Responsive Sonification of Well-logs

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ABSTRACT

Our goal is to apply and evaluate sonification for oil and gas exploration on a Responsive Workbench. The end-users are geological interpreters who build up models of underground formations, and stake holders in a consortium of oil and gas companies, software vendors, and Virtual Environments researchers. Based on the goals and users we formulated development criteria that the sonification should be easy to explain, quick to understand, useful and usable. The development is based on a scenario of interpreting a reservoir from multi-attribute well logs. The scenario helped us identify a Geiger-counter metaphor that is congruent with the domain and familiar to most users. The psychoacoustic design of the Virtual Geiger allows several logs to be heard together so that listeners may answer higher level questions about relations between logs. The Virtual Geiger has been demonstrated to hundreds of people at oil and gas summits and review meetings. Many who tried it have made suggestions for further sonifications. The consortium voted to continue work on sonification in the second round of the project. The work described here is supported by a demonstration video.

Keywords

Sonification, visualisation, sound design, interaction design, HCI, well-logs, oil and gas exploration, virtual environments.

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GOALS

Oil and gas exploration is a multi-disciplinary process in which experts work to build up a model of geology from geophysical data. The need for collaboration, to model complex 3D structures, and to analyse and interpret large multi-parameter datasets are in stark contrast to the small graphic displays in desktop computing environments. The VRGeo consortium [11] is developing prototype Virtual Environment (VE) applications so that consortium members can evaluate oil and gas applications on large scale, highly interactive, stereo-graphic display systems such as the Responsive Workbench [15]. Although VE systems are optimised for graphic rendering there is also the capability to synthesise and spatialise audio at real-time rates. We are exploring sonifications as part of our research on multi-modal interaction, with the goals to:

- demonstrate sonification applied in the oil and gas exploration domain
- provide experiences of sonification for evaluation by domain experts
- develop useful sonifications for oil and gas exploration through collaboration with domain experts
- transfer knowledge of useful sonification techniques to software developers

USERS

The users are interpreters who analyse geophysical data to build models of geology. A broad view of the users also includes the oil and gas company representatives, software vendors, and VE researchers who are stake-holders in the research consortium. It is important to recognise that the users are experts in oil and gas exploration but have little or no experience with sonification.

DEVELOPMENT

We formulated development criteria around the goals and the users, to guide the requirements analysis and design of the demonstrator. The criteria are that the responsive sonification should be:

- easy to explain - even to people who have never experienced a sonification before
- quick to understand - people can confidently understand information from the sounds after a short demonstration
- useful - the sounds provide information and affordances recognised as useful by experts in the domain
- usable - people can walk up and use the interface after a short demonstration, and are willing to use it for more than a few minutes

Requirements Analysis

A useful sonification provides information that improves a task. Our requirements analysis has three stages - task identification, scenario description and information characterisation [1], drawing on methods from Human Computer Interaction (HCI) [7] and scientific visualisation [16].

Task Identification

We can ensure the sonification is useful by identifying a task where there is demand for improvements over existing techniques. In seismic interpretation for oil and gas the tasks involve two main types of data - seismic surveys which give a broad overview of 3D structures in subsurface volumes, and well-logs which are large multi-attribute data-sets used to analyse detailed lithography down a drill-path. Chris Hayward has previously described sonifications for tasks with seismic surveys [14] and there is clearly potential to carry this work further with interactive interfaces. However the VRGeo demonstrator already includes a volume visualisation lens for exploring seismic surveys which works very well [12]. A visualisation of well-log data has also been developed for the VRGeo demonstrator but this work has highlighted the challenges of visualising data sets with typically 10 attributes measured at 10,000 points down the drill-path. The conventional technique is to print attributes in a specific order as line graphs at high resolution on paper (e.g. 10,000 points / 600 dpi = 16.7 inches), and to highlight regions of interest by hand according to specific colour schemes. Software packages that plot and automatically colour well-log visualisations allow rapid queries to be made by interactively cross-plotting different attributes, but the small screen size and much lower resolution (e.g. 14 inch screen width * 72 dpi = 1008 points) of a typical computer monitor reduces the density of data display by an order of magnitude. Often a graphic zoom is provided to give full detail in a local region. The Responsive Workbench is a table-size computer display in which the interactive 3D interface has potential to allow interpreters to more quickly and easily explore large multi-attribute datasets. It consists of two back-projected stereo-graphic computer screens, set horizontal and vertical as shown in Figure 7, to create an arm-size Virtual Environment. Although there are twice as many pixels the graphic display still does not approach the resolution possible on paper. Rather than migrate the conventional well-log plots onto the Responsive Workbench we decided to investigate the potential of the large 3D interface to allow interpreters to more quickly and easily explore large multi-attribute datasets in new ways. This led us to identify the interpretation of multi-attribute well-logs as a task where a novel multi-modal visualisation and sonification on the Responsive Workbench has potential to improve on existing techniques.

