Cutting-edge consoles target the television

THINK A BRAND NEW COMPUTER IS THE MOST POWERFUL HIGH-TECH PRESENT YOU COULD HOPE TO GIVE OR GET THIS HOLIDAY SEASON? MICROSOFT, NINTENDO, AND SONY HOPE TO GIVE YOU ANOTHER IDEA AND IN THE PROCESS TO CHANGE YOUR OPINION OF WHAT THE WORD "COMPUTER" MEANS.

Figure 1 Sony's PlayStation 2 (a), Microsoft's Xbox (b), and Nintendo's GameCube (c) are jockeying to be the console under your Christmas tree this year, and consequently to be the source of games, peripherals, and services in holidays to come.

BY THE TIME YOU READ THIS ARTICLE, you'll have a good idea of how successful or dismal this year's holiday shopping season was for both manufacturers and retailers. At press time, predictions are pessimistic with the aftereffects of September 11's terrorism action further exacerbating an already-slowing economy. One bright spot in an otherwise-gloomy electronics forecast, though, is the home-video-game-console market, in which products from Microsoft, Nintendo, and Sony are vying for consumers' ears, eyes, and expenditures.

One participant in this three-horse race (disregarding Sega,

who is heavily discounting its remaining inventory of Dreamcast systems and transforming itself into a multiplatform-software company) is Sony with PlayStation 2 (**Figure 1a**). Sony unveiled PS2 more than 18 months ago, but limited console and game availability dampened its success throughout the all-important 2000 shopping season. What a difference a year makes! Sony reported, at October's Rambus Developer Forum in Santa Clara, CA, that, by the end of June, it had sold nearly 15 million PS2s (more than 5 million of them in the United States) and almost 50 million units of software. With 425 software titles available worldwide in June, PS2 seems to have recovered any lost initial momentum. Sony's software title numbers are less impressive than they might appear at first glance, though, when you consider that they include both PS2 and older, less compelling PS1-targeted content (see **sidebar** "Evading Osborne's curse").

Microsoft with its Xbox and Nintendo with its GameCube are in similar situations to Sony's quandary a year ago (**figures 1b** and **c**). Both companies have pushed back their original launch dates and have scaled back the number of systems available for sale on those dates. And both platforms' currently available titles number a few dozen versus Sony's several hundred. Xbox hopes to outclass PS2 by offering, at the same base price point, additional features and increased audible and visual realism. GameCube, in contrast, is a stripped-down, gaming-focused machine priced $100 less than its competitors. But for all three companies, initial pricing and profit margin are secondary concerns (**Reference 1**). Selling the "box" is a means to an even more lucrative end: revenues deriving from follow-on sales of software, services, and peripherals. Note, for example, that all three consoles come with only one controller. Marketers call this strategy the "razor-and-razor-blade" approach: Sell the razor at whatever price is necessary to hook the customer and then recoup your losses—and then some—with subsequent sales of proprietary, high-profit-margin razor blades.

In this atmosphere of worldwide uncertainty and insecurity, how much success can any of these game consoles realistically hope to achieve? One school of thought says that, because people are "cocooning" at home more and traveling less, home-entertainment products, such

AT A GLANCE

- Look at all of a system's processors to get an accurate picture of its power.
- Forgiving displays limit peak fill rates, but complex scenes give no relief to polygon processing.
- Network connectivity enables consoles to supplement or supersede the PC.

EVADING OSBORNE'S CURSE

In April 1981, Adam Osborne introduced the Osborne 1, the first portable—or, at 24 lbs "luggable"—computer. At first, the Osborne 1 was quite successful. Unfortunately, Osborne and Osborne Computer's other marketers prematurely began talking about the Osborne 1's successor, and Osborne 1 sales dried up as potential customers instead waited for the next-generation system. By September 1983, with no Osborne 2 in sight, Osborne Computer was in bankruptcy court.

What's this all got to do with video-game consoles in 2001? Osborne's problem was similar to one Sony faced in 1999 with the potential demise of its PlayStation franchise at the hands of Sega's Dreamcast and its SH-4 processor and Imagination Technologies-developed PowerVR graphics subsystem. PlayStation, which Sony launched in Japan in December 1994 and elsewhere in September 1995, generated a disproportionately enormous share of Sony's corporate profits, but Dreamcast's capabilities were a generation beyond it. PlayStation 2 would similarly one-up Dreamcast but was at least a year away from going into production. How was Sony going to keep PlayStation users from defecting to Dreamcast without also causing them to stop buying PlayStation games, saving their money for the next-generation Sony console instead?

