Failure Case for ENTR200 Class Discussion

Based on http://en.wikipedia.org/wiki/3dfx accessed 12/13/07

3dfx Interfactive was a company that specialized in the manufacturing of cutting-edge 3D graphics processing units and, later, graphics cards. After dominating the field for several years in the late 1990s, by the end of 2000 it underwent one of the most high-profile demises in the history of the PC industry. It was headquartered in San Jose, California until, on the verge of bankruptcy, many of its intellectual assets (and many employees) were acquired by its rival, NVIDIA Corporation. 3dfx Interactive filed for bankruptcy on October 15, 2002.[1]

Early history

Founded in 1994 by Ross Smith, Gary Tarolli and Scott Sellers (all SGI alumni) with backing from Gordie Campbell's TechFarm, 3dfx released its **Voodoo Graphics** chip in 1996. The company only manufactured the chips and some reference boards, and initially did not sell any product to consumers; rather, it acted as an OEM supplier for graphics card companies, which designed, manufactured, marketed, and sold their own graphics cards including the Voodoo.

3dfx became popular mainly due to their great success within the arcade market. At the time, arcades were a very visible place to go visit and see the latest in 3D gaming and technology. The first arcade machine that 3Dfx Voodoo Graphics hardware was used in was called ICE Home Run Derby, a game released in 1996. Later that year they were featured in more popular titles, such as Atari's San Francisco Rush and Wayne Gretzky's 3D Hockey.[2] 3Dfx received a lot of focus from the media because of the obvious graphical prowess of these titles, and that new game consoles such as Nintendo 64, Sony PlayStation, and Sega Saturn would be showcases for similar next-generation graphics.

Voodoo Graphics PCI

A Diamond Monster 3D, utilizing the Voodoo 1 chipset

After a fortuitous drop in EDO DRAM prices due to the volatile DRAM market, Voodoo Graphics

cards became feasible for the consumer PC market. The **Voodoo 1**, as the Voodoo Graphics would be later known, was notable for its lack of an onboard VGA controller. As such, a Voodoo-equipped PC still required a separate VGA graphics card, meaning it was very expensive to have both 3D and 2D acceleration. The Voodoo 1 occupied a separate PCI slot and only engaged when the host PC ran a 3D game that had been programmed to use the card. A pass-through VGA cable daisy-chained the VGA card to the Voodoo 1, which was itself connected to the monitor. Although this was a cumbersome arrangement that somewhat hurt the analog signal quality of the separate 2D card, PC gamers were willing to put up with it to gain what was, at the time, the best in 3D graphics.

The Voodoo 1's main competitors were cards from PowerVR and Rendition. PowerVR produced a similar 3D-only add-on card with capable 3D support, although it was not comparable to Voodoo Graphics in either image quality or performance. 3dfx saw intense competition in the market from cards that offered the combination of 2D and 3D acceleration. While these cards, such as Matrox Mystique, S3 ViRGE, and ATI 3D Rage, offered unquestionably inferior 3D acceleration, their low cost and simplicity often appealed to OEM system builders over the addition of another expensive and limited-use card (especially with the then-unproven 3D game market). Rendition's Vérité V1000 was an integrated (3D+VGA) single-chip solution as well that was perhaps Voodoo's closest competitor, but it too did not have comparable 3D performance (equal quality, however) and its 2D was considered merely adequate relative to other 2D cards of the time (slower than ViRGE, Rage, and Mystique).

Glide API

Unreal rendering with Glide

Originally developed for use within the specialized resource constrained environment of an arcade game that included non-Intel architectures such as MIPS and PowerPC CPUs, as well as to support DOS-based, full-screen 3D games which were still popular at the time and which neither Microsoft nor Intel desired to support with their own APIs (Intel 3DR and Microsoft 3D-DDI), Glide was created to handle error prone tasks like chip initialization for the programmer, but implemented nothing more than what the Voodoo hardware was directly capable of. This strategy differed from that of other 3D APIs of the era (Direct3D, OpenGL, and QuickDraw 3D), which hid low-level hardware details behind an "abstraction layer," with the goal of providing application developers a standard, hardware-neutral interface.

The advantage of an abstraction layer is that game developers save programming effort and gain flexibility by writing their 3D rendering code once, for a single API, and the abstraction layer allows it to run on hardware from multiple manufacturers. This advantage is still in place today. However, in the early days of the 3D graphics card, Direct3D and OpenGL implementations were either non-existent or, at minimum,

substantially less mature than today, and computers were much slower and had less memory. The abstraction layers' overhead crippled performance in practice. 3dfx had therefore created a strong advantage for itself by aggressively promoting Glide, which was designed specifically around the Voodoo hardware, and therefore did not suffer from the performance hit of a higher level abstraction layer.

