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The 3D Sketch Slice: Precise 3D Volume Annotations in Virtual Environments

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Abstract

In the oil and gas application domain, there is a need for 3D volume annotations to sketch out uncertainty regions in seismic data sets. Together with geo-science experts, we identified actual requirements for efficient annotations of volumetric areas. As a result, we introduce the 3D Sketch Slice, a novel system for volumetric annotations. Based on a 3D-tracked pen tablet, the 3D Sketch Slice works as a prop for a subsurface volume slice. Using pen input, a user can precisely sketch 3D points on a 2D volume slice while directly controlling the 3D position and orientation of that slice within a seismic volume. The points selected define 3D sketches through 3D alpha shape representations. Furthermore, we define clutching and mapping functions and we present a novel visual feedback method for multi-user annotations. Finally, we performed an informal evaluation with expert users. Despite some ergonomic concerns, they confirmed an increase in perceived precision. In general, the requirements identified had been met and it was proposed to apply the 3D Sketch Slice methodology to other scenarios.

Categories and Subject Descriptors (according to ACM CCS): I.3.1 [Computer Graphics]: Hardware architecture—Input devices, I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques, I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality,

1. Introduction

In their search for possible oil and gas resources, geologists examine seismic data for density alterations in subsurface rock structures. They analyze the structural developments over time in order to identify reservoirs, which are structures that possibly could contain hydrocarbon resources [Wil05]. Ultimately, the resultant subsurface model is being used to assess costs and risks of the development of a potential oil and gas field. Since a decision about an exploration can have an extremely high impact on costs, the quality of an interpretation is crucial.

Unfortunately, seismic data itself is often affected by distortions and noise, which result from ambiguities in the raw seismic data. These ambiguities are caused by phenomena like amplitude decay, diffraction, multiple reflections, refraction, anisotropy, timing errors, and non-horizontal reflections. That is, interpreting seismic data always involves *uncertainty*. Thus, when characterizing reservoirs, geologists are required to assess the data quality and annotate specific regions as uncertain. Such annotations are not handwritten text, but sketches of 3D-shaped areas. These so called uncertainty sketches are essential to any decision making process in seismic exploration.

Through iteratively analyzing a seismic, a (human) user might conceive how an uncertainty region looks like and which data is to be included or not, creating a mental model. But, in order to share this information with a computer or with other people, a user has to formulate a 3D volume sketch out of such a mental model. The complexity grows with detail and precision of the model required. Furthermore, while some boundaries of a region might be easily identified, other areas may not show any particular characteristics for delimitation. Such fuzzy transitions have to be approximated in some way. In conclusion, to annotate a volume by creating a 3D sketch area, can become a difficult task. With this background and industrial applicability in mind, we identified actual requirements for volume annotation tasks in the domain of seismic interpretation. These requirements lead to a novel interface solution, the 3D Sketch Slice, which is our main contribution.

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The 3D Sketch Slice is a prop for a volume slice with pen input for sketching 3D-shaped area annotations and according input mapping functionality. As key benefit, the 3D Sketch Slice provides precise 3D input for adding points and intuitive spatial alignment of volume slices at the same time. Another advantage is the possibility to construct a 3D model from only few distinctive points, without requiring a user to explicitly define a complete 3D shape. Along with our implementation on an immersive display system we also provide a solution to mapping ambiguities for slanted volume slices. Finally, as the requirements identified include support for cooperative sketching, our system contributes a visual feedback system via multi-user markers to create awareness for other users' inputs.

This paper is structured as follows: We give an overview to related work in the respective domains of human computer interaction (HCI) in Section 2. Section 3 then analyzes the requirements of 3D volume annotation specifically to seismic interpretation tasks. These lead to the concept and implementation of the 3D Sketch Slice described in Section 4. Our system is subject to an informal evaluation through domain experts in Section 5. Finally, we discuss the results in Section 6 and give conclusions in Section 7, also providing an outlook to applicability in other scenarios.

2. Related Work

The work described in this paper relates to natural interaction, primarily to prop-based interaction in combination with pen and tablet interaction, used for a 3D sketching method based on 3D alpha shapes in an immersive display environment. This method is applied to uncertainty sketching on volumetric data in expert geo-science applications.

