Finding oil is always a difficult and expensive task, and moving exploration and production (E&P) offshore quickly drives those costs sky-high. Because most easy oil has already been found, any new discoveries are often subtle and relatively small. Once a company does find a reservoir, deciding where and how to drill to maximize production—and thus return of investment—is a major task. The wrong approach or small inaccuracies can easily ruin an entire reservoir’s ROI.

Clearly, we need good tools to complete these difficult E&P tasks. In the 1980s, graphics workstations significantly changed and improved the work process. As Mons Midttun and Christopher Giertsen noted, however, workstations had some fundamental weaknesses, particularly in manipulating 3D objects with 2D interaction, and in interpreting complex 3D structures on a small screen. In 1992, the University of Chicago’s Electronic Visualization Laboratory (EVL) introduced the CAVE, a room-sized, multiperson projector-based immersive VR environment. CAVE laid the foundation for a new paradigm: using VR for petroleum E&P.

Although VR was still in its infancy at that time, the Norwegian oil company Norsk Hydro saw the technology’s potential. Still, there was no framework for developing VR for E&P. Working with the Norwegian research institute Christian Michelsen Research (CMR), Hydro began work on a proof-of-concept demonstration. The goal was to show that, by using VR technology, a company could perform critical E&P operations “more efficiently, with better quality, and at lower costs.” In 1997, Hydro invested in a CAVE laboratory and CMR began developing the HydroVR application.

The HydroVR project both changed work processes and increased revenue for petroleum E&P in general. Here, we describe the project’s major application milestones and summarize how and why the project has sustained its extensive activity over the past 10 years.

First major milestone: Well planning (1998)

The CAVE easily accommodates six to eight people, making it ideal for interdisciplinary work. Because well planning involves experts from many different scientific disciplines, we selected it for a proof-of-concept implementation of an E&P VR system.

Traditionally, well-planning experts work in a highly sequential order, starting with the reservoir engineers, then moving on to the geologists and geophysicists, and finally to the drilling engineers and the contractors. It’s common to have several iterations at each stage—as well as across the entire process—because each expert has his or her own constraints and goals. Such goals often conflict with those of experts in other disciplines. Also, each discipline typically uses different software applications. Finally, the well path is often laid out only in 2D maps and cross sections, making it difficult to understand the 3D relationships between the reservoir model and the planned well bore.

From the users’ viewpoint, the E&P VR application’s main requirements were to

- import all of the various disciplines’ data types,
- offer functionality for displaying, analyzing, and manipulating those data types,
- permit interactive 3D drawing of the well path that obeys physical and technical constraints, and
- output the well path to a file format supported by conventional well-planning software.

We designed HydroVR to fulfill these requirements.

HydroVR overview

Figure 1 shows a sketch of the HydroVR design. At the lowest level, HydroVR has a kernel controlling the program flow and managing messages and events. Separate modules, called formats, handle data loading. Typically, there’s one format for each data type—one format for seismic 3D volumes, another for interpreted horizons, and so on. Some data types must be preprocessed before they can be imported; we do this preprocessing in a standalone application or at runtime during import.

For data-type rendering and interaction, we use modules called tools. Although some formats have corresponding tools, typically, a tool combines data from several formats and (likewise) several tools can manipulate a particular format’s data type. The tools are self-contained and include event-handling, GUI, and rendering routines. We designed the tools and formats according to a Model-View-Controller pattern, which automatically updates the tools if we change the formats.
From the beginning, we designed the formats and tools as plug-ins to the kernel for loading as needed. The plug-in design gives users and developers great flexibility. Users can configure the number of tools and formats available without any recompilation. Likewise, developers can build a new tool without recompiling the whole system, thus cutting developing time.

Figure 2 shows an example of a well-planning session. Well planning involves many tools, including those for direct and indirect volume rendering, geometry rendering, transfer-function manipulation, and editing the well path.

HydroVR renders all data types in a single coordinate system in a common arena. It renders geometry, such as horizons and well paths, together with volume data. Well planners can thus access all required information without having to change views, thereby improving the planning process. In addition, mixing data types offers a valuable tool for verifying interpreted data.

**Development context**

When we started the project in 1997, many researchers were working on VR. Actual VR systems, however, were limited to geometric-model walkthroughs; none were targeted for E&P, and there were no ready-made VR toolkits for implementing the HydroVR application.