While there were many hit games that used Glide, including several coin-op/arcade games from Midway Games and Atari Games (e.g., San Francisco Rush, NFL Blitz, Hydrothunder, etc.) and games like Eidos' Tomb Raider, the killer application for Voodoo Graphics was the MiniGL driver developed specifically to allow hardware acceleration of the game Quake, by id Software, on 3dfx cards. The driver implemented only the subset of OpenGL used by Quake.

By 2000, the improved performance of Direct3D and OpenGL on the average personal computer, coupled with the huge variety of new 3D cards on the market, the widespread support of these standard APIs by the game developer community and the closure of 3dfx, would make Glide obsolete.

Voodoo Rush

Intergraph Intense3D Voodoo

In August 1997, 3dfx released the **Voodoo Rush** chipset, combining a Voodoo chip with a 2D chip that lay on the same circuit board, eliminating the need for a separate VGA card. Most cards were built with an Alliance Semiconductor AT25/AT3D 2D component, but there were some built with a Macronix chip and there were initial plans to partner with Trident and Media Reality, but no such boards were ever marketed.

The Rush had the same specifications as Voodoo Graphics but performed worse because the Rush chipset had to share memory bandwidth with the CRTC of the 2D chip. The Rush chipset also was not directly present on the PCI bus but had to be programmed through linked registers of the 2D chip. Like the Voodoo Graphics, there was no interrupt mechanism, so the driver had to poll the Rush in order to determine whether a command had completed or not; the indirection through the 2D component added significant overhead here and tended to back up traffic on the PCI interface. The typical performance hit was around 10% compared to Voodoo Graphics, and even worse in windowed mode. Later Rush boards released by Hercules had 8 MiB VRAM and a 10% higher clock speed to close the performance gap.

A rare third version was produced which featured a Cirrus Logic 2D chip instead of the earlier model. This version fixed the PCI bus collisions and memory interface problems.

Voodoo2
STB Blackmagic 3D in SLI

In 1998, 3dfx released Voodoo's successor, the popular Voodoo2. The Voodoo2 was architecturally similar, but the basic board configuration added a second texturing unit, allowing two textures to be drawn in a single pass.

A problem with the Voodoo2 was the fact that it required three chips and a separate VGA graphics card, whereas new competing 3D products, such as the ATI Rage Pro, NVIDIA RIVA 128, and Rendition Verite 2200, were single-chip products. Despite this shortcoming, the card's dithered 16-bit 3D color rendering limitation, and an 800×600 resolution limitation, no other manufacturers' products could match the smooth framerates that the Voodoo2 produced. It was a landmark (and expensive) achievement in PC's 3D-graphics. Its excellent performance, and the mindshare gained from the original Voodoo Graphics, resulted in its success. Many users even preferred Voodoo2's dedicated purpose, because they were free to use the quality 2D card of their choice as a result. Some 2D/3D combined solutions at the time offered quite sub-par 2D quality and speed.

The arrival of the NVIDIA RIVA TNT with integrated 2D/3D chipset would offer minor challenge to the Voodoo2's supremacy months later.

SLI

The Voodoo2 introduced Scan-Line Interleave (SLI) to the gaming market. In SLI mode, two Voodoo2 boards were connected together, each drawing half the scan lines of the screen. For the price of a second Voodoo2 board, users could essentially double their 3D throughput. A welcome result of SLI mode was an increase in the maximum resolution supported, now up to 1024×768. Despite the high cost and inconvenience of using three separate graphics cards (two Voodoo 2 SLI plus the general purpose 2D graphics adapter), the Voodoo2 SLI scheme was clearly the pinnacle of gaming performance at the time.

SLI capability was not offered in subsequent 3dfx board designs, although the technology would be later used to link the VSA-100 chips on the Voodoo 5.

Having since acquired 3dfx, NVIDIA in 2004 reintroduced the SLI brand (now for Scalable Link Interface) in their GeForce 6 Series. ATI Technologies has also since introduced its own multi-chip implementation, dubbed "CrossFire". Although Scalable Link Interface and Crossfire operate on the original SLI principle, the algorithms used are now totally different.