Hinckley et al. introduced prop-based interaction in 1994 [HPGK94]. They used a head prop to apply surgical data visualization by a visualization slice. The work of Fröhlich et al. [FBZ*99] introduces the cubic mouse as a prop-based 3D input device for exploring geo-scientific data. This prop also makes use of a clutch to allow for precise alignment of slices. Hirota and Saeki introduce in [HS07] a tracked slice prop for volume inspection, which is used as a projection screen for the volume cross-section image. Using a tracked pair of pen and tablet as a prop in virtual environments has been implemented for several applications, including handwritten annotations [PTW98], navigation [BWHA98], creation of virtual scenes [BBMP97], or general system control [SES99, SG97]. The personal interaction panel [SG97] also works as spatial selection tool, by drawing a fishnet on it, but none of these systems was used to sketch out 3D volumetric areas. The Plexipad [dHKP02] offers a similar approach of dynamic data visualization as our work: a user moves a tracked plexiglas pad and stylus on a responsive workbench to "probe" 3D data. Here the pen in only used for data probing, no input of user data is available. According to Lindeman et al., such pen and tablet systems can augment functionality of a world, a view or an object, while staying within reach of the user without occluding the scene. They further state that the addition of passive-haptic feedback for use in precise UI manipulation tasks can significantly increase user performance and acceptance [LSH99].

3D sketching has been an extensive research area for long, mostly applied to 2D sketch-based 3D modeling. These systems include approaches like inflation of 2D contours, as introduced by Igarashi et al. [IMT06], literal-based drawing (e.g. SKETCH [ZHH06]) or mesh-construction through curved sketches projected on 3D aligned 2D planes (e.g. Bae et. al [BBS08]). Unlike our system they do not involve 3D interaction as used by Wesche [Wes04]. Bornik et al. [BBK*06] use simplex meshes to refine auto-generated segmentations in medical data sets by using a 3D interface for a VR display, as well as a 2D interface on a tablet PC. Both environments share the scene graph and can be controlled through one input device. Hirota and Saeki [HS07] introduce a tracked slice prop for volume inspection, which is used as a projection screen for the volume cross-section image. 3D drawn contours are used to construct models and Kuriyama Surfaces [Kur94]. Resulting models often lead to a bulbous 3D shapes or require skills in 2D drawing and conceptual modeling which is both not suitable for us.

Bi-manual 6-DOF sketching interaction was first examined in the 3-Draw system [SRS91] featuring a tracked reference pad and stylus for 3D curve creation within non-immersive CAD applications. Lapides et al. [LSSS06] built 3D Tractus, a mounted tablet pc that can be adjusted in height in order to sketch on different horizontal slices. Freeform 3D sketching is explored in only few works. Sketch Furniture (`http://www.frontdesign.se/`) enables furniture designers to 3D rapid prototyping and is simply tracked drawing in 3D. The sketches consists of 3D strokes and do supply volumetric forms. Schkolne and Schröder [SPS01] present a method of surface generation by drawings based on 3D hand movements and spatially applied tangible tools, which still requires determining the whole surface.

For the mathematical representation of a sketch, we use a 3D alpha shape, a concave approximation to the concave hull of a 3D point set, introduced by Edelsbrunner and Mücke [EM94] and primarily applied to 3D reconstructions of 3D scanner data, e.g. by Teichmann and Capps [TC98].

3. Requirements

To identify the main functional requirements of volume annotations for uncertainty sketching in seismic interpretation tasks, we worked closely together with industry domain experts. This was achieved through regular meetings of an international consortium of well-known oil & gas companies where experts represent their companies in terms of technical competence and user requirements [VRG09]. In addition, we conducted an informal field study together with a top 5 oil and gas company. Throughout this study, we analyzed typical work-flow patterns for geologists and we discussed shortcomings of currently applied systems.

3.1. Functional requirements

Uncertainty analysis is based on human judgment and experience currently not achievable through automatic data processing. When geologists recognize a data structure to be uncertain, they want to mark it directly, without interfering with other tools, e.g. a modeling tool palette or basic shape construction sets. Also, surface- or contour-drawing-based methods require a mental model of the whole form before starting the sketch. That is not suitable to the iterative approach of interpreting the data.