Sony's engineering accomplishment was brilliant. The I/O processor (**Figure 3a**) is backward-compatible in both architecture and clock frequency with the MIPS R3000 main CPU in PlayStation. It becomes PS2's primary microprocessor, running at 33.8 MHz, when you're playing PlayStation games. This dual-use function meant that PlayStation users could keep buying games, secure in the knowledge that they weren't wasting their investment when they later upgraded their consoles. Sony began touting PlayStation 2 in spring 1999, and Dreamcast's pending obsolescence is testimony to Sony's success. Sony continues to sell the original PlayStation, now renamed the PS One, for $99, enabling the company to compete against both Xbox for performance-hungry gamers and GameCube for more price-conscious consumers. And teasers about the claimed 1000-times more powerful PlayStation 3 are beginning to come from Japan.

If PlayStation 2's backward compatibility was a good idea, then Nintendo's decision to break compatibility between GameCube and previous-generation Nintendo 64 was a bad move, right? Not necessarily. GameCube's low price objective meant that Nintendo's engineers were under tremendous cost pressure; even the addition of a connector for a separate ROM-cartridge peripheral was potentially prohibitive. Backward-compatible software would have either restricted Nintendo's CPU, graphics, and OS options or have required costly PS2-like redundant silicon. And Nintendo 64's ROM cartridges were bulky and expensive, eating into Nintendo's profit margins compared with competitors' inexpensive CD and DVD plastic discs.

Xbox is Microsoft's first game console, so the company has no compatibility concerns, right? Wrong. Some pundits speculate that Xbox might cannibalize PC-software sales and reduce Microsoft's revenues and profits. In reality, though, sales of both new PCs and software upgrades for PCs have stagnated, and the list of companies developing PC games—one of the only performance-gobbling reasons *to* upgrade—is shrinking. Because Xbox games run on the same DirectX API as the one in Windows, Xbox game development might actually reignite the market for PC games and, with it, PC sales.

as game consoles, satellite-dish television receivers, and DVD players, will benefit. An opposing view suggests that, as people see their investment portfolios shrink, they'll slam the brakes on all spending, especially for items with three-digit and higher price tags. Practically speaking, pleas from children and children-at-heart for high-tech, high-ticket presents eventually subdue the most conservative fiscal intentions. At least one thing is clear: The shoot-'em-up game genre, popular in the past, is losing its appeal as television viewers behold the horror of real-life war on the evening news. What game genres will replace it is less clear.

MIPS MUNCH ON PHYSICS, POLYGONS

A cursory clock-frequency comparison of the CPUs inside the three console contenders might prematurely cause you to crown an incorrect king (**Table 1**). Clock speeds are an insufficient measure of real-life performance. You also need to consider what types of tasks the CPU will perform, how architecture-optimized the software is, and what coprocessor resources are available to supplement the CPU's speed.

The 300-MHz MIPS R4000/R5000 hybrid microprocessor core inside Sony's Emotion Engine chip, which Toshiba designed and built, contains dual 64-bit integer units, which gang together to perform 128-bit SIMD (single-instruction-multiple-data) operations, and a single-precision floating-point unit. Two 128-bit vector coprocessors, each of which performs a vertex operation (19 multiply-accumulates and a divide) in seven clock cycles, significantly beef up the chip's floating-point performance. They find use in performing object-physics calculations and in the geometry-transform-and-lighting portions of the 3-D-graphics pipeline. Sony even includes an image processor; this high-definition-capable MPEG-2 decoder and color-space converter also decompresses 3-D texture maps to multiple resolutions.

Figure 2 PlayStation 2 uses custom-packaged DRDRAMs to reduce memory and system-board cost.

Sony needed a high-performance main memory that could keep up with the PS2 CPU's code and data demands, especially considering the processor's diminutive 16-kbyte instruction cache and 8-kbyte data cache. Emotion Engine therefore also embeds a dual-channel DRDRAM (Direct Rambus-DRAM) controller, which, like the memory interface in Intel's i840 and i850 PC chip sets, can perform 3.2 Gbytes/sec transfers to and from the Toshiba 32-Mbyte, two-chip PC800 DRDRAM array. Toshiba custom-packaged the devices to reduce chip and board cost (**Figure 2**). PS2's focused set of functions, carefully tuned software, and long-burst-friendly multimedia data streams should better exploit DRDRAM's performance potential versus in a more generic PC. And, as with Intel's ill-fated Timna single-chip CPU and Compaq's 21364 EV7 Alpha microprocessor, Sony can, by integrating the memory controller, eliminate the additional latency caused by the handshake between a separate core-logic chip containing the memory controller and the CPU (**Figure 3a**).

