As the old political slogan goes, “You don’t need a weatherman to know which way the wind is blowing.” Even those of us in the ivory towers of academia can sniff something in the air. And that breeze is turning into a whirlwind as PCs with substantial 3D graphics arrive on desktops everywhere. It was only a few years ago that people sniggered at PC graphics and laughed out loud at the notion of PCs with robust and versatile operating systems. Now, however, PC operating systems—especially Windows NT—have software development, networking, multiprocessing, and other tools to rival Unix environments. A user or developer can add a 3D graphics accelerator offering pipelined rendering, full texture mapping, and a complete set of graphics tools with performance that competes with midrange graphics workstations. And no one is going to beat the price point.

On top of all this, it’s clear that Intel and Microsoft take this market seriously. Microsoft has developed its own 3D graphics library and scene development tools that closely integrate with its operating systems. Until recently, Microsoft was even developing its own graphics hardware, called Talisman. However, even Microsoft got the willies when it contemplated the cutthroat PC hardware market and turned Talisman into a software-only project.

Intel has no such qualms and has forged ahead with substantial graphics hardware and software system development. Not too long ago an Intel spokesman said that 80 percent of PCs would have 3D graphics by the year 2000. This may not be such a risky prediction, since Intel plans to supply most of those chips. At Siggraph 97 an Intel vice president declared that although in 1996 Intel was only a speck on the horizon, in 1997 it was competitive, and by 1998 it meant to dominate the 3D graphics market. Whether this combative bluster materializes into fact, few can ignore 1,000-pound gorillas stomping around in their midst. Microsoft and Intel aren’t alone: companies like Hewlett-Packard, DEC, IBM, Evans & Sutherland, 3D Labs, and others have also caught the 3D graphics bug.

All this presents users with great opportunities and a few challenges. Broad consumer applications are opening much wider markets than before. Certainly games and entertainment lead the way, but hopefully those will not be the only places for 3D graphics. In this market, even niche applications can grow much larger than major applications in the traditional graphics workstation arena. Before long many users may see heavy-duty graphics and visualization applications integrated on their desks alongside word processing and business tools. In fact, 3D graphics will be a part of word processing, spreadsheets, and business tools.

To catch the changing climate, several of us in visualization put together a workshop on PC-based visualization and computer graphics at Visualization 97. Participants came from industry, academia, and government labs. We discussed the current state and future directions of PC graphics and visualization hardware, software, and applications. We were impressed by the range of applications already available and occasionally astonished at present or planned PC capabilities. Here I’ll present some highlights and revelations from the workshop.

Not your father’s PC

The relentless onward march of Moore’s Law and the arrival of an industrial-strength operating system in Windows NT (despite some areas of immaturity) have made the PC quite a different beast than even a few years ago. Similar trends should make the PC just as different in the future. You can now get a PC with two or even four processors with tons of disk space and memory. If you put such a thing on your desktop, it might break it. PC used to stand for personal computer, but these multiprocessor brawny lads look and act like servers. That’s how Intel and other manufacturers see them too.

During the workshop this problem of definition quickly became obvious. What do you do when your Pentium machine sits on the floor and does a good job as an auxiliary space heater and your Unix box (like the sweet little Silicon Graphics O2) curls up on your desktop with plenty of room to spare? It became apparent that a machine ought to be called a personal computer, serv-
er, or workstation based on its applications, not on the microprocessor it contained or its operating system.

The PC hardware companies certainly will market all types of machines. As a result, things will never be the same in the workstation market. For one thing, completely different economic models exist—profit margins of 10 to 15 percent in the Unix world plunge to 0.5 to 1.5 percent with PCs. Research and development costs are amortized and profits made by selling lots and lots of units. In the future, hardware might become commodified and software will provide the added value with specialized hardware plug-ins to boost performance where needed. To an extent, this has already happened with PC graphics.

Currently, you need a graphics accelerator (plug-in card or graphics subsystem) to achieve interactive 3D graphics. Ranges of accelerators are available starting from cards such as the Permedia 2 from 3DLabs. At the higher end are boards based on 3DLab’s Glint GMX or DMX, the Intergraph Realizm II GT, Evans & Sutherland’s Reallmage 3D graphics card, and, at the very top, the Hitachi Spherix subsystem. This list is not exhaustive. From the low to high ends, all these cards have at least some hardware geometry processing. However the higher end cards also deliver 24- to 32-bit z buffers, true color, hardware support for texture mapping, and lots of texture memory (32 to 48 Mbytes in some cases). At the lower end the supported graphics library tends to be Direct3D (part of the DirectX multimedia family) and at the higher end, OpenGL (sometimes also with Direct3D). A Microsoft product used mostly in games and entertainment applications, Direct3D was initially the only library available on Windows 95, though OpenGL is now available. OpenGL is, of course, the Silicon Graphics library.