(R1) Volume annotation requires *a manual and iterative creation functionality directly on the data*.

Often, only few structures can easily be identified to belong to uncertain areas. Transitions between these distinctive structures then remain fuzzy. It would be impractical to draw complete contours, especially in 3D. So a user would prefer to construct an annotation volume only based on sketches of distinctive uncertainty areas.

(R2) A 3D annotation solution for volumetric areas is required to provide *approximation for areas of inconclusive data*.

To analyze seismic volumes, data is visualized through 3D volumetric rendering. To allow virtually seeing into the subsurface, all data is fully transparent while respective parts are being made opaque in volume slices or lenses. By actively moving those slices or lenses through a data space, geologists acquire further insight into subsurface structures. Handling of slices is particularly crucial as they are used to position sketch input.

(R3) Users require *re-alignment of volume slices to be as dynamic and direct as possible*.

Very often, sketching is performed alongside of not just one, but multiple slices used in reference to each other. Hence, similar structures on different slices are being connected and sketched out in uncertainty sketches.

(R4) A 3D annotation solution for volumetric areas is required to offer *management of multiple slices*.

Existing systems (such as GeoProbe [Hal09], GOCAD [Par09], or Petrel [Sch09]) use common GUI-based 2D interaction methods to subsequently re-align a view, to then re-align visualization objects in order to sketch into 3D space. To increase efficiency, a user should be able to synchronize these interactions.

(R5) Users require to *adjust a view, re-align a volume slice, and sketch on it at the same time*.

Results of seismic interpretation are inherently subjective and require special knowledge of diverse fields of geology, involving different experts e.g. stratigraphers, geophysicists, reservoir engineers, and production engineers. Thus, sketching on the data should be possible for multiple users at the same time. In order not to interfere with each other, users require real-time feedback on what the others are doing and which objects they are currently working on. Providing such information creates awareness [SSU01] in cooperative work.

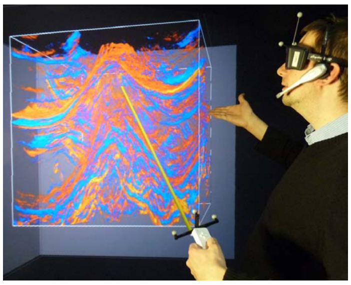


Figure 1: *The prototype application, showing a volume lens within the workspace and a Wiimote with pick-ray.*

(R6) A 3D annotation solution for volumetric areas is required to provide multiple users with *awareness about each other's actions*.

3.2. Ergonomic requirements

The following requirements relate to device handling and ergonomics. To provide a basis for discussion, we created a prototype that allowed visualization of seismic data in an immersive display, mainly through alignment of cutting slices and lenses within a data volume. As input device, we used a tracked Wii Remote ("Wiimote") by Nintendo. Visually, the Wiimote sends a pick-ray of unlimited length into the scene. A user can manipulate any hit object by either grabbing it, e.g. to align volume slices in the data space, or by opening a context menu for additional functionality (Fig. 1). In sketch mode, the pick-ray holds a sketch-cursor at an adjustable distance. A user can then create 3D points at cursor position. By using two Wiimotes, one in each hand with one in grab mode and the other one in sketch mode, a user can re-align volume slices and sketch on them at the same time.

One of the most impeding factors mentioned was the perceived little control when drawing freely with one hand in a 3D space. There is no possibility to rest the forearm somewhere while pointing into the scene precisely with the wrist.

(R7) Users require some kind of *physical support* to allow precise hand manipulation.

In addition, geologists reported little felt precision using the pick-ray with an increased distance to the picked objects. This also affected bi-manual sketching performance, especially when sketching on distant volume slices.

(R8) Input for 3D volume annotation requires *high precision* that remains *constant over distance*.

Apart from that, bi-manual sketching was received very positively as it offered real-time slice alignment and sketching at the same time. Users reported more direct feel about acting on spatial data and emphasized the need for direct 3D handling of volume slices, as previously identified in R3.

Figure 2: *The 3D Sketch Slice is used as a prop for a volume slice to sketch uncertainties into volumetric seismic (left). It is equipped with spherical handle (middle), and comfortably rests on the user's forearm (right).*

4. The 3D Sketch Slice

To meet the before-mentioned requirements, the 3D Sketch Slice (Fig. 2) uses a volume slice as the central interaction object. It is key to both data analysis and data selection in currently used applications. Our approach is to make interaction with and on such a slice as direct as possible by using a prop design (R3).