Voodoo Banshee

Creative 3D Blaster Banshee AGP

Near the end of 1998, 3dfx released the **Voodoo Banshee**, which used a lower price to aim at a more mainstream consumer market. A single-chip solution, the Banshee was

essentially a legacy VGA core combined with an overclocked but incomplete (only one Texture Mapping Unit) Voodoo2. The Banshee's single-chip form factor dictated a 128-bit memory bus, like the first Voodoo. Performance wise, the Banshee was a mixed bag. In scenes which used multiple textures per polygon, the Voodoo2 was substantially faster, due to the second TMU. In scenes dominated by single-textured polygons, though, the Banshee would match (or even slightly exceed) the Voodoo2 due to its higher clock speed. While it was not a hit on the scale of the Voodoo 1 or 2, the Banshee sold a respectable number of units, although 3dfx started losing some market share to NVIDIA's RIVA TNT.

While the 3D performance was somewhat of a disappointment, Banshee's 2D core was anything but. It rivaled the fastest 2D cores from Matrox, NVIDIA, and ATI. The chip was equipped with a 128-bit 2D GUI engine and a 128-bit VESA VBE 3.0 VGA core. It was perhaps the fastest MS-DOS performer released, certainly at the time. Windows performance was equally impressive. The graphics chip capably accelerated DirectDraw and supported all of the Windows Graphics Device Interface (GDI) in hardware, with all 256 raster operations and tertiary functions, and had hardware polygon acceleration. All of this helped the 2D core be able to boast near-theoretical performance with a null driver test in Windows NT. 3dfx had indisputably fixed part of the weakness of the older Voodoo Rush with its slow 3rd-party 2D chip.[3][4]

Sega Dreamcast

In 1997, 3dfx was working with Sega to develop Sega's next video game console. The process involved two competing designs: a unit called "Katana" being developed in Japan using NEC and VideoLogic technology vs. the "Blackbelt", a system designed in America using a 3D accelerator from 3dfx. This deal had the potential to get 3dfx's foot in the home console door, provided the Blackbelt became the console that would become the Sega Dreamcast. Unfortunately for 3dfx, Sega chose the NEC solution. 3dfx sued Sega for breach of contract when the Katana was chosen, accusing Sega of starting the deal in bad faith to take 3dfx technology, and eventually the case was settled out of court; but the failure of the Blackbelt was 3dfx's own doing.

When 3dfx declared its Initial Public Offering (IPO) in April 1997, it made the mistake of revealing every detail of the contract with Sega. By law, when a company files an IPO in the United States, it has to make public all details of its business and financial situation, but sensitive information can be kept secret, so long as it does not materially affect the company's statement of its financial position and outlook. Sega had been keeping the development of its next-generation console secret during this competition, and was outraged when 3dfx publicly laid out its deal with Sega over the new system in the IPO; Sega quickly quashed the Blackbelt and used the Katana as the model of the Dreamcast.

Decline

In early 1998, 3dfx embarked on a new development project. The Rampage development project was new technology for use in a new graphics card that would take approximately two years to develop, and would supposedly be several years ahead of the competition once it debuted. The company hired hardware and software teams in Austin, Texas to develop 2D and 3D Windows device drivers for Rampage in the summer of 1998. The hardware team in Austin initially focused on Rampage, but then worked on transform and lighting (T&L) engines and on MPEG decoder technology. (Later, these technologies were part of the NVIDIA asset purchase in December 2000.)

Voodoo3 and strategy shift

Voodoo3 3000 AGP box art.

3dfx executed a major strategy change just prior to the launch of Voodoo3 by purchasing STB Technologies, which was one of the larger graphics card manufacturers at the time; the intent was for 3dfx to start manufacturing, marketing, and selling its own graphics cards, rather than functioning only as an OEM supplier. This alienated 3dfx's OEM customers, all of whom chose to switch, and source their 3D chips from other manufacturers, rather than do business with a company who was their direct competitor at retail. With the purchase of STB 3dfx created a line of Velocity boards (a STB brand) that used crippled Voodoo3 chips, as a product to target the low-end market. The chip came with only a single functional TMU, making it similar to a Voodoo Banshee.

This strategy change was one of the main contributors to 3dfx's downfall; the company did not sell any Voodoo 4 or 5 chips to third party manufacturers. The company was also presumably distracted by the need to focus both on the retail market as well as the OEM market, selling cards to computer manufacturers. The latter was hard-won business, but provided a steady income to fund subsequent development. A significant requirement of the OEM business was the ability to consistently produce new products on the six month product refresh cycle the computer manufacturers required; 3dfx did not have the methodology nor the mindset to focus on this business model. In the end, 3dfx opted to focus on the retail business using its own manufactured and branded products.