Depending on your application needs, the computer supporting the graphics accelerator can have a range of sizes and costs. For bigger, multiprocess applications you may need a model with dual Pentium II processors running at 300 or more megahertz. Units with 4-Gbyte disks and 128 to 256 Mbytes of memory cost between $4,000 and $6,000. For smaller applications, you might get by with a single-processor machine with smaller disk and memory in the $2,000 to $3,000 range. Thus a complete 3D graphics machine, depending on need, might range from $2,500 to well over $10,000. However, as discussed in the “Applications” section below, graphics PCs starting at $3,000 to $5,000 prove adequate for many applications usually run on graphics workstations, and higher priced systems can handle other, more complex applications. Compared to Unix workstations, these PC solutions will continue to deliver significant price advantages.

The future will be different. To glimpse it we can follow the Intel development plan, since other chip makers must at least stay abreast. In the next few years we will see the advent of an integrated PC platform built for real-time media (including 3D graphics) and communication. It will have a factor of 10 improvement in memory bandwidth and a comparable improvement in compute power, with a full 64-bit architecture. These two improvements alone will close much of the performance gap between PCs and Unix workstations.

In addition, the PCI graphics bus will be replaced by the accelerated graphics port (AGP) configuration with pipelining, availability of both Direct3D and OpenGL, and a factor of 10 improvement in graphics memory bandwidth. The AGP graphics output (number of triangles per second and so on) will be 10 times better than hardware-accelerated performance at the 1996 level with such high-end effects as advanced filtering, atmospheric effects, bump mapping, and shadows becoming standard.

By the end of 1999 the standard home PC will be a $1,500 machine with a graphics pipeline handling everything but geometry generation, which would still be done in the CPU. The “workstation” would have pipelined geometry and other specialized processing capabilities. To top it all off, another order of magnitude increase in graphics performance is planned for the three years ending in 2002. The number of vendors selling graphics accelerators will certainly shrink as a result of all this. However, manufacturers will likely continue to offer accelerators with special capabilities or higher performance.

Unix extinction?

Will the PC meteor produce the explosion that annihilates the Unix dinosaur? A little historical perspective is useful here. The deaths of beasts such as the mainframe and Fortran were proclaimed loudly—several times. The mainframe remains as something called an “enterprise system,” and the only people who don’t realize that Fortran is still vibrant and useful may be computer scientists. There’s no reason to believe that Unix, and in particular Unix graphics workstations, are on their last legs.

But how will these animals co-exist? At Siggraph 96, graphicists from the PC and Unix worlds squared off in a “point-counterpoint” debate that encouraged extreme viewpoints. The PC advocates, of course, proclaimed that PCs were rapidly overtaking workstations and would drive them into Chapter 11. Michael Deering from Sun retorted that while PCs had found their killer

Web Resources
For more information on various topics mentioned in this article, visit the following Web sites:
http://www.zdnet.com/pcmag/features/workstations/_open.htm
for a comparison of latest 3D graphics workstations including PCs and Unix systems.
http://www.sgi.com/fairenhert/ for details on the Farhrenheit agreement and its impact
http://www.epa.gov/gisvis/ for a description of work at the Environmental Protection Agency’s Scientific Visualization Center
http://www.cc.gatech.edu/gvu/virtual/Phobia for a description of several VR.phobia projects
### Scene graphs

Building scene graphs

Toolkits for large-scale data and large 3D geometric models containing millions of polygons—such as those appearing in major CAD/CAM applications—have arrived on the market. One is DirectModel from Hewlett-Packard and the other is OpenGL Optimizer from Silicon Graphics. The former is implemented on top of graphics APIs such as Starbase or OpenGL, while the latter is an extension of OpenGL. Both appear on a variety of Unix platforms, plus Windows NT and Windows 95 PCs.

The central concept is to build a scene graph describing the 3D model or models in terms of their spatial relations. The scene graph is a directed acyclic graph whose nodes may contain geometry and texture information for components, branching information for levels of detail, nodes describing behaviors, and other attributes. The graph structure applies simplification and culling strategies where large parts of a single model or large numbers of objects may be discarded immediately because they’re out of view or simplified because they’re too far away. In addition, the toolkits treat the model as a database where appropriate parts are paged from disk as needed and cached in main memory. For certain applications, you can achieve interactive visualization for models 100 times larger than those handled by the standard graphics libraries. This is yet another case of significantly extending performance by applying clever algorithms without modifying the hardware.