To provide constantly high precision (R8), 3D positioning is based on combined 2D and 3D input from a digitizer pen and a tracked tablet, which offers additional physical reference support (R7). While moving the tablet controls 3D alignment of a volume slice within the workspace; positioning the pen on the tablet controls the sketching cursor on the slice. This combination allows reaching any 3D position within the workspace.

4.1. Prototype hard- and software

The prototype was implemented in an immersive Two-View display system [FI09], a rear-projected power-wall of 3.60m x 2.40m. Two optically tracked users can see correct binocular stereo through active shutter glasses at the same time with support for additional tracked users for each view.

The Sketch Slice is based on a commonly available Wacom Wireless pen tablet with electromagnetic resonance (EMR) touch sensor, capable of precise pen interaction offering a resolution of 16720 x 12080 points on an active area of 209 mm x 151 mm. The tablet comes with a battery-free pressure-sensitive pen with 512 pressure levels, both at the tip and on the eraser end. The pen also features two buttons in addition to the tip button event. The tablet was connected via Bluetooth, communicating to the Linux event system; multi-tablet support was added in a proprietary driver. Two additional buttons are placed on the tablet above the active area. We copied these buttons to a spherical handle mounted under the tablet. The spherical form of the handle provides an optimal grip for a regular-sized hand in many different holding postures. Both buttons can be easily reached most of the time, even in awkward positions.

The software was implemented as a prototype demonstration application. It runs on AVANGO® NG [KWRB08], an open source VR software framework using OpenSceneGraph for scene management and Python as a scripting language. External libraries can easily be accessed through the framework. Volume rendering is done through Octreemizer® [PHF07]. For the 3D sketching functionality, we use CGAL [CGA09] for mesh tessellation and CVML-CPP [CVM09] for voxelization of the resulting triangle sets.

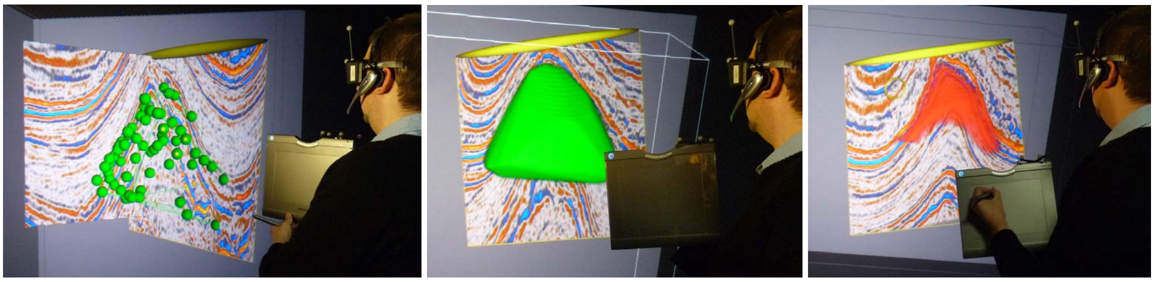
The application allows loading a volumetric seismic data set into a spatial working area object, called workspace. Such a workspace object can hold several visualization objects, i.e. volume lenses and volume slices. These objects can be arranged within a workspace to take a look at the volumetric data.

4.2. 3D volume annotation for uncertainty sketching

To meet the requirements on sketch interaction (R2), we chose 3D alpha shapes [EM94] as our basic 3D modeling structure. A 3D alpha shape is a generalization of a convex hull of a point set. The 3D shape is defined through a parameter, called alpha. Given a 3D point set, the 3D alpha shape surface encloses all points, where no sphere of a squared radius of alpha would fit in between. That means, the smaller this parameter alpha, the more concave details has the resulting shape while the maximum alpha value would give the 3D convex hull of the point set. In our system, we let CGAL choose the minimum selectable alpha value to still result in a connected closed mesh.