Scenario Description

Scenario description is a method for capturing and characterising user tasks that has been applied to user interface design. We applied this method to our sonification design problem by drawing a scenario from a text book description of a typical well-log analysis task [17].

Well-logs such as the gamma, neutron, bulk density, caliper, sonic velocity, and conductivity are measured by lowering instruments down a drill-hole. Gamma, neutron and density are radiation logs measured by a 'scintillation' counter in American Petroleum Units (API). Gamma measures natural radioactivity which is high in rocks like shale which might be an oil source rock or a trap rock, and distinguishes it from a limestone which might be a reservoir rock. The neutron log relates to porosity and is measured by bombarding the formation with neutrons and recording gamma emitted by hydrogen from oil, gas and water in the pore space. The bulk density log is measured by bombarding with gamma and recording the gamma returned by electron density of atoms in the formation.

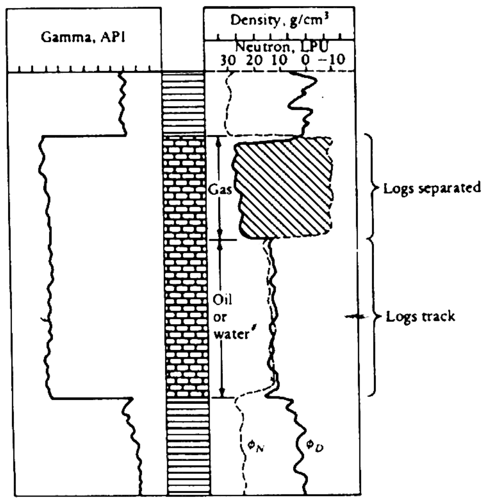


Figure 1: Radiation logs in a reservoir [17]

The conventional display of well-logs in Figure 1 shows a reservoir with interpreted lithography in a central column flanked by the gamma on the left and the neutron and bulk density logs on the right. Gamma defines the reservoir boundary, and is important for identifying lithography, calculating shaliness and correlating geological structures between adjacent wells. The neutron and bulk density logs separate in gas reservoirs, with neutron high and density low, track in regions of oil or water, and move erratically with generally lower neutron and mid-level density in rock formations. The plots are often calibrated so that the neutron and density traces merge in regions of oil and gas. This calibration draws attention to likely oil regions where the traces merge and regions of gas where the traces separate widely.

Information Characterisation

The Scenario Description captures the information an interpreter uses in the analysis of an oil and gas reservoir from radiation logs. In his seminal theory of graphic information design Bertin characterises information at three levels [3]

• overall information about all elements
• intermediate information about sub-sets of elements
• local information about single elements

Bertin defined useful information as the answer to a question. The answers can be characterised as

• nominal - having difference e.g. oil, water, rock
• ordinal - having difference and order e.g. low, medium, high
• interval - having difference, order and scale e.g. 10, 15, 20 degrees Celsius
• ratio - having difference, order, scale and natural zero where all scales agree e.g. 0 Kilometres = 0 Miles

These characterisations of information in terms of questions and answers is a basis for analysing the information requirements of the scenario.

The *local* questions have ratio answers which we have normalised to a scale with range from 0.0 to1.0

• Q: what is the gamma here? *ratio* A: {0.0 to 1.0}
• Q: what is the neutron here? *ratio* A: {0.0 to 1.0}
• Q: what is the density here? *ratio* A: {0.0 to 1.0}

The *intermediate* questions have ordinal answers with ordered levels

• Q: how does neutron relate to density logs in this region? *ordinal A:* neutron {low, mid, high} density {low, mid, high}
• Q: what is gamma in this region? *ordinal* A: {zero, low, mid, high, peak}

The *overall* questions have nominal or categorical answers

• Q: is there a reservoir in this dataset? *nominal* A: {yes, no}
• Q: what is in the dataset? *nominal* A: {oil, water, gas, rocks}

Design

Since we are designing an interactive tool we have to consider the user interface as a major part of the sonification. We also need to ensure the sound is easy for the user to understand and to relate to the task. Finally the users have to be able to use the sonification to answer questions required by the task. This section describes the design process in four stages, starting with the identification of a metaphor that is familiar to the users and congruent with the task domain, followed by the design of the interaction, the sound design of an auditory metaphor and the design of the psychoacoustics to convey the required information. This method differs from other popular methods for sonification design because it explicitly characterises the task and data (for an overview and comparison with Earcons and Auditory Icon techniques see [2], for another example of application see [5]).