### Visualizing geography

Terrain visualization and geographic information systems (GIS) are making a big show on the little boxes. A group at Shizuoka University in Japan has developed a terrain display system that connects a PC client with a server via the Web. The standard http (hypertext transfer protocol daemon) from the National Center for Supercomputing Applications and Netscape Navigator software are used for the server and client, respectively. The client has a clickable map to call digital elevation model (DEM) data from the server, which is then processed into a VRML file and transmitted to the client for viewing. After selecting Mount Fuji, for example, the client has full control of the view, spinning the mountain for a better view, zooming in or out, or flying over it.

Combining the Web and a client-server architecture effectively handles large data repositories or computation-intensive tasks. The Environmental Protection

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**User interface** to a prototype Terrain Modeling Web page under development at the US EPA Scientific Visualization Center. With a VRML browser, the user can interactively explore a specified terrain model.
Agency’s Scientific Visualization Center has also found that Java and VRML can be used for interactive geographic visualization (see Figure 1). In addition, they’re using the Environmental Visualization Toolkit—a customized AVS Express application developed by C Tech Development—on Windows NT and Windows 95 platforms. Their tests indicate that both Windows NT and Windows 95 could support visualization tasks for EPA users, and they’re confident that both platforms will be commonly used in three or four years.

Applications like these are part of a trend to make more data accessible to users, both in terms of large, networked repositories and tools to rapidly explore and understand the data. However, we still don’t know how to get the data to visual interfaces, which will increasingly be able to show more data than a standard network connection can provide at interactive rates.

Can a PC be used for a high-end visualization application? To answer this question, a group at Georgia Institute of Technology, working with researchers at Hitachi, ported VGIS (Virtual Geographic Information System)—which runs mostly on SGI Maximum Impacts and Reality Engines—to the Windows NT platform. VGIS, a multifaceted application, permits real-time navigation of environments including terrain, vehicles, building, roads, and other objects. It’s portable, using OpenGL and Posix threads. High-resolution scenes can contain more than 10 million polygons, but on-the-fly detail management algorithms can reduce this number by a factor of 100. Databases can also be several gigabytes in size, and the one used in the Windows NT version approached 2 Gbytes.

Since the application has five threads, three of which are intensive, and large I/O requirements, the Georgia Tech group expected that it might require extensive reprogramming to attain adequate performance. To their surprise VGIS ran without revamping of central algorithms on a two-processor Pentium Pro PC with a Spherix graphics subsystem at about 60 percent of the speed on a four-processor SGI Infinite Reality Engine. (See Figure 2 for some frames from PC VGIS.)

The main changes included rewriting the X Window interface and hand scheduling of the threads. VGIS still ran at 50 percent of the Infinite Reality speed with a cheaper UltraFX graphics card and, with some further thread optimization, at 40 percent of the IR speed on a one-processor Pentium Pro with an UltraFX card. Thus on a $7,000 desktop machine you can get adequate performance on an application that typically runs on a $100,000 to $200,000 graphics workstation. Considering the plans of Intel and others, the price of this PC graphics capability should drop significantly during the next few years.

**Porting Data Explorer**

Researchers at IBM have developed visualization services for consumers used to shrink-wrapped software. They ported the full-fledged Data Explorer (DX) visualization and analysis environment to laptops and other PCs. A recurring nightmare is what happens when they start getting phone calls for help from millions of users. To prevent this from happening, IBM provided a *fluid* client-server environment with a flexible boundary between the server and client spaces. You might have “thin” or “medium” clients with varying amounts of work being done on the server, which could provide design layers for choosing visualization composition based on user needs and intents, a warehouse layer for accessing various databases, and other services. The PC would produce visualizations from remote or local data, but the user would not have to know much about the DX system. Its visualization environment could be built on a variety of platform-independent tools such as VRML for geometry, Java applets for video and interactors, and Web browsers for text and hyperlinks.

**Steering environment**

Since PC graphics will soon be ubiquitous, why not make visual tools that produce or collect data ubiquitous, too? This requires bringing the steering of the sim-
ulations or data collection agents to the PC and is the object of a research group at the Center for Mathematics and Computer Science (CWI) in the Netherlands. The power of the PC will probably be adequate for this task, at least in a few years. However, the problem will lie in inadequate bandwidth for remote steering and display, and in providing useful interfaces for a much broader range of users, where the information needs may vary from user to user. But the outcome would be marvelous: providing “science on demand” for a range of activities from purely informative to educational.