During our project’s initial phase, we visited several research environments. Among them was the National Center for Supercomputing Applications, which developed the Crumbs VR application for biological applications. To give HydroVR a quick start, we purchased the Crumbs VR source code and used parts of it for our implementation. We use VRCo’s CAVELib to set up the VR projections and communication with 6 degrees-of-freedom (6DOF) VR devices.

**Case studies**

Several case studies at Hydro have evaluated well planning in the CAVE. Midttun and colleagues, for example, describe example applications at the Troll and Oseberg oil fields in the North Sea. At the Troll field, the experts had difficulties executing traditional well planning. After experts joined in a CAVE work session, they more easily understood each other’s objectives and the technical problems involved. After just one day in the CAVE, the experts agreed on a more optimal well path. In another CAVE session, experts discovered a flaw in the geological model compared to the seismic data. By updating the model accordingly, they discovered more valuable oil-filled sand, resulting in an estimated production increase of 100,000 m³ oil. At Oseberg, several wells planned in the CAVE had about 20 percent more oil-filled sand compared with nearby (traditionally planned) wells.

As these examples show, well planning in VR led to several improvements. Experts detected errors in their models and interpretations. The planning process, which typically required two to three weeks, required only two to three days in the CAVE. Most importantly, well accuracy improved and thus the wells produced far more oil.

**Second major milestone: Remote collaboration (2002)**

Well planning proved that VR and the CAVE offered a valuable tool for interdisciplinary cooperation. Initially, however, HydroVR was based on same-time/same-place cooperation. Hydro has many offices around the world and thus wanted to extend HydroVR to support same-time/different-place cooperation, or remote collaboration.

When we started, remote collaboration in VR was in the research phase; no production-ready solutions were available. In the E&P context, it was also important to support low-bandwidth connections. These were crucial, for example, in connecting the company to its overseas and offshore installations, sometimes via satellite communications. We also decided that, to succeed, our applications would need a high degree of presence in the visualization to facilitate the feeling of close cooperation across sites.
Participants in the virtual environment.

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A collaborative session between two clients. Avatars represent remote participants in the virtual environment.

Solution overview

Our solution is based on a client-server model. In contrast to typical client-server architectures, however, our server is very thin. Instead of storing the shared arena on the server, each client runs a separate instance of HydroVR. The server broadcasts events that trigger state changes on one client to all other clients. Although the events are quite small, some can trigger change in large amounts of data. By distributing only the events, we reduce the amount of transferred data to an absolute minimum. A drawback is that HydroVR must duplicate all data at each client before the collaborative session can start. Also, if the event results in calculations, all clients have to perform them, instead of having one client do it and distribute the result. These are minor issues, however, compared to the reduced needs for data transfer.

To take maximum advantage of available bandwidth, we use an unreliable connection (UDP) for continuous events, like moving objects. After the movement is finished, the system sends a package with the final position on a reliable connection (TCP) to ensure that all clients are in sync if packets are lost. Our implementation is based on EVL’s CavernSoft library.

In the virtual arena, an avatar represents each remote participant. The avatars reflect remote users’ movements and actions, such as when they select and edit menus and objects. An avatar’s viewing parameters, as well as its interaction parameters, is based on 6DOF tracking at their respective sites. The avatars also serve an important social need—experts can address coworkers when discussing their work, particularly when they also establish phone connections between sites.

In HydroVR, users can create shared or private tools. Shared tools can be operated by only one client at the time, but all clients can see them. We’ve implemented a mechanism for tool ownership transfer so all clients can assume a leader role. Private tools are seen only by the client who created them, so they don’t clutter the view of the other clients.

Experiences and support issues

Experts have successfully applied remote collaboration, including in seismic exploration and well-planning sessions between Bergen and Oslo in Norway and Houston, Texas. Their work showed that international offices could access home-based experts and teams to discuss problems and challenges without having to travel.

In developing support for remote collaboration, we saw a need for running HydroVR on lighter, less expensive VR installations—including a version that could run on a desktop computer. During this period, graphics accelerators on PC workstations seriously gained performance momentum, becoming an alternative to the graphics servers. Developers could thus build less expensive VR installations around PCs, and powerful PC workstations became common on users’ desktops. When we ported HydroVR to a PC architecture, we maintained third-party libraries, such as CAVELib and CavernSoft.