IF IT WALKS AND TALKS LIKE A PC...

DRDRAM, which manufacturers use in high-end Intel Pentium III- and Pentium 4-based PCs, and DDR SDRAM, which they use in AMD Athlon-based systems, are battling for dominance in game consoles, too (**Reference 2**). Take the top off Microsoft's Xbox, and you'll swear you're looking at a PC motherboard (**Figure 4**). Actually, for all intents and purposes, you are. Xbox is a quan-

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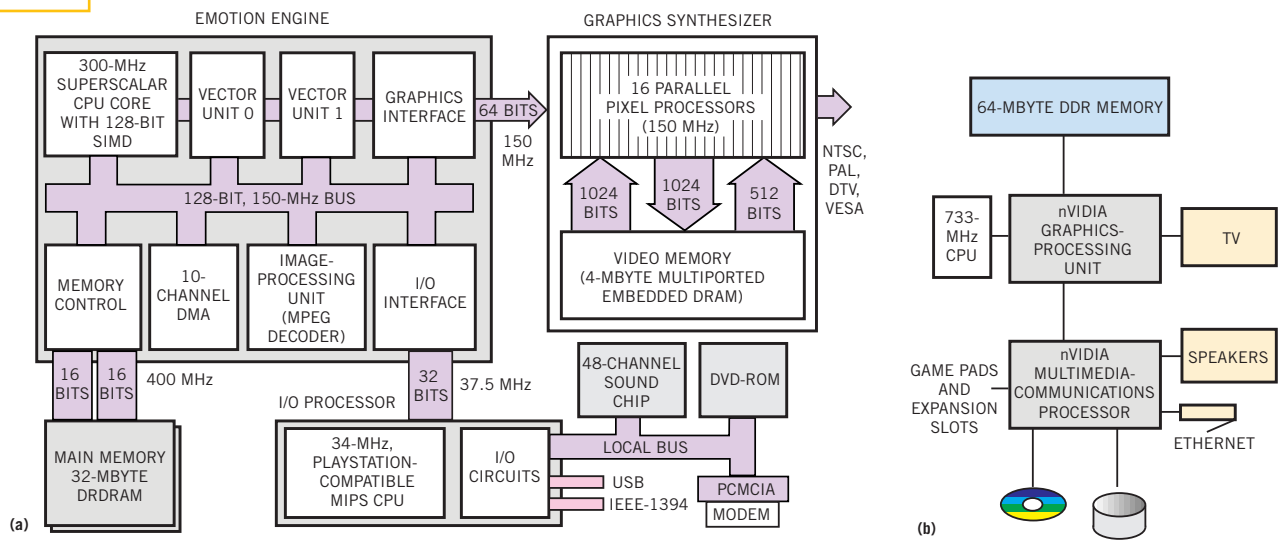
Figure 3



PlayStation 2 (a) and Xbox (b) architectures reflect their designers' conflicting perspectives on necessary system functions and on the partitioning of those functions in hardware and software (courtesy Cahners MicroDesign Resources and Nvidia, respectively).

tum leap beyond the keyboards, mice, and ActiMates *Barney* and *Teletubbies* toys that exemplified software-centric Microsoft's previous hardware projects. Instead of building its own factories, Microsoft wisely contracted manufacturing to Flextronics; let partner Intel design the motherboard; and bases Xbox on a stripped-down, DVD-bootable variant of Windows 2000. This approach, which debuted in Microsoft's version of Windows CE for Sega's Dreamcast, binds the application software on the DVD to an unalterable version of the operating system, DLLs, APIs, and drivers. In conjunction with Xbox's sealed-box hardware architecture, the result should be a far more stable and predictable user experience than with a PC.

