A Platform for Audiovisual Seismic Interpretation

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ABSTRACT

We are describing a pilot study investigating the use of sonification techniques in seismic interpretation for oil exploration. Due to emerging development criteria of conformance and usefulness, the project was redirected from a free experimental tool box to a primitive but functioning work station for seismic interpretation. The emphasis was put on extracting interesting seismic parameters for sonification. The most important elements are objects (allowing encapsulation of structures), attributes (allowing multiple data sets for each object) and methods (how the chosen data is transformed to sound). Among the methods are standard mapping from data value to pitch, mapping from structural position to pitch, mapping from entire object content to sound with moving objects. All methods can be both mouse-driven and automatic. The audio is MIDI-based using common soundcards. Separation of different data streams are done by instrumentation, octave placement and panning. The major assets of using sound were evaluated to be multidimensionality, time resolution, pattern sensibility and new data representations (methods). The pilot study ended successfully insofar that it will be integrated in a new software package featuring 3D-visualization and audio for seismic interpretation.

INTRODUCTION

The notion of using sound in interpretation of seismic data should only seem natural . Seismic data are in fact generated by low-frequency, explosive sounds reflected in the rock layers below the earth surface, and geophysicists have been listening to the seismograms for a long time. Auditory discrimination of time-compressed seismic signals is documented by Speeth [3] and Frantii [1]. Still, to our knowledge, there are no commercially available tools for sonification of seismic data. Hayward [2] described some techniques for auditory analysis using the seismic traces with time compression, frequency doubling and gain control for rescaling to audio. This audio solution is not well suited to exploration seismology where the traces only lasts for a few seconds, and where the interesting comparisons are done laterally (a seismic trace is a vertical record).

Our project is a pilot study directed towards audio interpretation of seismic data in oil exploration. The project is funded by the national Norwegian oil company Statoil, and is administrated by the geophysical company Geonera. It was initiated January 1996 employing one full-time programmer/researcher with background in music technology (and no geophysical knowledge whatsoever - a deliberate choice). The rest of the personnel involved had a geophysical background and acted as consultants and evaluators when needed.

The initial goals of the project were to investigate the ability of the ear to interpret seismic information, considering how this ability can be exploited in a tool for seismic interpretation. Important tasks involved were development and evaluation of transformations from seismic parameters to sound or even music. In short, the project should produce a versatile tool box for experimenting with mappings from seismic data to sound.

PROJECT DEVELOPMENT - CRITERIA AND CONSEQUENCES

When establishing the project, there were no rigid criteria for the development process. It was supposed to be as open as possible - giving room for crazy ideas. However, it soon turned out that the work had to be given a sharper focus, and that the funding situation put restrictions on our liberty. The need for early successes became apparent. As a consequence some more or less explicitly stated criteria emerged, in fact reshaping the project goals:

- **Availability and compatibility:** We decided on using PC's with Windows NT and Soundblaster soundcards.
- **Fast development:** Matlab from The Math Works Inc. was chosen as development platform, customized with MIDI-functions, thereby promoting rapid development and saving time on graphics, matrix calculations and data processing.

- **Pleasantness:** The sounds should not be very noisy or annoying since the user then probably will turn it all off. We decided to focus on MIDI-solutions based on parametrization of the seismic data, and did not give much attention to direct audification (although one can listen to the traces if one wants to).
- **Conformance:** The user interface should be fairly familiar to the seismic interpreter, and some domain-related functionality had to be included, including import of the most common file formats for seismic data, tools for manipulating the graphics, and reflector tracking (treated below).
- **User friendliness and usefulness:** The sonification techniques should be easy to understand and easy to use for a person inexperienced with tools of this kind. They should address problems with actual interest to the geophysicist, documenting the usefulness of our approach.

The last two criteria above resulted in a marked redirection of the project. Instead of a toolbox of sonification techniques for unrestricted experimentation, we ended up with a primitive, but acceptable work station for seismic interpretation including and promoting sound as interpretation tool. As long as the users, geophysicists and geologists, were the only ones to evaluate the project, their demands pointed out the direction of our research and development.

Seismic data have certain properties that we exploited in order to address the domain-specific issues. First of all the vertical record, the trace, is a low-frequency amplitude function obeying the wave equation. It can be viewed as the real part of a complex trace permitting the unique separation of envelope amplitude and phase as well as calculation of instantaneous frequency and other seismic attributes [4]. This implies that the single data set representing seismic amplitude, can generate a multiple of others, each representing a certain attribute.

Secondly, the main structures visible in a seismic section are generated by reflections from the borders between rock layers. They will therefore be mostly lateral with moderate dips and discontinuities. Reflectors are lateral amplitude peaks of this kind. The fine-grained structure between the strong reflectors contains stratigraphic information and noise. The interpreter is interested both in the structural shape (represented by reflectors) and content (represented by stratigraphic information).