Metaphor

Interface designers commonly use a metaphor to help the user understand how to interact with computer tools. Metaphor is an important part of Gaver's 'Auditory Icon' method for designing sounds which can be quickly understood to relate to objects and events in a computer interface [13]. The familiarity and context of sounds are important aspects of the schema level of listening in Bregman's theory of auditory scene analysis [6]. A metaphor can make our sonification easier to explain and quicker to learn. We scanned the Scenario Description for explicit references to sounds but there are none. Next we looked for descriptions of audible objects or events and noticed the mention of a 'scintillation' counter for measuring radiation. The scintillation counter suggests a 'Geiger counter' which is a device that makes audible clicks in response to radiation levels, shown in Figure 2. Most people are familiar with the Geiger-counter, recognise the clicking sound and understand the way the change in the rate of clicking conveys quantitative information about the radiation level. The widespread recognition and use of Geiger-counters, and the congruence with the application domain, led us to choose the Geiger-counter as the metaphor for the responsive sonification of well-logs.

Figure 2: Geiger-counter

Interaction Design

We would like people to be able to walk up and use the Virtual Geiger after only a short demonstration. In order to reduce the time and training required we modeled the interface on the familiar interaction with a real Geiger-counter which has a probe attached to a control box as shown in Figure 2. The user holds the probe in one hand and points it to toward a region of interest to hear the level of radiation, much like a microphone. Switches on the control box are used to configure the sensitivity of the Geiger probe to radiation level. Likewise the Virtual Geiger has a probe which can be picked up and directly pointed in 3D space. The probe is tracked in 3D space by a six degree of freedom (6 DOF) Polhemus sensor, allowing a natural tool-based interaction style. The Virtual Geiger is sensitised to different well-log attributes by pressing buttons on a graphic dial-like control panel. The Virtual Geiger has the advantage that it can sense any type of well logs, and is not restricted to radiation like its real counterpart.

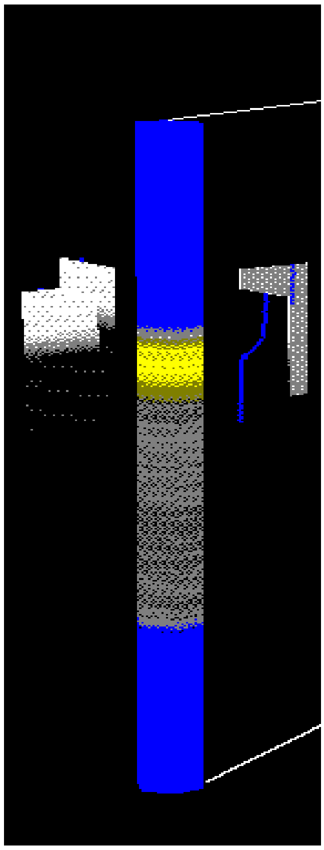


Figure 3: Well-log Visualisation

The Virtual Geiger interaction is built on the 3D direct manipulation tool/dragger paradigm developed in the Avango VE framework [19]. The tool appears as an icon that can be selected with the tracked stylus from a tool-bar in the 3D work-space. A graphic probe is attached to the stylus and can then be used to interact with virtual objects. The probe is shown as a green ray that passes through objects in the scene. Interaction is mediated by ‘draggers’ which are attached to nodes in the scene graph to specialise the responses of different objects to different tools.

The Well-log is visualised by the path of the drill-hole rendered as a 3D geometry. The global distribution of two attributes is colour-mapped as a blue-yellow bivariate colour sequence onto the visualisation, as shown in Figure 3. In the application the colours show the global distribution of a low-resolution smoothed version of the data-set containing 500 points. Intermediate and local queries can be made on two additional attributes graphed on small sliding lenses on the side of the central visualisation. The lenses move up and down with the probe of the Virtual Geiger, which accesses attribute values at the point where the stylus ray intersects the drill-path geometry. The sonifications can be used to query data at a different resolution to the visual information. Sonification queries at the local, intermediate and global levels are made by sweeping the Virtual Geiger probe along the visualisation. Local queries are made by sensing a single attribute, such as gamma, and pointing the probe at a place of interest, for example the edge of a reservoir. Small, slow sweeps of the probe access the full-resolution 10,000 point dataset so that sharp spikes can be heard and homed in, even when they are not visible. Intermediate queries are made by pressing buttons on the control panel to sensitise the probe to more than one attribute at the same time. For example a query about the regions where neutron and density logs track can be made by pressing the relevant buttons on the control panel and probing inside a region of interest such as a known reservoir. Sweeps that traverse between 5 and 20 per-cent of the spatial range of the data per second retrieve the data from a pre-smoothed mid-size version of the dataset containing 1000 points. This limits the number of points to be sonified per attribute to 200 per second. Global queries are made by pressing a central button on the control panel to sensitise the probe to all attributes in the well-log. The probe is then swept along the drill-path to detect overall distributions of the attributes e.g. where the dense regions are, where there is missing data etc. Since there is a limit on the amount of data we can sonify in real-time we allow access to three levels of detail on the data-set depending on the rate of movement of the probe. Fast sweeps along the well-log access a low-resolution smoothed version of the dataset containing 500 points.