When Microsoft unveiled Xbox 18 months ago at the Game Developer Conference in San Jose, the console's 733-MHz processor was near the performance pinnacle of Intel's product line. Now, thanks to Intel's heavily pipelined Pentium 4 and new 0.13-micron-lithography manufacturing process, it's near the bottom. Don't be surprised, therefore, if you shortly begin to hear rumors of a higher-performance Xbox 2 waiting in the wings. Intel says that the CPU is a Pentium III "derivative" but doesn't provide specifics. Potential processor enhancements include second-generation SSE (Streaming SIMD Extensions) support, larger and more efficient caches, and local-bus frequencies higher than 133 MHz. Nvidia's graphics-processing unit, the "north-bridge" portion of the core-logic chip set, interfaces to 64 Mbytes of 200-MHz (clock)/400-MHz (data) DDR SDRAM, most of which Micron Technology claims to supply. The DDR SDRAM's eight-chip, dual-bank-array peak bandwidth doubles the speed of the dual-DRDRAM channels in PS2 (**Figure 3b**).

Nintendo, like Sony, based its previous-generation N64 game console on a MIPS CPU. For GameCube, though, Nintendo turned to IBM, whose 485-MHz PowerPC 750/G3 CPU, built on a 0.18-micron process with copper interconnect, is the core of GameCube's Gekko chip. IBM made unspecified enhancements to the PowerPC core for Nintendo; one popular speculation is that the company added AltiVec SIMD support, which is also in the CPUs that Apple uses for its high-end Macintosh computers, via IBM's technology-sharing agreement with Motorola. Gekko also contains a 256-kbyte Level 2 cache, supplementing the 32-kbyte Level 1 instruction cache and 32-kbyte data cache.

Nintendo gambled on then-little-known Rambus when, in 1996, it launched its N64 with first-generation RDRAMs inside. With GameCube, Nintendo is rolling the dice with another little-known memory supplier, MoSys, whose MDRAM (multibank DRAM), also known as 1T-SRAM, is notable for its fast random-access capability. In GameCube, the 24-Mbyte, two-chip, main-memory array, code-named Splash and running at 405 MHz, delivers less-than-10-nsec sustained access speeds (**Figure 5**). GameCube's Flipper multimedia chip contains the MDRAM controller and also interfaces to 16 Mbytes of conventional 81-MHz SDRAM, which the system uses as a DVD-ROM-drive-read cache, as well as for other buffering and non-performance-critical temporary storage functions. Flipper connects to Gekko through a 64-bit, 162-MHz bus with 1.3-Gbyte/sec peak bandwidth.

SOUNDS, SCENES STIMULATE SENSES

You'll also find MDRAM *inside* GameCube's Flipper. A 16-Mbit MDRAM-based combination frame buffer and Z-buffer comprises four 4-Mbit arrays, each with a 96-bit transfer bus. It achieves 6.2-nsec random-access speeds, which translate to 7.8-Gbyte/sec peak bandwidth. A separate 8-Mbit embedded MDRAM texture cache, comprising 32 independent 256-kbit arrays each with a 16-bit bus, delivers 10.4-Gbyte/sec peak bus bandwidth. When ATI Technologies

last spring acquired ArtX, it also obtained the graphics technology that Nintendo uses in GameCube.

The ArtX-designed core that Acer Labs previously embedded in its Aladdin7 core-logic chip set included a then-revolutionary (at the price) front-end geometry processor. ATI's design team combined a 203-MHz ArtX-based graphics accelerator with a 16-bit Macronix audio-DSP core, and NEC fabricates the resulting Splash chip. Splash supports 64 simultaneous audio channels, and it encodes incoming analog audio to the ADPCM (adaptive-differential-pulse-code-modulation) format that finds use, for example, in voice-enhanced multiperson gaming. The GameCube highly integrated system board reflects Nintendo's optimistic financial aspirations even in the face of a $199 price tag. Nintendo predicts that GameCube will be profitable within months of introduction based solely on console sales—not even counting on game royalties.

Sony also uses 4 Mbits of embedded DRAM inside Graphics Synthesizer, the Toshiba-manufactured 147-MHz graphics controller for PS2. The interface between the Emotion Engine CPU and Graphics Synthesizer is 64 bits wide and runs at 150 MHz. Recall that Emotion Engine handles all of the floating-point-intensive geometry and lighting calculations. Graphics Synthesizer, comprising 16 parallel pixel processors, therefore, manages the back end of the 3-D pipeline. Creating software that makes efficient use of this parallelism has proved to be one of the biggest challenges facing PS2 developers, although opinions vary on how difficult this task is. A separate 48-channel sound chip handles PS2's audio functions.

