Return of the Cavemen

The CAVE: a tunnel into the virtual future

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Dark gloomy light reaches the back of the cave and draws vague shadows of moving people on it. They do not talk, but communicate with low growls, crude gestures, and, when needed, with straightforward acts of violence. The people, living on the transition from apes to humanoids, do not know about luxury, nor do they think of making their cave a comfortable place to be. All they care for is the protection the cave offers; without it, they would have frozen to death or been eaten by some of the powerful predators. Therefore, their reality stretches not far beyond the entrance of the cave, in fact, the cave and life are pretty much the same...

The scene sketched above could be part of a fiction book about prehistoric men. However, could there be similarities with people living in the near future? Surely, we do not think we will leave our homes and move back to the woods, seeking shelter in caves. But, maybe, new technologies could gain a prominent place in our daily lives, such that it would resemble the importance of the cave to the cavemen.

This article is about a new technology that does have the potential to become very useful. The technology is called the *CAVE*, yet another similarity, and it can create a three dimensional virtual world in which you can ”move” freely in any direction you like. The CAVE is a GNU-like acronym that stands for “Cave Automatic Virtual Environment”. We, the authors, visited the computer center SARA in Amsterdam, and were given a demonstration of their CAVE by Mr Breedveld, marketing manager.

Excavating the CAVE

A schematic picture of the CAVE is given in Figure 1. The picture is a top view of the CAVE and shows the relative position of the four cameras and the four projections screens (three walls and the floor).

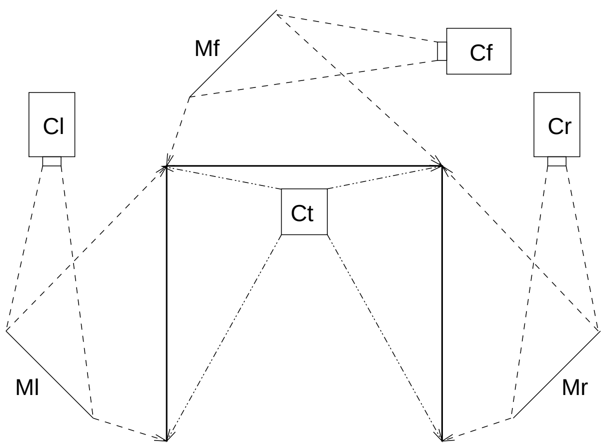

Figure 1. Schematic view of the CAVE. Cl, Cf, Cr, and Ct are the left, front, right, and top cameras, respectively. Ml, Mf, and Mr are the corresponding mirrors.

At a high level, the CAVE technology can be split up in the following parts:

The room

To the external observer, the CAVE is a space of 3 × 3 × 3 meter, delimited by cloth curtains at three of the sides. These walls and the floor are used to project images on their back, allowing the light to shine through the fabric. The projectors used are ordinary BarCo projectors, well known from the better-equiped auditoria. The distance between projectors and curtains is shortened by using mirrors which reflect the light halfway. Since human vision easily distinguishes minute nuances, the projected images have to be very accurate, and, consequently, the relative positions of walls, the mirrors, and the projectors have to be calibrated well, which can takes hours.

To prevent the people in the CAVE from seeing their own shadow, the floor image is projected at a certain angle (see camera Ct in Figure 1). If a person in the CAVE faces one of the three walls or the floor, he will not see his own shadow. However, if he turns around, facing the void in the back of the CAVE, he will see his own shadow on the floor.

Hardware

To generate realistic and realtime images, advanced supercomputers are needed. For SARA's CAVE, this is a Silicon Graphics Onyx2 RealityMonster (What's in a name). This computer is capable of producing detailed 3D graphics primitives based on the actual position and viewpoint of the user in the CAVE. Tracker devices, placed at the ceiling of the CAVE, track the position of the user. This information is input to the RealityMonster, which uses it to compute the two dimensional projection images. To this end, each of the four projection walls is served by a dual graphics pipeline. To simulate the 3D effect, shutter glasses are used. This is a pair of goggles which shut (hence the name) left and right glasses alternatively. This alternation is synchronized with the projection of images of the graphics pipelines for left and right eye. Now, as for the right eye, the left eye will only see images computed for the left eye. Although shutter glasses have been known to cause nausea after extended use, the high alternation frequency of 60 Hz eliminates this effect. The current frequency (120 Hz) and resolution (2048×1576)? are about the maximum possible with current RAMDAC technology. However, these values prove to be effective in providing a very realistic 3D experience.