The Voodoo 3 was heavily hyped as the graphics card that would make 3dfx the undisputed leader but the actual product was below expectations. Though it was still the fastest by a small margin, the Voodoo 3 lacked 32-bit color and large texture support, features that fledging rival NVIDIA included in the competing RIVA TNT2. While at the time, few games supported large textures and 32-bit color, and those that did generally were too demanding to be run at playable framerates, the features "32-bit color support" and "2048x2048 textures" were much more impressive on paper than 16-bit color and 256x256 texture support. The Voodoo3 sold relatively well, but was disappointing compared to the first two models and 3dfx gave up the market leadership to NVIDIA. Ironically, 3dfx's actions in the STB buyout had turned a lot of its former board partners

into NVIDIA-exclusive suppliers (ATI did not start outsourcing its products until 2002), giving NVIDIA a major advantage in the marketplace.

As 3dfx attempted to counter the TNT2 threat, they were caught off guard by NVIDIA's GeForce 256, which took the performance crown by a wide margin, making it superior to the Voodoo 3 in all respects (except price). 3dfx missed a product cycle as they attempted to match the GeForce.

Voodoo 4 and 5

Voodoo5 5500.

The company's next (and as it would turn out, final) product was code-named Napalm. Originally, this was just a Voodoo3 modified to support newer technologies and higher clock speeds, with performance estimated to be around the level of the RIVA TNT2. However, Napalm was delayed, and in the meantime NVIDIA brought out their landmark GeForce 256 chip, which shifted even more of the computational work from the CPU to the graphics chip. Napalm would have been unable to compete with the GeForce, so it was redesigned to support multiple chip configurations, like the Voodoo2 had. The end-product was named VSA-100, with VSA standing for Voodoo Scalable Architecture. 3dfx was finally able to have a product that could defeat the GeForce.

However, by the time the VSA-100 based cards made it to the market, the GeForce 2 and ATI Radeon cards had arrived and were offering higher performance at that price point. The only real advantage the Voodoo 5 5500 had over the GeForce 2 GTS or Radeon was its superior anti-aliasing implementation, and the fact that it didn't take such a large performance hit (relative to its peers) when anti-aliasing was enabled. 3dfx was fully aware of the Voodoo 5's speed deficiency, so they touted it as quality over speed, which was a reversal of the Voodoo 3 marketing which emphasized raw performance over features. 5500 sales were respectable but volumes were not at a level to keep 3dfx afloat.

The Voodoo 5 5000, which had 32 MB of VRAM to the 5500's 64 MB, was never launched, as the smaller frame buffer didn't significantly reduce cost over the Voodoo 5 5500.

The only other member of the Voodoo 5 line, the Voodoo 4 4500, was as much of a disaster as Voodoo Rush, because it offered performance well short of its value-oriented peers combined with a late launch. Voodoo 4 was beaten in almost all areas by the GeForce 2 MX — a low-cost board sold mostly as an OEM part for computer manufacturers — and the Radeon VE.[5]

One unusual trait of the Voodoo 4 and 5 was that the Macintosh versions of these cards had both VGA and DVI output jacks, whereas the PC versions only had the VGA connector, and lacked DVI. Also, the Mac versions of the Voodoo4 and 5 had an

Achilles' heel in that they did not support hardware-based MPEG2 acceleration, which hindered the playback of DVDs on a Mac equipped with a Voodoo graphics card.

The Voodoo 5 6000 never made it to market, due to a severe bug resulting in data corruption on the AGP bus on certain boards, and was limited to AGP 2x. It was thus incompatible with the then-new Pentium 4 motherboards. Later tests proved that the Voodoo 5 6000 outperformed not only the GeForce 2 GTS and ATI Radeon 7200, but also the faster GeForce 2 Ultra and Radeon 7500. In some cases it was shown to compete well with the GeForce 3, trading performance places with the card on various tests.[6] However, the production cost of the card, particularly the 4 chip setup, external power supply and 128 MB of VRAM, would have likely hampered its competitiveness.

In late 2000, not long after Voodoo 4's launch, several of 3dfx's creditors decided to initiate bankruptcy proceedings. 3dfx would have had virtually no chance of successfully contesting these proceedings, and instead opted to be bought by NVIDIA, ceasing to exist as a company. Most of the design team working on "Rampage" (the successor to the VSA-100 line) was transferred to the team working on what has since become the GeForce FX series.