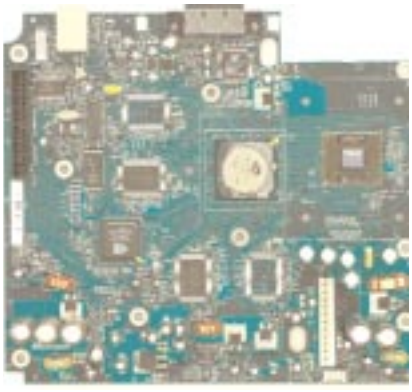


Figure 4 If you think the Xbox system board looks a lot like a computer motherboard, you're right; PC- hardware and -software compatibility is key to Microsoft's strategy (courtesy Semiconductor Insights).

Xbox's multimedia-processing architecture differs from that of its competitors in several key areas. Unlike both PS2 and GameCube, the graphics accelerator in Xbox's Nvidia-designed graphics-processing unit doesn't employ separate DRAM arrays for main memory and for the frame buffer, Z-buffer, and texture-buffer graphics functions. Instead, the 233-MHz graphics-processing unit employs a unified, or shared, memory array in which the DDR SDRAM handles all of these tasks. Unified-memory-array architectures have economic appeal but have until recent years achieved limited success, primarily due to low memory bandwidth. Xbox's 400-Mbps-per-pin DDR SDRAM speed neatly solves the performance problem, further aided by Nvidia's TwinBank crossbar memory controller, whose dual 64-bit banks enable the CPU and graphics subsystem to simultaneously access the memory array for higher sustained bandwidth usage.

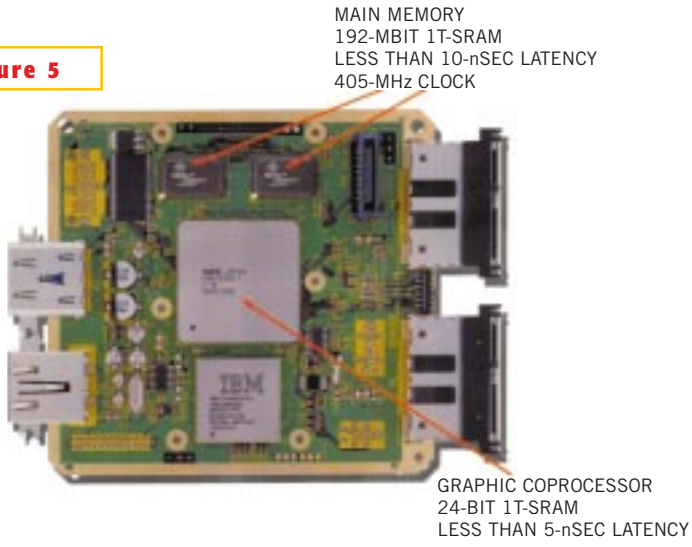
The other key difference between Xbox and PS2 is that in Xbox, as with GameCube's Flipper, the graphics controller has a greater role in handling all aspects of 3-D graphics processing. The graphics-processing unit in Xbox is conceptually similar to the integrated graphics processor in Nvidia's nForce chip set with

TABLE 1–CONSOLE MANUFACTURERS, PRODUCTS, AND FEATURES

	Microsoft Xbox	Nintendo GameCube	Sony PlayStation 2
Dimensions (in., height×width×depth)	4×12×8	4.3×5.9×6.3	7×12×3 (can also stand on end)
CPU	733-MHz Intel Pentium III	485-MHz IBM PowerPC Gekko	300-MHz MIPS Emotion Engine
Graphics chip	233-MHz Nvidia graphics-processing unit GeForce 3 derivative	203-MHz ArtX/ATI Flipper with 24-Mbit embedded multibank DRAM	147-MHz Graphics Synthesizer with 4-Mbit embedded DRAM
Audio	Dual programmable DSPs, three fixed-function DSPs, and three microcontrollers; 256 2-D voices and 64 3-D voices; real-time Dolby Digital encoding	16-bit DSP, 64 channels	48 channels
Main memory	64-Mbyte, 200-MHz (clock)/ 400-MHz (data) DDR SDRAM	24-Mbyte, 405-MHz multibank DRAM; 16-Mbyte, 81-MHz SDRAM	32-Mbyte PC800 Direct Rambus DRAM
Mass storage	8- or 10-Gbyte hard-disk drive, dual memory cards, DVD-ROM drive	Memory card and Secure Digital card, proprietary DVD-ROM derivative	Dual memory cards, DVD-ROM drive
Maximum number of controllers	Four USB-derived controllers, can also be used for other peripherals	Four	Two
Video resolutions	1080i, 720p, 480p, 480i, including RGB	480p, 480i	480i (RGB upcoming)
Network connectivity	Ethernet (included)	Analog modem and optional Ethernet	Analog modem and optional Ethernet
Other peripheral interfaces	One additional USB-derived controller, composite, S-Video and component video, analog and digital audio	Two serial, one parallel, composite and component video, analog and digital audio	Two USB, one IEEE-1394, one PC Card, composite, S-Video and component video, analog and digital audio
Price and kit contents	$299, one controller, composite-video and analog-audio cable	$199, one controller, composite-video and analog-audio cable	$299, one controller, composite-video and analog-audio cable