Sound Design

The design of a familiar auditory metaphor allows users to predict how changes in the sound relate to changes in the phenomena it represents, and more quickly understand how to listen for information in what they are hearing. The sound design for the Virtual Geiger needs to suggest the familiar Geiger-counter ‘clicking’ sound, and respond to changes in the level of radiation logs in a predictable manner. A Geiger-counter clicks whenever a radioactive particle passes through its sensor - at zero there is no sound and stochastic increases in radiation particles produce a stochastic increase in clicks. This model was used as the basis for the Virtual Geiger sound schema developed in the Max [8] visual programming environment for rapid prototyping and real-time control of sound synthesis algorithms. The Virtual Geiger algorithm is built from a 'tfog' granular synthesis module [9] which has 10 parameters - number of outputs, sample name, maximum number of fogs, table offset, transposition, bandwidth, amplitude, attack, release, decay. The tfog was configured to produce short click-like 20 ms grains from an ‘aiff’ format sound file containing noise samples. Stochastic clicking is produced by gating the output level of each grain with a random number generator to vary the granular density from 0 to maximum over the normalised 0.0 to 1.0 range of an input parameter. The synthesis algorithm needs to sonify up to 200 values per attribute per second. The scenario with three attributes required a maximum of 20% CPU to run three simultaneous tfogs each generating 200 grains per second on an SGI O2 workstation equipped with 180 MHZ IP32 CPU and a MIPS R5000 floating point co-processor. The synthesis algorithm, shown in Figure 4, is loaded into a networked MAX-based sound-server at run-time. Parameters are sent from the Avango VE interface to the MAX sound server by UDP protocol [10].

