of memory, 512 MB, in addition to the 512-MB bank of the regular development kit. Development tools can determine whether the console on which they run is an XDK-GB console and make use of its additional RAM, which can reduce or remove the overhead cost of running the tools from analyses of a title's performance.

The Xbox 360 compiler uses a custom PowerPC back end and the latest Microsoft Visual C++ front end. The back end uses technology developed at Microsoft for Windows NT on PowerPC. The Xbox 360 software group includes a dedicated team of compiler engineers, who have updated the compiler to support Xbox 360-specific CPU extensions and optimizations.

Performance Investigator for Xbox (PIX) is also available for Xbox 360 development. It allows developers to fine-tune the performance of every aspect of their title, from graphics to CPU to audio.

Summary

The Xbox 360 console has been fine-tuned at every level to give game developers powerful hardware that can be effectively tapped by using industry-standard tools such as Visual C++ and PIX. Xbox 360 has much different hardware architecture than the original Xbox, but programming and utilizing its full capabilities remain just as easy.