2001: A Graphics Odyssey

Games Get the Spotlight, But PCs See More Progress

By Peter N. Glaskowsky {1/28/02-03}

Video games dominated media coverage of graphics technology in 2001. Sony's PlayStation 2 had its first full year of sales, and both Microsoft and Nintendo shipped their own consoles in time for the critical Christmas season. The new machines did as well as could be expected in a weak U.S. economy, but PS2 systems and games did even better.

Consoles don't seem to be much of a threat to the PC, however, despite predictions to that effect by Sony and other companies. In fact, technology developed for video games is now making PCs faster. For example, Nvidia's integrated-graphics chip set, designed for Microsoft's Xbox, formed the basis of its nForce Athlon chip set. Similarly, ATI is migrating elements of the ArtX 3D core in the Nintendo GameCube Flipper graphics chip into its own PC products.

To help resolve this controversy, we at *Microprocessor Report* have decided to give an Analysts' Choice Award for Best Gaming Chip Set of 2001. Console systems are represented by three nominees: Microsoft's Xbox, with Intel's Pentium III and Nvidia's XGPU/MCPX chip set; Nintendo's GameCube, with IBM's PPC405-based Gekko processor and the ATI/Nintendo Flipper system controller; and Sony's PlayStation 2 with Sony's own Emotion Engine processor and Graphics Synthesizer chip. We also considered the PC chip set most highly regarded by gamers: AMD's Athlon XP 2000+ processor, VIA's Apollo KT266A core-logic chip set, and Nvidia's GeForce3 graphics accelerator. (The Athlon XP 2000+ processor was available in sample quantities during 2001, although it was not announced until the first week of 2002.)

Microsoft Raises Bar for Console Gaming

The introduction of Microsoft's Xbox in November set a new standard for video-game console features, quality, and performance. Xbox was the first console to ship with an internal hard disk as standard equipment, and its unified-memory system architecture gave the system capabilities unmatched by the competition, such as full-time antialiased graphics and support for high-definition video output.

Most Xbox games match the visual quality of the best PlayStation 2 titles. Where the same title is available on both platforms, such as SSX Tricky from Electronic Arts, Xbox produces distinctly superior graphics. There are excellent games on both platforms, of course; hardware considerations are still secondary to the effort applied by game developers. Xbox offers two key advantages over PlayStation 2 for game developers: a simpler, yet more powerful, programming model and significant compatibility with the Microsoft Windows platform.

The Xbox programming model is already familiar to most PC software developers. It is conceptually simple: high-level application code runs on Xbox's 733MHz Pentium III–based custom processor, while low-level audio and 3D functions are handled by dedicated silicon. Table 1 shows the basic specifications of Xbox, along with those of GameCube and PlayStation 2. Published reports claim the Xbox CPU has just 128K of L2 cache, making it more like a Celeron product, but full details of the chip's configuration have not been officially released.

Microsoft and Nvidia codeveloped the Xbox graphics processing unit (XGPU), which acts as a memory controller, PCI bridge, and graphics accelerator. The XGPU is connected by a HyperTransport link to the Media/Communications Processor for Xbox (MCPX), designed by Nvidia and including a pair of high-performance MediaStream DSPs sourced from Parthus Technologies.

Microsoft, of course, provided the Xbox system software and software-development platform. Xbox is designed to run a customized version of the kernel from Windows 2000, but, in principle, any OS could be used; we expect Microsoft will eventually move developers to a Windows XP–derived kernel. Device drivers support the OS kernel and application programming interfaces (APIs) derived from those used in Windows 2000, most notably the DirectX multimedia API set. Game developers can share the majority of the code used for an Xbox game with a Windows game, and vice versa, because of this software architecture.