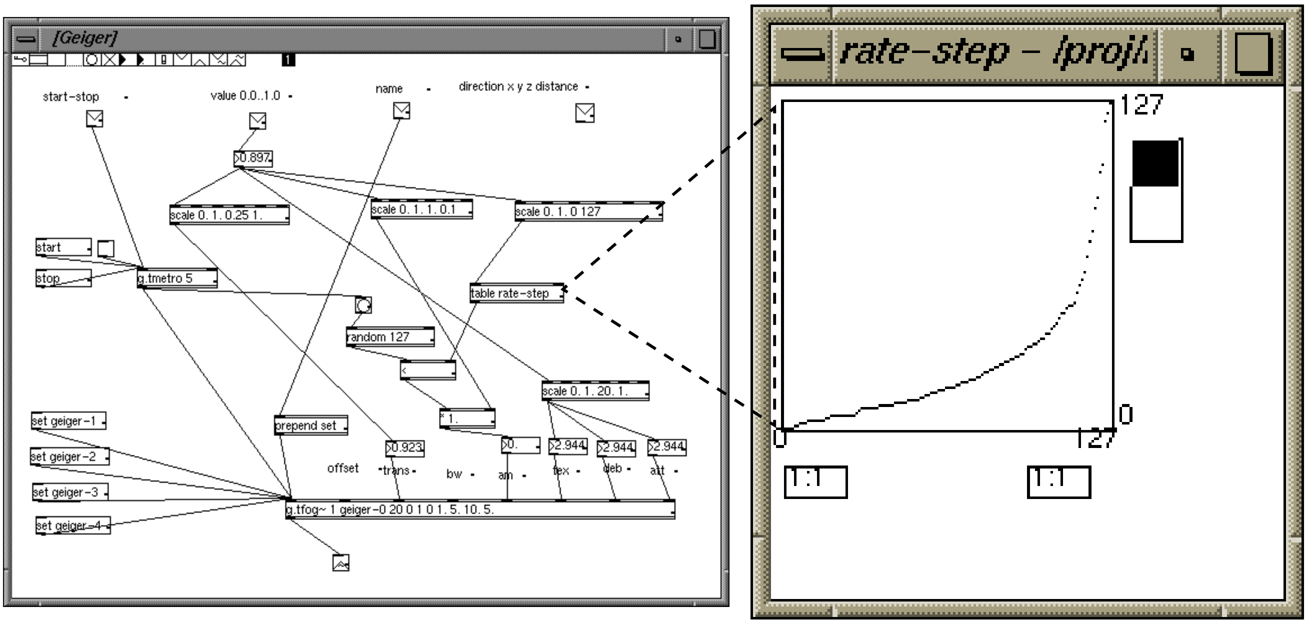


Figure 4: Sound design of the Virtual Geiger showing the perceptually linearized clicking density mapping

Psychoacoustic Design

The psychoacoustics of the sonification need to be designed to allow the listener to quickly, confidently and correctly answer questions from the sounds. A poor display only allows answers to questions at the local level, whereas a good display allows answers to questions at local, intermediate and global levels [3]. This section describes the psychoacoustic design of the Virtual Geiger to allow answers ar all three levels.

The local level questions in the information analysis have quantitative *ratio* answers, for example

Q: what is the gamma here? *ratio* A: {0.0-1.0}.

The ability to give ratio type answers depends on the perception of a continuous, ordered scale with a natural zero. The change in clicking density of the Virtual Geiger is a ratio (prothetic) perceptual variation which has appropriate characteristics [18]. However the metric must be scaled so that equal changes in an attribute produce equal changes in the sound. Ratio perceptions can be scaled by the fractionation method of judging doubles and halvings. The Virtual Geiger was scaled by fractionating the grain gating function to give 9 steps of equal difference in the subjective clicking density - from one click per second to 200 clicks per second. The linearised mapping measured for one subject is shown in the rate-step graph in Figure 4.

The intermediate level questions have ord*inal* answers, for example

Q: how does neutron relate to density logs in this region? *ordinal A:* neutron {low, mid, high} density {low, mid, high}

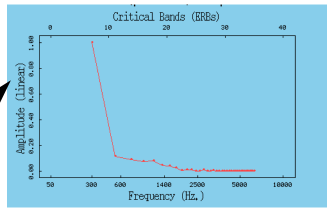
The ability to answer questions about the relations between the neutron and density logs requires the listener to be able to hear both variables at the same time. The prothetic clicking sound in the Virtual Geiger causes simultaneous sonifications to produce a single clicking sound with density that is the sum of components. We need to design the psychoacoustics so that a listener can answer questions about the relations between attributes rather than about the additive sum. We can do this by using a metathetic perception which does not sum when two components occur simultaneously. An example is pitch - when you play two piano keys at the same time they do not produce a new pitch that is the sum, but instead overlay each other [18]. From a ‘streaming’ viewpoint pitch is a strong factor in the perceptual segregation of simultaneous sounds [6]. We varied the pitch of the grains synthesised by the Virtual Geiger to perceptually segregate sonified attributes. The normalised input parameter 0.0-1.0 is linearly mapped to the pitch transposition factor 0.1-1.1 of the tfog algorithm. The effect is a co-varying increase in the pitch of the clicking with the increase in click density which conveys the Geiger-counter metaphor. The listener hears two distinct sounds when two attributes differ by more than 0.25 throughout the normalised input parameter range. While testing the sonification we found that high values attract attention away from simultaneous low value streams. The perceptual weighting was improved by linearly mapping the input parameter range 0.0-1.0 to the grain duration in the range 45.0-12.0 ms using the attack, sustain, and decay envelope shaping parameters of the tfog algorithm. This evens up the energy differences between high levels which generate many short grains and low levels which produce fewer but longer grains. Regions where neutron and density separate are heard as two distinct sounds, regions where they track sound stable, and regions where both have similar levels are heard as a single sound stream. The listener can answer questions about the ordinal level of two variables at the same time.

The *global* question is

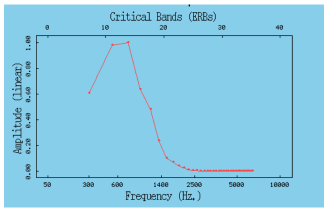
Q: what is here? nominal A: {oil, water, gas, reservoir, rocks}

To answer the global level questions the listener needs to be able to disambiguate gas regions (where neutron is high and density is low) from rock regions (where neutron is low and density is high). We built a palette of ‘timbre grains’ that sound different but preserve intermediate psychoacoustic properties of segregation and grouping. The timbres are re-synthesised musical instrument spectra downloaded as aiff format audio files from the SHARC timbre database <http://sparky.ls.luc.edu/sharc/>. Timbre grains are made by loading these samples into the tfog algorithm to ‘colour’ the Virtual Geiger sound. The samples were chosen to have equal pitch and sharpness to equalise these two major influences on simultaneous grouping. The samples were chosen from SHARC timbres of pitch C4 shown in Figure 5.