After NVIDIA acquired 3dfx, mainly for its intellectual property, they announced that they would not provide technical support for 3dfx products. Drivers and support have since been available at Voodoo Files and other various websites. NVIDIA offered a limited time program where 3dfx owners could trade in their cards for NVIDIA cards.

Cause of decline

3dfx's decline is a matter of debate. 3dfx lavishly spent on its employees — it reported spending $30,000–50,000 on company lunches and other perks a month, even up to the last two weeks before it went under.

3dfx's fall is most often attributed to managerial prioritizing of research and development. Voodoo cards were typically highly expensive, and left the mid and low end of the market to ATI and NVIDIA. NVIDIA chose short development cycles, whereas 3dfx pursued lengthy, ambitious development cycles, and NVIDIA and ATI cards eventually ended up with better overall performance, with Matrox holding the edge in image quality. NVIDIA's flagship GeForce 256 and GeForce 2 GTS are often given credit for the demise of the competing Voodoo 3 and Voodoo 5, respectively, and thus that of 3dfx. However, it is also important to note that the GeForce's midrange derivative, in the form of the GeForce 2 MX, was what successfully targeted the masses and grabbed a huge amount of market share for NVIDIA. By the time that 3dfx rolled out the Voodoo 4 4500 to counter the MX, it was late to the market and failed to match Nvidia's offering in price and performance.

When Greg Ballard became CEO of 3dfx in 1997, analysts marked it as a turning point since Ballard was a marketing guru, but he failed to understand R&D in the graphics industry. His attempt to develop a single-card 2D/3D solution in the forms of the Voodoo Banshee and the Voodoo3, even though that was 3dfx's weak point, ended up costing the company millions in sales and lost market share as well as diverting vital resources from the Rampage project.

3dfx also released word in early 1999 that the Voodoo2 would not support DirectX when running in Windows 2000. OpenGL support and Glide support would remain, but this announcement caused many eager gamers to switch to alternative Nvidia or ATI offerings for their new machines.

The "Rampage" project, which 3dfx put much effort into but never was able to bring to market, debuted in 3dfx's labs in December of 2000, within weeks of the sale of 3dfx's assets to NVIDIA. The Rampage design team was using a pioneering synthesis tool set which was still under development as the design proceeded.

In addition, the company continued to vacillate on its commitment to the delayed Rampage project versus the need for short-term retail products, such as the Voodoo 3 and Napalm/VSA-100. Because Rampage was oft-delayed — it had been scheduled to show at the 1998 Comdex — 2D and 3D driver software was up and running when it hit the lab.

However, the impending release of Rampage was too little, too late. The deal to "wind down" the company was less than 2 weeks from closure at that point. The history of and participants in the 3dfx/NVIDIA deal making can be read in the respective companies financial filings from that time period. The resolution and legality of those arrangements (with respect to the purchase, 3dfx's creditors and its bankruptcy proceedings) was still being worked through the courts as of August 2006, nearly 6 years after the sale.

While some have speculated that shipping the "Rampage" might have saved 3dfx, the fact remains that the company never mastered the new concept of relatively cheap, high-performance dies with integrated 2D acceleration, which was to become the *de facto* standard of PC graphics cards very soon. The success of "Rampage" would not have simply depended upon raw performance, but also the cost of manufacturing, very much reflected in retail prices. According to documents from late in 3dfx's life, the "Rampage" core was evidently not too much more than a more powerful version of the VSA-100, with an entirely separate chip code-named "Sage" required for T&L and hardware shader operation; though to their credit, support for DDR-RAM was implemented. It remains unknown whether "Rampage" would have been a practical product, let alone enough to keep the company alive in the card industry.

Chipset table

Chip	Release Date	Components (PPxTMU)[6]	Core (MHz)	Memory (MHz)	Fillrate[7] Pix/Tex	Memory Bus	Memory (MiB)	Bus