Although the same potential for portability applies to PC productivity software, we don't expect to see Microsoft Office on Xbox. Microsoft is unlikely to risk its revenue from

Feature	Microsoft Xbox	Nintendo GameCube	Sony PlayStation 2
Processor	Custom Intel Pentium III	Custom IBM PowerPC 405	Emotion Engine
Processor Speed	733MHz	485MHz	295MHz
Architecture	Superscalar x86 core 64-bit integer SIMD 128-bit FP SIMD	Superscalar PowerPC core 64-bit FP SIMD	Superscalar MIPS core with 128-bit integer SIMD Two 128-bit vector units
Processor Cache	L1: 16K I + 16K D L2: 128K unified	L1: 32K I + 32K D L2: 256K unified	L1: 16K I + 8K D
System Memory	64M 128-bit 200MHz DDR	24M 64-bit 325MHz 1T-SRAM 16M 8b 81MHz DRAM	32M RDRAM 2 16-bit 800MHz channels
3D Engine	Custom Nvidia GeForce3	Custom ATI/ArtX	Graphics Synthesizer
Clock Rate	250MHz	162MHz	147MHz
Pixels/cycle	4	4	16
Texels/cycle	8	4	8
Polygons/second	60M (theoretical)	33M (theoretical)	75M (theoretical)
Graphics Memory	Unified in main memory	Frame buffer: 2M 1T-SRAM Texture buffer: 1M 1T-SRAM Integrated	4M embedded DRAM Integrated
Audio	Dual 200MHz DSPs	81MHz DSP	Handled by CPU
Mass Storage	DVD-ROM 8G hard disc	8cm optical disc (1.5G)	DVD-ROM
I/O options	4 controller ports Ethernet	4 controller ports 2 serial, 1 parallel	2 controller ports USB, 1394

Table 1. Specifications of the major video-game consoles vary widely, but all produce roughly the same level of effective performance for running game software and rendering 3D graphics.

PC operating-system and application-software sales. A cheap Xbox running cheap productivity software would surely pose such a threat.

It's worth noting that Xbox is not Microsoft's first foray into gaming, as some reports have claimed. It's actually the company's second hardware platform for gaming and its third software platform. The first game console designed with Microsoft's help was the 8-bit MSX machine of the 1980s, which had some success in Asian markets but only limited sales in the United States. Much like Xbox, MSX was intended as a home-entertainment computer system. MSX machines were made by several vendors and were offered with games and some limited personal productivity tools.

Microsoft's Xbox software strategy is even more directly comparable with the company's effort to promote a derivative of Windows CE as a development and runtime environment for Sega's Dreamcast console. Sega determined Dreamcast's hardware architecture, however, and offered its own software environment, which gave better access to the features of the system's PowerVR-based graphics core.

Microsoft learned much from both these prior experiences, likely explaining why the company retained complete control of the critical elements of Xbox: hardware, software, and marketing. Because of this increased control, Xbox will easily surpass MSX and Dreamcast as contributors to Microsoft's revenue stream—if it has not already done so.

Nintendo Goes It Alone

Much less is known about the hardware and software that underlies Nintendo's GameCube. We know that GameCube's CPU was designed by IBM and Nintendo, and that it uses a PowerPC 405 core. This core runs at 485MHz, achieving a nominal 1,125 Dhrystone mips at that speed. The chip's 64-bit, 162MHz bus connects to the Flipper system controller codesigned by ATI and Nintendo.

Flipper includes memory and I/O controllers, as well as a graphics core based on the ArtX technology ATI acquired in 2000, an audio DSP core from Macronix, and two banks of integrated DRAM. These banks of DRAM—2M of frame buffer and 1M of texture cache—are implemented with the MoSys 1T-SRAM technology, giving them (nearly) the speed of SRAM with (nearly) the density of conventional DRAM. GameCube, like PlayStation 2, uses integrated DRAM to reduce the bandwidth demands on off-chip memory. This approach also limits the resolution of the display; with most game consoles connected to low-resolution TV sets, however, this limited resolution is not a severe handicap.

Software development for GameCube uses a mix of tools from Nintendo as well as third-party tools, including CodeWarrior from Metrowerks, and middleware such as Numerical Design Labs' NetImmerse and Criterion Software's RenderWare. These third-party tools simplify porting titles among the various gaming platforms. Versions of the CodeWarrior tools are available for the PC and PS2; both NetImmerse and RenderWare also support PC, PS2, and Xbox development.

Nintendo is exclusively focused on gaming; the company chose not to make GameCube capable of playing DVD movies, for example, believing the portability allowed by small physical size is more important to gaming than the ability to play DVDs. GameCube is less than half the size and weight of Xbox—with PS2 in between—and has a built-in carrying handle the others lack. The downside to GameCube's small size is the fact that it's too small to accept a DVD movie disc. Although the machine contains all the electronic hardware needed to play DVD movies, it is physically unable to do so.