two major alterations: the graphics-processing unit's local-bus interfaces to an Intel, versus an AMD, processor, and the graphics-processing unit is based on GeForce3 technology versus the previous-generation GeForce2 MX inside nForce's integrated graphics processor. The Pentium III processor with its SIMD integer and floating-point units is capable of tackling repetitive geometry-transform-and-lighting tasks. However, the graphics-processing unit's programmable vertex processors are equally up to the task and free up the CPU to handle less predictable operations, such as object physics. Think, for example, of ripples on water or the realistic flowing "hair" on Aki Ross, the realistic cyber-character in the movie *Final Fantasy: The Spirits Within* (**Figure 6**).

Figure 5



Nintendo's minimal-chip, MDRAM-centric design reflects the company's attempts to balance cost and performance (courtesy MoSys).

HOME THEATER PUMPS UPS PROCESSING

An 800-Mbyte/sec HyperTransport bus connects Xbox's graphics-processing unit and media-and-communications processor, which is identical to its equivalent in the nForce chip set. The media-and-communications processor tackles Xbox's audio and can simultaneously process as many as 256 voices, of which 64 are 3-D. Because PS2, GameCube, and Xbox are all DVD-friendly, they contain Dolby Digital decoders and downmixers. They can all also route Dolby Digital and DTS audio bit streams from a movie or game soundtrack to a separate audio decoder, such as the one in a home-theater audio receiver. Only Xbox, though, also *encodes* Dolby Digital audio on the fly; the others rely on prerendered audio tracks stored on the DVD. Xbox's added capability, with a claimed maximum latency of 50 msec, promises increased audio realism because it places sounds in 3-D space as a function of a character's exact position at each point in time. If, for example, a football player turns to one side, the crowd noise doesn't remain in the back speakers. Sensaura-licensed algorithms virtualize surround sound for two-speaker or headphone configurations in conjunction with Wolfson Microelectronics-supplied DACs (**Reference 3**). Dual integrated DSPs, developed by Parthus Technologies and supplemented by dedicated Dolby Digital encoding circuits and other fixed-function hardware, tackle the audio-processing tasks.

Turning the focus from audio back to video, keep in mind that conventional television is a comparatively effortless display environment for graphics hardware and software, versus a computer monitor. Only the best NTSC televisions approach 480 lines of resolution, and their interlaced display modes and limited color depths and gamuts further ease the performance requirements of a video game console's graphics and video-playback subsystems (**Reference 4**). Newer ATSC-ready televisions can decode incoming signals with as much as 720 progressive and 1080 interlaced lines of resolution, although you'd be hard-pressed to see more than 480 lines of output resolution on anything but the largest front- and rear-projection systems. ATSC's 720-line mode has an optional 60-frame/sec refresh rate, but 1080 lines of resolution deliver only 30-frame/sec, or 60-field/sec, screen refreshes. Compare these specifications to the 85-Hz or higher frame-refresh rates and to the 768 (XGA), 1024 (SXGA), and 1200 (UXGA) progressive-scan lines of resolution, which computer users demand of their CRTs, LCDs, and graphics chips.

PS2, GameCube, and Xbox all offer optional component video cables, and PS2 and Xbox also market S-Video output adapters (**Reference 5**). PS2 outputs only 480-line interlaced video, whereas GameCube can support both interlaced- and progressive-scan 480-line outputs. Xbox specifications tout the ability to output 480i, 480p, 720p, and 1080i video resolutions and RGB color if the game supports these display modes; these claims are reasonable because the Nvidia GeForce3 graphics-accelerator and its video DACs have proved themselves able to deliver these capabilities in PCs. Specifications suggest that Xbox and Matsushita's GameCube derivative can output a progressive-scan video signal only with games—not when playing DVD-Video movies (**Reference 6**). Microsoft's and Nintendo's documentation mentions digital-video capability; this ability does *not* mean that the consoles can output a digital-video bit stream, such as DVI, but instead reflects their ATSC-compatible analog-video modes.