Our implementation processes an input set of 3D points of which CGAL calculates a 3D alpha shape based on a Delaunay triangulated mesh. The resulting triangles are then voxelized. Voxel matrices are normalized and transformed in the data space's coordinate system, ready for volume rendering. While mesh processing and visual update of the points set works in real-time, a second process is being triggered with each pointŠs addition that handles voxelization in the background to preserve interactive frame rates during sketching.

This leaves a user with manual sketching of a few points as s/he identifies distinctive locations in the data iteratively (R1). For adjusting the approximation of unspecified areas on the sketch, a user can control the convexity of the uncertainty sketch by moving a slider, which technically adjusts the alpha value (R2).



(a) Adding 3D points to a sketch in respect to spatially aligned slices. (b) The generated uncertainty sketch, visualized as opaque voxels. (c) The sketch at lower alpha value, visualized as semi-transparent voxels.

Figure 3: *Workflow of 3D volume annotation*

4.3. Visualization of volume annotations

Visualization of volumetric annotations serves two different purposes: during editing it should allow for easy definition of positions that belong to the sketch area without experiencing occlusion problems. Thus, by default, uncertainty sketches are visualized through their points (Fig. 3(a)), each by a sphere, color-coded according to the sketch's uncertainty level (green, yellow, red). To emphasize the boundaries of a sketch, the underlying mesh can be visualized in wire-frame or solid modes. Finally, voxel representations are available for seamless visual integration with the seismic data (Fig. 3(b)). The opacity of the voxels can be adjusted continuously (Fig. 3(c)).

The second purpose of visualization is to implicitly warn a user when taking certain parts of data into account. This is achieved by rendering the corresponding voxels only on intersecting visualization objects, such as volume lenses or slices. Intersecting voxels are being animated as with desaturated color cycling, displacement, or blurring effects.

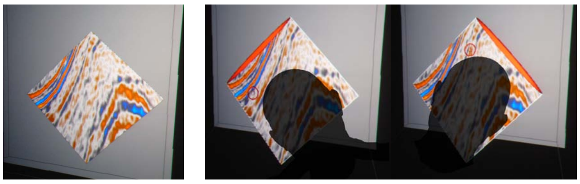
4.4. Tablet-based 3D slice control

To let a user directly control the alignment of volume slices by prop-metaphor, the input transformation matrix generated from tracking the tablet reflectors can be coupled with the actively controlled slice (R3). This is achieved by using a clutch mechanism. With the clutch engaged, which is achieved by pressing a tablet button, relative translation and absolute orientation of the tablet is mapped 1:1 to the slice within the workspace. Hence, regardless of workspace orientation and user location, the connected slice always shows the same orientation. It follows the same movement as the tablet. This enables slice alignment, view alignment through user tracking, and sketching at the same time (R5).

As precise sketching or view alteration may require moving around without an alteration of the coupled slice, a user can de-clutch the 3D Sketch Slice. Then, the pen control is still coupled with sketch input, but the slice remains static at its current position.

4.5. Pen-based 3D point manipulation

Pen input is used for precise volume annotation. The active area on the tablet is directly mapped to the active volume slice in absolute positioning. Hovering with the pen tip above the active area moves the cursor across the slice. Touching the tablet with the pen tip creates a point and adds it to the active sketch. As the pen cursor touches another existing point, the point can be grabbed and subsequently moved to another position on the same slice. In combination with a clutched slice, a point can thus be moved to any other location within the workspace. Points can be deleted by using the eraser end of the pen with pressure sensitivity controlling the size of the cursor, making it easy to quickly delete many points.



(a) Ambiguous perception of the top edge. (b) View-controlled orientation of a mapping area, indicated by the slice cursor bar in red color.

Figure 4: *View-controlled orientation of a mapping area on a volume slice.*

4.6. View-controlled orientation of mapping area

With the clutch engaged, the pen position on the tablet is directly mapped to the slice in absolute positioning mode. The upper edge of the tablet corresponds to the upper edge of the slice, respectively, as defined by the prop metaphor and indicated by the colored slice cursor. After having de-clutched the tablet from the slice, the user often intends to switch to other slices at different orientations or s/he reorients his/her view on the slices, i.e. by moving around or tilting the head. In addition, in clutch mode, the tablet might have been rotated and twisted around, to vividly look at the data. Now that the clutch is released for precise sketching, orientation of the tablet and the slice might differ severely from each other, causing irritation: when touching the upper left corner on the tablet, the perceived lower right corner might be reached on the slice. This would require continuous rethinking by the user and therefore is not acceptable.