Sony Settles In as Number One

PlayStation 2 is only a little more than a year old, but it has already sold more than 23 million units worldwide, according to Sony—more than 10 times the sales volume of either Xbox or GameCube. Game sales are also running at a brisk clip, with each console buyer picking up four to five games on average. During the 2001 Christmas holidays, PS2 games

dramatically outsold those for Xbox and GameCube, owing to Sony's larger installed base.

Even the PS2 console itself outsold the new arrivals in 4Q01. Although Xbox and GameCube arrived midquarter, initial sales represented significant pent-up demand that presumably more than compensated for the smaller sales window. The PS2's volume is all the more impressive, considering that the year-old machine still sells in the United States for the same price it fetched at its debut. Sony considered, and ultimately rejected, a U.S. price cut before the holidays, knowing it would still sell, at the full price, all the systems it could make; Japanese buyers did get a 15% discount, to about $220.

PlayStation 2 sits somewhere between the other two consoles in overall hardware sophistication. PS2's Emotion Engine offers more raw computing horsepower than either competing CPU, but reports from game developers suggest this potential is difficult to realize in real games. The complexity of the Emotion Engine's dual-vector engines, with their asymmetric connections—one paired with the processor core, the other attached to the graphics interface—does not readily lend itself to easy software development.

PS2's Graphics Synthesizer doesn't match the display quality of Xbox or GameCube, but it still leads all contenders in at least one metric—bandwidth to its integrated-DRAM frame buffer. The chip's multiported DRAM array has a 2,560-bit bus running at 150MHz for 48GB/s of peak throughput, some 7.5 times faster than the interface to Xbox's external DDR SDRAM array. These numbers make for impressive specifications, but in the low-resolution world of television monitors, the Graphics Synthesizer's bandwidth goes mostly unused.

The GS chip can render up to 1.25 billion pixels per second, about the same rate at which Nvidia's NV25 core generates pixels in Xbox. Even an HDTV set, however, can accept only about 62 million pixels per second.

However difficult software development may be for PlayStation 2, the market does not lack PS2 titles. Popular gaming Web site *www.gamespot.com* lists, for the U.S. market alone, 449 PS2 titles, some of which are still in development. This figure compares to a few dozen titles currently shipping for Xbox and GameCube. PS2's advantage in title availability will keep it the system of choice for most customers for some time to come.

Sony is likely to drop the price of the PS2 console at some point this year, which will help maintain system sales and ultimately lead to more game sales. Sony says it is producing more than 1.5 million PS2 systems per month. It will be quite some time before Xbox or GameCube can match this sales rate, and potentially years before either can achieve a larger installed base.

PCs Still Outsell Game Consoles

Because they are useful for so many other purposes, PCs outsell game consoles by about 12:1—and at much higher system prices. Total revenue from PC software sales similarly outstrips that from console games. We see no signs that this status quo will be reversed anytime soon.

Nevertheless, PC games do not generate the kind of revenue that console games do. There are tens of thousands of PC games on the market. Indeed, shovelware distributors offer CD-ROMs that each contain more than 500 (old) PC games. No single game on the PC, however, can match the popularity of the best console games. A hot PC game might sell a few hundred thousand copies, whereas some console games sell millions.

PCs provide a very different environment for game play than do consoles, and many of the differences favor the PC. Most PCs are desktop or laptop systems designed to be used by one person at short range. PCs run general-purpose operating systems and are equipped with general-purpose hardware. Top-of-the-line PCs generally have faster CPUs and more capable graphics subsystems than any game console has.

Today's best PC processors deliver about three times the performance of the fastest game-console CPUs. The PC's marginal advantage in graphics is particularly slim right now, since Nvidia offers comparable cores in its Xbox and PC 3D accelerators. The company's PC-oriented GeForce3 is slightly faster than Xbox's NV25 core, but only because it has its own dedicated DDR SGRAM memory array running faster than the DDR SDRAM used for both graphics and processor operations in Xbox. The greater memory bandwidth available to GeForce3 gives it the ability to support higher-resolution displays and better rendering quality, principally through superior antialiasing.

On the flip side of the equation, PC games can't be written to run exclusively on top-of-the-line systems. PC games, instead, are written to run on some large fraction of the installed base of systems. PC games can't try to use all the available performance of the CPU, memory, or hard disk, because they must ensure adequate playability, even when the system is running background tasks: soft-modem codecs for Internet connections, file sharing, and so on.