To approach this goal, the CWI researchers brought their Unix-based steering system into Windows NT. Quite interestingly, the port of 50,000 lines to NT took only four days, as opposed to three weeks for a previous port from SGI Unix to Sun Solaris. (We always knew that these weren’t really versions of the same operating system!) When the CWI folks compared a two-processor Dell PC with a Fire GL card to a two-processor SGI Octane with Impact graphics, they got similar results. The difference was the price tag, since the workstation cost more than six times as much.

The steering system uses “parametrized graphical objects” (PGOs) for both the steering of the simulation and display of the results. Users may customize the visualizations by constructing the PGOs with a simple builder and then attaching variables to the object attributes (for example, attaching \( x, y, z \) to object position and a scalar variable to object color). Figure 3 shows the steering environment in action for a smog forecasting simulation.

**Cyber Mall**

All these applications are noteworthy, but everybody knows the ultimate way to interact with consumers is to get them to consume. Researchers at the Systems Engineering Research Institute (SERI) in Korea are attacking just that problem by developing a Cyber Mall, a distributed VR system where you can share your virtual world (and purchases) and shop till you drop—virtually.

The Cyber Mall turns out to be a rather complicated system with Web servers, player clients, avatars, and authoring tools for mall rooms, contents, and avatars. The client side runs on a Pentium PC with Fire GL or a GLyder/TX card using Visual C++ and Open Inventor. The multi-roomed environment might have a toy store, clothing stores, and home furnishing stores (see Figure 4 for pictures of the toy store authoring environment and browser). In this world you can show off a dress to a friend or discuss a purchase with a salesperson avatar.

**Fighting phobias in VR**

Finally, growing evidence suggests that instead of serving as places to retreat from the real world, virtual worlds can actually help you learn to cope with the real world. A variety of clinical studies show that VR environments can make phobics react realistically to virtual heights, airplane rides, public spaces, or combat situations, and can provide conditions under which they can overcome their phobias. As researchers at Georgia Tech and Emory University have shown, all this capability can be delivered on a stand-alone PC, meaning
that it’s affordable, compact enough, and supportable in a doctor’s office. The PC can support the entire virtual environment including head and hand tracking, head-mounted display, geometry storage and real-time display, and nonvisual effects such as sound. A Pentium II PC running Windows 95 and Direct3D with a Glint 500 TX card does nicely. Figure 5 shows displays from battlefield stress and fear of flying simulations.

Looking ahead

The workshop and this report provide just a glimpse of what’s going on in PC graphics. Hardware, software, and application development are moving so fast that any written report becomes dated as soon as it’s published. Perhaps a more active way of keeping up with the field is necessary (see the sidebar “The Next Step in PC Graphics”). Still, the several broad themes discussed will continue.

Certainly PC graphics has arrived with substantive capability and real applications. Workstations or personal systems will be defined by their capabilities and focus, not by their operating systems. As a result, a sort of grand unification has been taking place so that for the casual consumer, the line between Unix and the latest flavors of Windows will blur to the point of irrelevance. Graphics applications and customers will soon be much more numerous than now, and the traditional graphics market will become a niche. This doesn’t necessarily mean that traditional vendors of graphics hardware and software will struggle, but rather that all segments of the market will grow.

However, consumer-targeted applications will grow the fastest. Since PC home office, business, and Web products are already here, we can expect to see an integration of 3D graphics with these tools. If we’re lucky, we’ll see completely new tools as well, such as interactive visual browsers that permit you to quickly explore vast collections of files (your PC may soon be able to hold tens of thousands), knowledge bases, multimedia stores, and deep Web structures.

But beware—a completely different economic model for graphics and visualization is now appearing. The consumer orientation means that there’s fierce competition, many new products, and significantly lower prices. It also means that the market will be controlled by forces well outside the interests of the graphics and visualization community. For example, how will the demand for PCs under $1,000 affect the ability or desire of Intel and others to produce high-end chips and applications? These forces, of course, affect everybody now, and the stable workstation environment of the past is also ending. Perhaps the best we can do is buckle our seatbelts, because it’s going to be a wild but interesting ride.

References


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The Next Step in PC Graphics

A more complete report of the workshop with links to PC-based research projects can be found at http://www.cc.gatech.edu/gvu/tccg/pcvis.html. We’re interested in hearing suggestions as to what the next step should be. Should we continue to have a workshop or establish another venue, or should we just expect PC visualization and graphics to be integrated into the regular IEEE Computer Society Technical Committee on Computer Graphics conferences? Since PC graphics capabilities and applications are changing so rapidly, perhaps the Web itself can be used as a means for compiling and disseminating information. Send comments to ribarsky@cc.gatech.edu.