THE WORK STATION

After eight months of programming, the work station was released for extended testing and evaluation, partly by us and partly by potential users. The main elements are the following:

Work area

A large amplitude display of the seismic section filling the entire screen with a few buttons and pop-up menus readily available in a frame. Most of the work is mouse-driven involving two modes:

- Draw mode **-** defining objects
- Play mode **-** playing objects

Objects

For practical and memory-saving purposes the more advanced calculations and methods are limited to smaller objects drawn by the user. There are five different kinds:

- Straight line
- Rectangle
- Trace **-** a vertical record
- Reflector **-** an object generated by the program tracking a reflection amplitude peak (negative or positive) across the seismic section. Start and end point defined by the user.
- Reflector box **-** a box with parallel and equal length sides, but with a freely drawn base line. It could be used to encompass a reflector.

In principle there are no limits to the number of objects drawn and calculated at one time.

Attributes

As mentioned earlier it is possible to calculate a number of attributes using the single amplitude data set. These calculations are done on objects, actually making multiple data sets with the same coordinates. They are memory-consuming and therefore not applicable to the entire data section. We are offering ten attributes including envelope amplitude, phase, instantaneous frequency and acoustic impedance.

Methods

When the objects are defined and attributes calculated, the playing can begin. The methods are the heart of the program, and they all involve some kind of mapping from seismic parameters to MIDI data. Due to the need for convincing the potential users of the usefulness of the program, more emphasis was put on extracting the interesting seismic parameters than on exploiting the perceptual qualities of the sounds. The only MIDI parameters employed were pitch and velocity, and to a limited extent panning. Four methods are currently supported:

- Mapping - straightforward mouse-driven mapping from data value to continuos MIDI-pitch. It can be applied to all objects, and the seismic section as a whole. The mapping is limited by the maximum and minimum values of each object. For the one-dimensional objects (trace, line and reflector) the playing can be done automatically from start to end, with a cursor indicating progress. Two reflectors can be played simultaneously for comparison (exposing multiples, i.e. ghost copies of strong reflectors).
- Mapping max/min-values - related to the above, but limited to two-dimensional objects (rectangle or reflector box). Plays the max- or min-value or both of each vertical segment of the object. Can be played by mouse or automatically. This method makes it possible to find the coordinates of the maximum value in any object.
- Structure - applicable to two-dimensional objects. Instead of mapping from data value to pitch, it maps the position of the peaks in each vertical segment to pitch, e.g. a low pitch implies a peak at the bottom of the object, structures tilting upwards increases the pitch. When played automatically an interesting sound cue can be identified and positioned by using a sound cursor, moving the mouse vertically in the object until the cursor pitch corresponds to the pitch of the sound cue. Off the record, the structure method can give very beautiful sound images, already presented in a concert for new music (playing the seismic of the arctic mountain Mediumfjellet).
- Signature - applicable to small rectangles. Mapping the content of the entire object to a single complex sound using statistical and structural calculations - the choice of content calculations is made by the user. The object can be moved around by the mouse and sounds generated in real time. Two rectangles can be played simultaneously for comparison, one moving and the other standing still. When moving, the sounds are panned to each side, afterwards the comparison can be checked by playing the objects in succession. Two structurally defined signature objects can be used for correlating the rock layers on each side of a discontinuity.

For any method except signature, all ten attributes or any selection of them, can be played simultaneously. This can lead to a far too complex sound to be of any use (at least as long as instrumentation is the only way of distinguishing attributes). To limit the complexity, the user can define data bands for each attribute so that only data values inside the band triggers sound.

Sound parameters and settings

Each attribute and each method can be assigned a standard GM instrument and related to a center pitch (the structure method disallows different center pitches across attributes). Separation of data is thereby alleviated by instrumentation, octave placement and panning. The pitch bend sensitivity can be adjusted for better data resolution.

WHAT NOW?

The pilot study ended on a very positive note, even though the initial goals were changed along the way. Applying the work station to real seismic sections, the usefulness could be documented on a variety of phenomena. However, the training aspect was strongly emphasized: It will take a long time for any user to get full advantage of the sound techniques. The most interesting features pinpointed by the evaluating interpreters were:

- Hearing what you cannot see - playing a different attribute from the one you are looking at.
- Multidimensionality - playing many attributes at the same time, without having to change focus (e.g. moving the eyes between data windows).
- Time resolution - hearing details along a reflector, which visually looks the same all the way.
- Pattern sensibility - immediate recognition of deviations from “normal”, especially when using data bands (on/off-effects).
- The signature method has a great and mostly unused potential for characterizing stratigraphical information.

One major conclusion remains: A purely auditive interpretation system is out of the question. To have any chance at all of raising interest for a sound-based work station, it will have to be integrated with something more familiar to the user. As a consequence, our pilot study will be one major component in a new software package for seismic visualization integrating advanced 3D-graphics with audio on a PC-platform. Integration work will be initiated early next year. The first step is to leave Matlab, making a stand-alone C++ version for Windows - hopefully ready for demonstrations at ICAD-97.

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