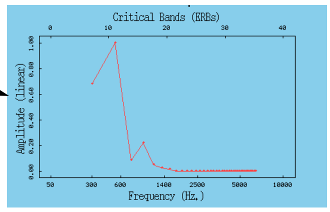
Timbre	Sharpness (Acums)
C trumpet (muted)	10.8
Bb-trumpet	5.3
english-horn	3.9
oboe	3.5
french horn (muted)	3.25
violin (bowed vibrato)	3.2
flute	2.8
trombone (muted)	2.75
cello (pizzicato)	2.6
trombone	2.5
violin (pizzicato)	2.5
bassoon	2.4
viola (pizzicato)	2.3
bass flute	2.1
french horn	2.1
tuba	1.7
contrabass (pizzicato)	1.7



cello (pizzicato) => gamma



trombone => neutron



bassoon => density

Figure 5: Timbre grain palette mapped to Geiger attributes

No three timbres have exactly the same sharpness but cello (pizzicato) =2.6 Acums, trombone = 2.5 Acums and violin (pizzicato) = 2.5 Acums are close. The categorical timbre difference between gas (neutron = 0.8, density = 0.2) and rocks (neutron = 0.2, density = 0.8) was tested for pairwise combinations of these timbre grains, with the interface shown in Figure 6. We found it difficult to disambiguate gas and rocks with the cello (pizzicato) and violin (pizzicato) pair. We arrived at a palette of three distinct timbre grains by substituting bassoon for violin (pizzicato). The spectra of the timbre palette are shown in Figure 5, along with the mapping to Virtual Geiger attributes. This palette of timbre grains allows the listener to hear nominal difference between regions of gas and rocks. The differences in timbre reduces the difference between attributes required to cause segregation from 0.25 to 0.15, and improves the capability to listen to more than one attribute at a time. Hot-spots are heard as high dense regions, clumps stream together in dense masses, thin data regions sound low and thin and regions where there is no data make no sound.

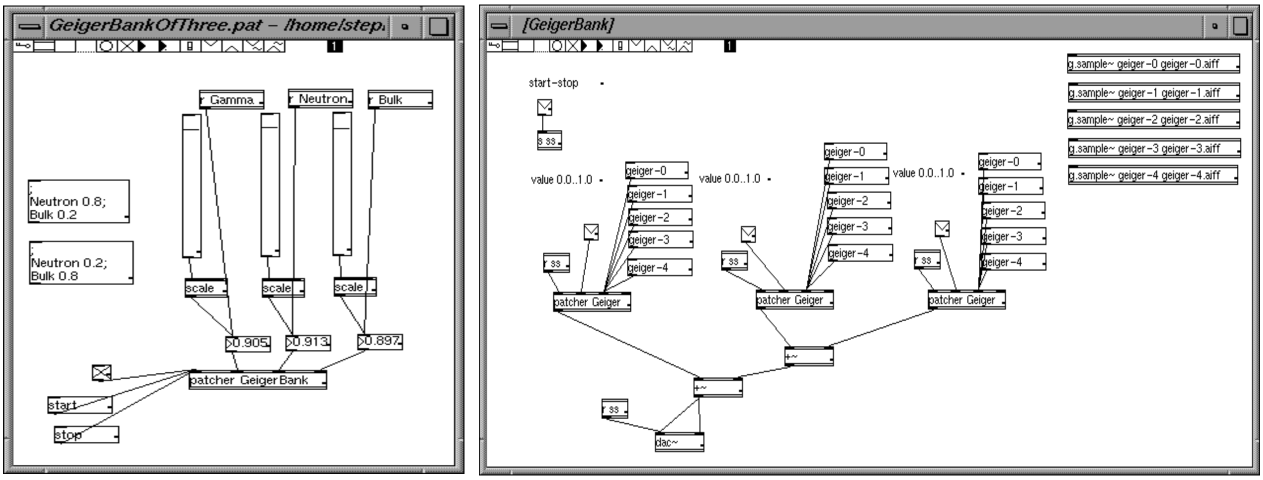


Figure 6: Interface for testing perceptual segregation of timbre grain streams.