Today, we use a desktop HydroVR for training and data preparation, thus making the immersive sessions more effective and focused. We also see that HydroVR’s rich, interdisciplinary functionality set is often more attractive to users than having to use many different applications and convert data back and forth.

Currently, HydroVR is available on Microsoft Windows XP (32 and 64 bits), and Red Hat Linux (64 bits), as well as on its original platform, SGI’s IRIX.

Third major milestone: Multi-attribute cross plotting (present)

Visualizing 3D data in a VR environment gives users better insights and understanding than a desktop visualization. Currently, our focus is on developing new methodology to further improve data understanding in VR. Porting HydroVR to a PC platform and the possibilities of graphics processing unit (GPU) programming have opened up a world of new possibilities.

For example, seismic data contains considerable information about geologic structures. By combining seismic data with log data from trial wells, velocity models, and rock physics models, we can compute seismic attribute data about rock types and fluid contents. This opens possibilities for exploring hypotheses about where oil-filled reservoirs might be located. If two vintages of seismic surveys are available, it’s also possible to compute pressure and saturation changes. This makes it possible to hypothesize about where in the reservoir to drill.

Using multi-attribute cross plotting offers a powerful method for extracting and visualizing 3D bodies that fulfill specific value ranges in several seismic attributes. Experts can then adjust the ranges to test hypotheses in a trial-and-error process. Previously, each step in this process required heavy computations and data management, making hypothesis testing cumbersome.

By implementing this process on a GPU as part of HydroVR, we can now offer hypothesis testing interactively and in real-time. This opens a new dimension in cross-plot use. Geophysicists can interactively set the criteria and instantly compare how the identified classes match other data, such as well logs. Users can perform
both coarse browsing and fine-tuning of hypothesis testing in mere minutes. Figure 4 shows the cross-plot tool.

Recent results have shown that the flexibility of HydroVR and the VR environment is essential to determining whether identified classes make geological sense. Given this, we believe that multi-attribute visualization will be HydroVR’s next major milestone.

**Foundations for long-term project vitality**

Our initial research project was scheduled to last three years, but it’s still ongoing, with more activity than ever. Total investments in our project now exceed US$25 million. Why has our project been and remained so vital?

First, Hydro and CMR have a unique cooperation model. Our development process consists of frequent iterations and close collaboration with Hydro end users. Developing HydroVR has always been in the forefront of VR research, so we rarely know the specifications when we start developing a new tool. As a result, both Hydro and CMR understand that requirements might change considerably during development. This understanding has been crucial to the project’s success. In many ways, we began using agile development approaches long before the term received widespread attention.

Second, an important project goal has been to identify business-critical activities and improve them through VR. Well planning is a perfect example of this. In contrast to the early days, when VR and visualization were new, it’s now more difficult to get funding for general, technology-focused R&D. We’ve been successful because we’ve emphasized the business benefits, as well as the possible technological and algorithmic improvements. The challenge for visualization experts is thus to identify business benefits and link them to new technological opportunities.

**Conclusion**

Here, we’ve focused on only three of HydroVR’s major milestones and their supporting tools. Today, HydroVR consists of more than 40 tools and 25 formats. At this point, we can confidently conclude that our architecture has been highly flexible and an important contributor to the project’s many prolongations.

If there is one place where we’ve yet to develop an ideal solution, it’s in the scalable GUI area—that is, from the desktop to immersive VR. We’ve experimented with different solutions, including tracking, keyboard simulation, and force-feedback, but have yet to find a solution for a unified GUI that works well across the different display platforms.

In 2000, we commercialized HydroVR as Inside Reality. Schlumberger later purchased the commercial rights, and our VR technology is now being incorporated into the company’s E&P software portfolio and sold around the world.

Clearly, VR has fulfilled all of our project’s founding expectations.

**Acknowledgments**

We thank all the people at Hydro and CMR who have participated in this project over the past 10 years. In particular, we thank Gunnar Halvorsen at Hydro; his great insight into both software development and geosciences has been a vital link between the two domains. Also, we thank Tyge Lovset at CMR for his role as the main architect of HydroVR’s kernel.

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