						Width[9]		
Voodoo Graphics	October 1996	SST-1 chipset (1x1). No VGA.	50	50	50/50	64-bit×2	4/6 EDO	PCI
Voodoo Rush	April 1997	SST-96 chipset (1x1). 2D Chip.	75	75	75/75	64-bit×2	6/8 EDO	PCI
Voodoo2	January 1998	SST-2 chipset (1x2). No VGA.	90	90	90/180	64-bit×3	8/12 EDO	PCI
Voodoo Banshee	October 1998	Single-Chip (1x1) (**2D/3D**)	100	110	100/100	128-bit	8/16 SD/SG	AGP 1x/PCI
Velocity 100	July 1999	Avenger core (1x1). 1 Disabled TMU.	143	143	143/143	128-bit	8 SG	AGP 2x
Velocity 200	Not released	Avenger core (1x1). 1 Disabled TMU.	143	143	143/143	128-bit	16 SG	AGP 2x
Voodoo3 1000	March 1999	Avenger core (1x2)	125	125	125/250	128-bit	8 SG	AGP 2x
Voodoo3 2000	April 1999	Avenger core (1x2)	143	143	143/286	128-bit	16 SD/SG	AGP 2x/PCI
Voodoo3 3000	April 1999	Avenger core (1x2)	166	166	166/333	128-bit	16 SD/SG	AGP 2x/PCI
Voodoo3 3500	July 1999	Avenger core (1x2), A/V processor	183	183	183/366	128-bit	16 SD	AGP 2x
Voodoo 4-2 4200	Not released	1 x VSA-101[8] (2x1)	183	183	366/366	64-bit	32 DDR	AGP 4x/PCI
Voodoo 4 4500[5]	October 2000	1 x VSA-100 (2x1)	166	166	333/333	128-bit	32 SD	AGP 4x/PCI
Voodoo 4 4800	Not released	1 x VSA-100 (2x1)	166	166	333/333	128-bit	64 SD	AGP 4x/PCI
Voodoo 5 5000	Not released	2 x VSA-100 (2x1)	166	166	667/667	128-bit×2	32[1] SG	AGP 2x/PCI
Voodoo 5 5500[5]	June 2000	2 x VSA-100 (2x1)	166	166	667/667	128-bit×2	64[2] SD	AGP 2x/PCI
Voodoo 5 6000	Not released	4 x VSA-100 (2x1)	166/183[4]	166/183[4]	1333/1333	128-bit×4	128[3] SD	AGP 2x
Spectre 1000	Not released	1 x Rampage (4x1)	200-250 (planned)	200-250 (planned)	800-1000	128-bit	64 DDR	AGP 4x

Spectre 2000	Not released	1 x Rampage (4x1) + 1 x Sage T&L-Chip	200-250 (planned)	200-250 (planned)	800-1000	128-bit	64 DDR	AGP 4x
Spectre 3000	Not released	2 x Rampage (4x1) + 1 x Sage T&L-Chip	200-250 (planned)	200-250 (planned)	1600-2000	128-bit	128 DDR	AGP 4x

Notes:

- **2D/3D** - products released before the Banshee can only display 3D graphics..
- [1] Shared by two processors; effectively 16 MiB VRAM.
- [2] Shared by two processors; effectively 32 MiB VRAM.
- [3] Shared by four processors; effectively 32 MiB VRAM.
- [4] The Voodoo 5 6000 was originally intended to have a core and memory clock of 183 MHz, but 3dfx reduced the clock speed to 166 MHz in an attempt to get the boards stable while operating in 2/4/8x AA modes. Since the instability problem was due to a design flaw in the PCB the reduction in clockspeed did nothing in regards to the problem. 3400 and 3700 boards with the "PCI bus modification" by ex-3dfx engineer H.S. run stable in all modes with speeds upwards of 190 MHz.
- [5] Macintosh versions were released later with the same specs, but only in PCI.
- [6] Pixel pipeline/s x Texture management unit/s (TMU).
- [7] Fillrate is measured in Megapixels/sec for pixel fillrate and Megatexels/sec for texture fillrate. Taking advantage of double texture fillrate per clock cycle requires the game engine to make use of multitexturing.
- [8] Daytona core
- [9] Voodoo boards with multiple chips often have independent memory busses for each chip's memory bank. This resulted in boards with large amounts of memory, but the memory was split between the completely separate chips. So while a Voodoo2 has 8 or 12 MiB of RAM, this RAM is split up between the texture and framebuffer.

  In the case of Voodoo2 12 MiB, there is 4 MiB texture RAM for each texture processor and 4 MiB for the framebuffer. When a game is not multitexturing, a total of 8 MiB texture memory is available. With multitexturing, this is halved to 4 MiB. SLI, however, does not double the available RAM because the boards separately calculate their part of the scene.
  This split-RAM architecture caused the resolution limits on the older boards. For Voodoo Graphics' 4 MiB RAM (2 MiB framebuffer) framebuffer size only allowed for a 640 × 480 resolution when z-buffering was used. Some games managed 800 × 600 without z-buffer, such as MechWarrior 2 3Dfx Edition, Jedi Knight, and Need for Speed III.[7]

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