DEMONSTRATION

We built a demonstration of the Virtual Geiger on the Responsive Workbench for evaluation at a consortium review meeting. The demonstration interface is divided into three parts shown by three well-log visualisations with Virtual Geiger control panels in front of each, as shown in Figure 7. The left most part is a training well, in the middle is the text-book reservoir scenario, and on the right is an extension to the scenario in which additional directional well-logs are sonified by spatialisation.

The training well is made up of simple test sets that are easy to describe, understand and predict

• gamma - ramp from 0.0 to 1.0
• neutron - stepped ramp from 0.0 to 1.0 in 10 steps of 0.1 difference
• density - stepped ramp from 1.0 down to 0.0 in 10 steps of 0.1 difference

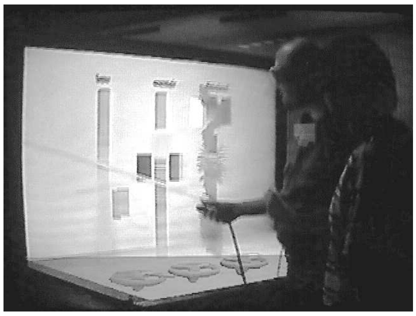


Figure 7: Responsive Sonifications

A person who is demonstrating the Virtual Geiger can use the training well to introduce the interface metaphor, the sound design schema, and the capability to answer local, intermediate and global queries by listening to sounds. A typical session begins with a description of the Responsive Workbench technology, followed by an explanation of the well-log interpretation task. The concept of three levels of information is introduced through the well-log visualisation. A global overview is shown by mapping the gamma ramp onto the well-log visualisation as a grey ramp from dark at 0.0 at the top to light at 1.0 at the bottom. The local view of gamma is shown by moving the graphing lens up and down the visualisation. Intermediate relations between two attributes are shown by mapping the neutron log to blue and the density log to yellow so that the visualisation appears blue at top passing through grey at the midpoint and becoming yellow at the bottom. The Virtual Geiger sound metaphor is introduced by selecting gamma on the control panel to sensitise the probe, and pointing it at the visualisation to produce the familiar Geiger-like clicking sound. The correspondence between variations in the sound and variations in the gamma log is established by sweeping the probe up and down the visualisation several times, while the graphic of the gamma is shown on the sliding lens. The flexibility to sonify to other attributes is shown by selecting the neutron log which changes the nominal timbre but keeps the Geiger metaphor. The metric of the sonification is demonstrated by listening to the differences between equal steps of 0.1 difference up and down the neutron log. Finally the possibility to listen to two attributes at the same time is demonstrated by switching on the density log while leaving the neutron on at the same time. Intermediate relations between the two attributes are sonified by sweeping the probe up and down and listening to the way the sounds stream together into a single sound where the ramps cross-over at the middle and stream into two distinctly separate sounds away from this point.

The next demonstration shows the responsive sonification of a well-log. The radiation log plots in the text-book reservoir of Figure 1 were used to generate synthetic log data for gamma, neutron and density. The demonstration is organised around answering the questions in the information analysis from both the visualisation and the sonification. The visualisation shows neutron mapped to blue, density to yellow, and gamma on the lens. This automatic colouring demonstrates the nominal answer of overall questions about what is in the dataset from the colouring into three different regions where blue at the top and bottom indicates rocks, yellow indicates gas, and grey indicates oil or water. The level of gamma can be scanned with the lens to find the step change boundaries of the reservoir. The possibility to use sound to obtain the same information is then demonstrated. First the Virtual Geiger is used to re-confirm the gamma boundary with local sweeps of the probe. Next the capability to give ordinal answers to questions about the level of neutron is demonstrated by probing the blue high level, yellow low-level and grey mid-level regions with the Virtual Geiger to hear low, medium and high levels from the Geiger sound. Next the capability to answer questions about two attributes at the same time is demonstrated by switching on the density sonification and probing the blue and yellow regions to hear the levels of each attribute. The nominal difference between rocks and gas is demonstrated by probing the blue-yellow boundary to hear a distinct nominal change in timbre. Finally the capability to make queries on all three variables is demonstrated by switching on the gamma and probing the rock / gas boundary where a nominal change in overall timbre and simultaneous step increase in gamma can be heard.