Xbox Wins

After considering the technology underlying these platforms, as well as performing considerable hands-on testing, we have decided to give the ***Microprocessor Report* Analysts' Choice Award for Best Gaming Chip Set of 2001** to the Xbox team of Intel, Microsoft, and Nvidia. The Xbox hardware offers performance very close to that of the best PCs, and its software environment offers easy game development and reliable game play.

Xbox may lag significantly behind Sony's PlayStation 2 in overall sales and title availability, but these factors do not count against the chip set. Any game that can be run on a PC can be adapted to run on Xbox, and we expect that, in the coming years, most PC games will be offered on both platforms.

Notable 3D Events of 2001

ARM licenses two PowerVR graphics cores from **Imagination Technologies** for high-performance and low-power embedded applications (*MPR 2/20/01-01*).

ATI rolls out Mobility Radeon, a low-power version of the Radeon architecture for laptop computers. Two versions include 8M and 16M of SGRAM integrated in the chip package to reduce physical size and power consumption (*MPR 3/12/01-02*).

Sony, **IBM**, and **Toshiba** announce a joint-development agreement for "Cell," an advanced multiprocessor architecture that could be used in future Sony PlayStation videogame consoles (*MPR 3/19/01-02*).

Separately, Toshiba spins off the group that developed PS2's Emotion Engine to create **ArTile Microsystems**. (*MPR 4/23/01-01*). In September, ArTile announces the TMPR7901XB microprocessor, its first system-on-chip product.

VIA ships the ProSavage KN133, an integrated-graphics chip set for AMD's Athlon and Duron processors (*MPR 6/11/01-05*).

Nintendo reveals the final configuration and release schedule for GameCube (*MPR 7/16/01-03*), although actual release is delayed by two weeks.

Microsoft reveals details of the DirectX version 8.1 multimedia application programming interface included with Windows XP (*MPR 8/6/01-02*). DX8.1 enables 3D features supported by ATI's Radeon 8500 graphics chip, announced in August at Siggraph (*MPR 9/24/01-01*). Also at Siggraph, **Nvidia** announces the Personal Cinema (a video input/output solution meant to compete with ATI's All-In-Wonder series) and the Quadro2 Go mobile-workstation 3D chip.

Transmeta announces the TM6000 integrated processor at Microprocessor Forum 2001 (*MPR 10/15/01-01*). The chip, intended primarily for embedded systems, includes a 2D-only graphics core.

National rolls out the Geode GX2 integrated processor, aimed at the same market as Transmeta's chip (*MPR 11/5/01-02*). Although the GX2 adds 3DNow to the original Geode design, they share the same old 2D-only graphics core.

An Xbox game is inherently more stable than a PC game. The Xbox platform may be extended, and improved models are sure to arrive eventually, but its base hardware functionality will never change, whereas PC gamers risk losing the ability to play their favorite games every time they upgrade some hardware or software element of their system.

Xbox's standard Ethernet port provides a more convenient connection for multiplayer gaming than the proprietary interfaces on the other consoles. The advantage of the standard port is perhaps even more significant than Microsoft expected: enthusiasts have already figured out how to enable multiplayer gaming over the Internet on one title—Microsoft's Halo combat game—meant to support LAN connections only.

Finally, Microsoft's decision to give every Xbox a hard disk shows that the company understands how to deliver value to customers, even at some increased cost to itself. The Xbox console must be the best value in computing devices on the market today—$300, for what amounts to a complete 733MHz desktop PC (sans display and keyboard), is a great deal. Devoting all that value to gaming was a gutsy call, but it is likely to pay off for Microsoft in the long run.

Other analysts have criticized Microsoft for pricing the Xbox console below its manufacturing cost. The general complaint is that Microsoft will "lose" more than $100 per sale when hardware and marketing costs are taken into account. These criticisms show a profound lack of business sense. When a company spends money today in expectation of generating a larger income stream in the future, we do not call it "losing money"; we call it "making an investment."

It may take a year or two for Microsoft's investment in the Xbox platform to pay off, but with $36 billion in the bank, Microsoft can afford to take the long view. In the meantime, the rest of us get to enjoy the best gaming experience on the market. This sounds like a good deal to us. ◇