Apart from vision, the aural senses are served by a Dolby surround sound system. The sound system is supportive to the 3D experience.

The CAVE user uses a 3D joystick, called the wand to move through the virual world, and to select and move objects in this world. In turn, the moves of the wand are translated to changes of the user's position in the 3D model.

Software

Applications for the CAVE can be programmed using standard 3D software libraries like OpenGL. Consequently, the applications can be designed and tested on a desktop PC, leaving the expensive CAVE resources available to user facilities only. There are also tools available to convert output of e.g., CAD software to simulation formats.

The OpenGL interface to the RealityMonster is provided by Silicon Graphics. The underlying software is highly specialized, for example, part of this software is dedicated to control the four projection screens. As the OpenGL interface, this dedicated software comes with the CAVE, and therefore, application programmers need not have detailed knowledge about it.

What's on the CAVE tonight?

Considering the expense of building a CAVE (roughly a 7 figure amount), it has to be of good use to someone. Fortunately, several commercial applications justify existence of the thirty-something CAVE's around the world.

Civil works

An interesting application was a virtual mock-up of a "sluizencomplex" near Enkhuizen. By converting existing CAD files to the simulation format, a virtual model of the complex could be build in hours for much lower cost than a physical set-up with fixed viewpoints. Using such mock-ups ensures Rijkswaterstaat that what they are actually building will fit to its purpose.

Biochemistry

In biochemics, making models of molecules is quite common (remember the double helix?). However, making such models of enzymes is time-consuming and provides little interactivity. The virtual enzyme application allowed researchers from Unilever to examine in detail how a dust particle would be 'consumed' by an enzyme used in detergents.

Climatological

Climatological data is vast and complex to analyse numerically. Therefore, using models to visualize the data is already very common in this research area. One CAVE application made it possible to analyse data from a storm cloud in five dimensions: the ordinary three, colour for temperature and projected arrows for wind speeds. The dataset thus became a cloud which could be watched over time.

Collaborative Environments

An interesting future application may be collaborative environments. Although some experiments futuring CAVEs already take place in this research area, synchronization of the CAVEs is a far from trivial problem that still needs to be addressed. One example project to examine these issues is based on an artificial soccer match. The annual Robocup competition, in which teams of scientists construct robots that are able to play soccer with eachother, has shown that soccer is an ideal game to test artificial, agent-based, distributed intelligence. The challenge that some VU scientists have posed to themselves is to have human actors cooperate in these teams, and even to have teams in several CAVEs play against eachother.

Training

A truly interactive environment is the one in which mechanics can deconstruct a virtual car engine. Using the wand, a virtual hand can grap parts of the engine and move them out of the way. The 3D data required to construct the model is often already available from engineering departments. Apart from reducing the need for expensive physical prototype and the time before training can begin, the mechanics insight in the engine construction and operation can be greatly improved.

Entertainment

Of course, there always is DOOM and the like. Although we didn't get the change to "shoot some up", according to Mr Breedveld this becomes a truly daring experience.

Conclusions

The CAVE gives a very impressive experience of the power of immersive virtual reality. On our personal account, we found much realism, despite the seemingly low resolution and the use of only four out of six walls. We tended to twist our bodies when moving around through this space as though compensating for non-existant gravity forces. The capability to look around corners also is quite intriguing. The glasses seem non-existant after some time.

Further, the business benefits of the technology are also clear. It is currently too expensive a technology to have within your company. However, with hardware pricing continuing to drop, we can soon expect that many companies will own a CAVE on their own. Should your company be interested in the CAVE, just contact CAVEman Breedveld of SARA. He'll be happy to show you around in the CAVE.