The third demonstration is work-in-progress which extends the reservoir scenario with a spatialised sonification of directional well-log data. Directional well-logs include stress-directions, the direction of borehole breakout or the orientation of sedimentary layers. The spatial sonification places the virtual sound source away from the user in the direction in which the data points. Local queries are made with the Virtual Geiger probe. This work explores the idea that the spatial sound could convey spatial correlation and spatial patterns which are important in well-log interpretation tasks. If the direction of the data correlates well there is a clear sound from this direction. Less well correlated data produce a more diffuse spatial effect which tends toward ambient. Spatial patterns, slow trends and sudden breaks in the directional data along the well-path could be heard, for example while sliding along the well-path from top to bottom, the user might hear the sound-source moving around from SW to NE and than moving down. Suddenly there is a break, and the sound is coming from SW again.

EVALUATION

The goals of our project were to demonstrate sonification applied to oil and gas exploration, provide experiences of sonification for domain experts, develop useful sonifications to support important but difficult tasks, and to transfer knowledge to software developers. We addressed these goals by demonstrating the Responsive Sonification of Well-logs to many hundred of people at summits on oil and gas exploration in Europe and the U.S in the past two years. Most were able to pick up the Virtual Geiger and use it to probe the test well-log almost immediately after the short demonstration. People seem to readily understand the tool-based 3D manipulation of 3D objects very quickly. Some have trouble with the button on the stylus until it is explained in terms of a mouse button which is held down to pick objects. Explaining the sonification as a "Geiger-counter" is much quicker and easier than explaining in terms of auditory variations. Explanations such as "when the data is high then the pitch is high and the clicking is fast" generally require more discussions and clarifications, prompt comments such as "I'm tone deaf", and can result in a refusal to try out the demonstration at all. People who do try the test ramps and the reservoir scenario can usually readily answer questions such as "where is the gamma high or low?", and "are the neutron and density tracking or separate in this region?". However we observed that most people can only make ordinal answers on a scale of low, medium and high and finer levels of judgement may not be quick or easy to learn. People can hear differences between oil, gas and rock but cannot correctly answer which is which after such short term use. During demonstrations we had requests from nearby stands to turn the sound level down and discovered that the Virtual Geiger works quite well in noisy environments because the answers do not depend on hearing loudness variations. We found that the sounds draw passers-by and stimulate curiosity to try the demonstration and explore the data. Many people who have never heard of sonification before have now experienced the concept through the Virtual Geiger. People who previously commented that they found it difficult to imagine how sounds could be useful in oil and gas exploration have made suggestions for additional sonifications after they tried it. One interpreter tested the sonification for more than thirty minutes and verified an expected change in sonic velocity at a point where an interpreted horizon passed through a drill-hole. After the first review meeting the members of the VRGeo consortium voted to continue research on sonification in the second phase of the project.

FURTHER WORK

Our longer term experience with the Virtual Geiger has raised many issues of human-computer interaction. The first issue involved the ergonomics of long term usage versus the quickness of learning a direct interface. We found that precise aiming of the Virtual Geiger probe to make local queries was difficult with the hand unsupported in space. When we experimented with actual 3D well topologies we found difficulty steering along the long, thin, irregular drill-hole geometries winding through virtual space. As an alternative we tested a 1D manual slider that better matches the task of probing a one dimensional well-log (as opposed to its 3D geometry). The slider potentiometer was attached to the stylus and you can use your thumb to move the probe along the selected well-log. A problem with jittering in the position due to the 8 bit resolution of the slider potentiometer was overcome by relative rather than absolute positioning. The probe itself still functions and allows gross absolute movement to regions of interest while the slider allows finer movements. The slider is more precise and more comfortable for longer periods than the 3D virtual probe, but is less direct and congruent with the Virtual Geiger metaphor. Another problem was the need to divert attention between the probe and control panel to make new local queries on a point of interest. For example once you have homed in on a gamma peak you have to move the probe onto the control panel to alter the query to neutron and density, and then try to find that point again on the well-log. We tried a two-handed interface with tracked stylus in each hand but you still have to shift visual attention to make the switch. Possible solutions include placing a semi-transparent control panel on the end of the probe, or dropping some kind of marker at the point of interest.

Our experiments with the spatialisation of directional data are still underway. The Responsive Workbench has two speakers, one on each side, about two metres apart. This set-up allows two or three people to hear direction in about a 90 degree arc in front and answer in terms of far left, left, middle, right, far right. In tests on an 8 channel surround sound system in the Cyberstage we found it was difficult to make answers about the direction at all. The directional cues are smeared by the acoustics of a large overhead mirror and hard floor which produce a lot of reverberation in the 3 metre cubed room. When we reduced the configuration to the four lower speakers it was at least possible to hear horizontal directions. We also found that only one person at a time could use the spatialisation because other people in the space occlude the speakers. A solution could be tracked headphones and binaural rendering to generate more exact spatial sound.

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