Lower resolutions, restricted color depths, and reduced refresh rates all limit a game-console graphics subsystem's maximum required pixel-fill rate. However, they don't provide any relief to the front-end polygon-processing requirements, which are a function of scene complexity. Each strand of Aki Ross' "hair," for example, reportedly contained hundreds of polygons, and each movie frame took 90 minutes to render on a Sun workstation farm. After game players see near-photorealism in movies such as *Final Fantasy: The Spirits Within*, *Monsters Inc*, *Shrek*, and *Toy Story*, why would they accept anything less from the consoles sitting in their living rooms? Keep in mind, too, that, whereas PC-graphics replacement is as simple as opening the case, plugging a new card into the AGP slot, and installing software drivers, a console's graphics subsystem isn't upgradable, and most consumers won't tolerate buying a new system and games

suite every year, either. Microsoft, Nintendo, and Sony must be sure to provide not only enough graphics horsepower for today's user demands, but also sufficient headroom for the increased expectations of the future.

Table 1 intentionally omits polygon-processing numbers. Theoretical peak specifications are available from the manufacturers' Web sites, or you can derive them from the graphics accelerator's internal-clock frequencies. However, sustained polygon-processing rates depend heavily on scene characteristics, and analysts' estimates vary regarding each consoles' real-life capabilities (**Reference 7**). You need to consider how much depth complexity is in the scene, how this complexity translates to the likelihood of a given polygon obscuring the one behind it, and how quickly the graphics subsystem detects this situation and discards the hidden polygon versus wasting clock cycles on its continued processing. You also need to know the size of the average polygon, the range of polygon sizes in a scene, and how many textures and how many light sources of which type get applied to each polygon. Is simple bilinear-texture filtering acceptable, or does the scene require far more computationally demanding anisotropic filtering and full-scene antialiasing to avoid the creation of distracting artifacts?

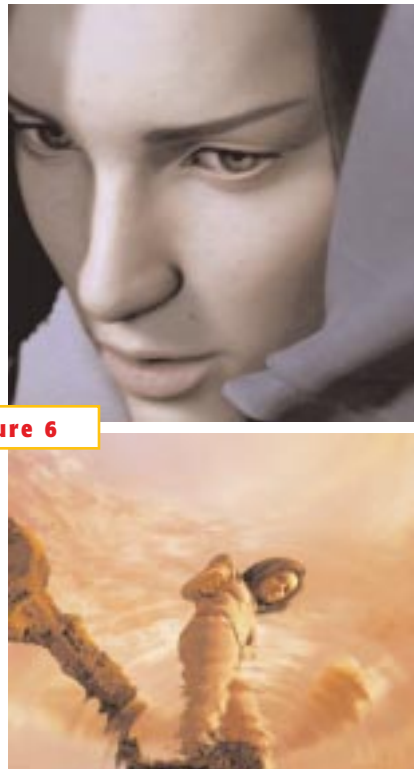


Figure 6

The cyber-characters of *Final Fantasy: The Spirits Within* are lifelike enough to make real actors like Tom Hanks nervous, and they give game-console hardware and software developers a near-photorealistic aspiration to strive toward (courtesy Columbia Pictures).

MASS-STORAGE DETAILS MAKE A DIFFERENCE

PS2's all-important backward compatibility with PS One games means that PS2's 4×-speed DVD drive must be able to read PS One's Super Discs based on the CD-ROM/XA format, which, ironically, Sony developed in the late 1980s for use with a never-released Super Nintendo game-console peripheral. PS2, like its PS One predecessor, also plays audio CDs. PS2-targeted games come on both copy-protected CDs and DVDs, and the console also plays DVD-Video discs if you buy the $19.99 remote-control accessory. Memory cards let users store saved game states and other personal data for use when they play friends' consoles (**Reference 8**). PS2 accepts two such cards.

Both in its choice of microprocessor and of storage media, and unlike Sony, Nintendo made a conscious decision with GameCube to break backwards compatibility with the previous-generation Nintendo 64. Nintendo's version of GameCube employs a 3-in.-diameter, 1.5-Gbyte, proprietary, Matsushita-developed DVD-ROM variant, and, unlike PS2 and Xbox, it doesn't play DVD-Videos. Matsushita will sell a GameCube version that supports movie playback. GameCube also accepts proprietary memory cards and, via an adapter, Secure Digital cards.

Xbox, like PS2, stores games on copy-protected but otherwise-conventional DVDs; plays audio CDs and DVD-Video movies, again, with an optional $29.99 remote control; and accepts user-customizable memory cards. Xbox clearly differs from PS2 and GameCube in that Xbox has a Seagate- and Western Digital-manufactured 8- or 10-Gbyte hard-disk drive. For gaming, possible hard-disk drive uses include the storage of time- or use-limited evaluation software, as a graphics-texture and audio-stream cache, or for extra levels or other options you buy after your initial purchase. For example, you can update your basketball and football games with next year's National Basketball Association and National Football League team rosters. In today's games, bad guys disappear or turn into nebulous lumps after you blast them, and wrecked cars leave no residue on the racetrack. With a multigigabyte, nonvolatile, and updatable game-state memory, though, developers can archive exacting details of a scene for your next visit to the dungeon room or next lap around the speedway. *Tony Hawk's Pro Skater* players can even customize the game's soundtrack or compose their own music masterpieces ripped from audio CDs and transportable to friends' consoles via memory cards.

It's a safe bet, though, that Microsoft hasn't restrict its vision for Xbox to just gaming. Consider the company's .Net strategy, the digital-rights-management and high-quality audio and video codecs in Windows Media Technologies, and Microsoft's recent acquisition of high-fidelity audio-technology developer Pacific Microsonics (**Reference 9**). Xbox could double as a home media server and a repository for purchased Internet audio and video streams. With the addition of a wireless keyboard and a keyboard, along with a Microsoft Network Internet-service-provider account, of course, it could become a multipurpose computing platform. But under the assumption that potential Xbox customers already have one or more PCs in their homes, it remains to be seen whether consumers will deem these features more important than GameCube's lower price or PS2's more extensive game portfolio.

Competitor Sony has made some grandiose claims for PS2, such as forecasting that, within a few years PS2s will outnumber computers in US homes. The company intends for PS2 to be the home-entertainment hub, and an upcoming 40-Gbyte hard-disk-drive peripheral is key to that strategy. Sony is beta-testing a Linux OS-based software-development kit, along with an SXGA resolution-capable RGB cable in Japan. At the recent Rambus Developer Forum, the company mentioned e-mail and Web browsing, digital television, and personal-video-recorder functions as potential applications. Other hints to Sony's ambitions in-

clude its partnerships with Cisco for TCP/IP support, RealNetworks for RealPlayer support, AOL Time Warner for America Online access, and Sun Microsystems for the Java virtual machine.

PERIPHERALS COMPLETE THE PICTURE

PS2 includes two USB connectors and a Firewire connector. The inclusion of a Firewire connector is not surprising, considering Sony's strong corporate support for IEEE-1394, which the company refers to with the i.Link brand name. One could conceive of it, for example, as a means to transfer digital-videocamera clips to PS2, but the only use that's emerged to date is linking multiple consoles together for gaming with more than two people. Internet-connected gaming sessions are also feasible. Sega's Dreamcast first seriously pursued this concept, and PC games *Quake III Arena* and *Unreal Tournament* further explored it. For that application and further indicating Sony's broader future vision for PS2, the company offers a PCMCIA-based analog modem, and a 100-Mbit Ethernet adapter is on the way.

GameCube and Xbox both provide four controller ports and are a more economical solution to three- and four-person gaming sessions than PS2's approach of multiple connected consoles. Xbox's $14.99 System Link cable extends the fun for two consoles and as many as eight players. All vendors' controllers have "rumble" modes, which give tactile feedback to game players, supplementing the audible and visible stimulus, and they come in both wired and wireless variants. Xbox includes a 10BaseT Ethernet port for broadband LAN and WAN connectivity but no analog modem or HomePNA option. Nintendo also plans to roll out analog-modem and broadband adapters in the future; for now, Dreamcast makes do with serial and parallel ports. Nintendo will provide a means of docking Game Boy Advance units to GameCube for game-parameter interchange and for using Game Boy Advance as an LCD-enhanced GameCube controller. The company has not announced plans for a GameCube hard-disk drive, though persistent rumors indicate that one might be under development.□

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