Our solution for this problem was to reorganize the orientation of a de-clutched slice according to a user's visual perception. Looking at the tablet, a user can easily identify the upper edge, implicated by industrial design, e.g. a logo. Looking at a quadratic volume slice however, we intuitively choose one of the edges to be the perceived upper edge. Trivial as it sounds, perception of what the upper edge is can be quite ambiguous, especially when looking at a slant, which is perceived as a diamond-shape. Each edge adjacent to the top corner can be regarded as the top edge. Respectively, the perception changes with a user rotating his/her head. In the end, the choice of the perceived upper edge seems to depend on a user's visual horizon. Thus we transform the slice into the user's projected coordinate system to choose the edge with a minimum angle to the user's horizon. Then, we map the upper left corner of the tablet's active area to the leftmost point on that edge, being the perceived top edge (Fig. 4).

4.7. Multi-user markers (MUMs)

As previously stated, seismic interpretation and thus volume annotation is often achieved cooperatively by multiple users at the same time. One issue that came up early in development was the confusion if users were editing points on the same or on different sketches. Especially when groups of users work on multiple sketches, they should be aware of who is adding points to which sketch, without getting confused by other sketches' points.

As a solution, we introduce the concept of multi-user markers or MUMs. MUMs consist of tiny solid tubes, colored in user-custom colors, one sticking out of each point of the currently active sketch. They all point towards the annotating user. From this view, the tubes appear as colored spots in the centers of the points. As another user joins to sketch on the same annotation, all points are being extended with a tube of a different color accordingly. The first user now sees, in addition to the colored spot in the center, a tube pointing towards the additional user. Respectively, the additional user's view is being rendered (Fig. 5). Orientation of the MUMs is animated in real-time, always pointing towards their owning users. This location-based approach potentially supports user identification more implicitly, compared to non-ordinary color-coding, and hence provides cooperative awareness (R6).

5. Evaluation

The 3D Sketch Slice primarily aimed at the before-mentioned requirements and its actual applicability to an industrial uncertainty sketching scenario. We performed an informal evaluation consisting of tryout sessions, followed by group discussions with common agreements.

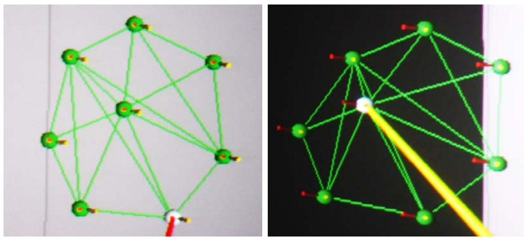


Figure 5: *Multi-user markers on the same sketch from two different views: red user (left) and yellow user (right)*

After the tryout sessions on a test seismic, we asked individuals to fill out a short evaluation questionnaire by rating main interaction aspects on a 5 level Likert-scale which was accompanied by a visual analog scale, clearly indicating equal spacing of response levels. We thus treat it as interval-level data, hence analyzing descriptive data through arithmetic mean, normalized to a scale of 0 to 1 with 0 being extreme negative, 1 extreme positive and 0.5 resembling a neutral rating. As statistical validity of this method is being discussed widely, we also provide medians in addition.

Eight users participated in the questionnaire, being all experts from globally leading oil and gas companies. They professionally represent geologists, i.e. the actual users, in their respective companies and they have key competences in assessing the applicability of technology to their employees and co-workers.

5.1. Results

Overall, the concept of slice-based data visualization through handling a slice prop was a fascinating idea to the geologists. It was considered as a potential expert tool for actually being integrated into their daily work-flow. This caused a very intensive assessment of the prototype in demo sessions and the whole sketching functionality with the 3D Sketch Slice was accordingly rated very positively ($\mu = .86$; $\sigma^2 = .04$; $\tilde{x} = 1.00$).

The geologists were eager to work with a pen on the seismic data. According to the comments, a much more direct feel and self-judged higher precision could be accomplished. It was also stated that pen interaction had more expert-like appeal than a Wiimote. Even the concept of absolute mapping and indirect drawing, sometimes seen as the biggest burden for first time pen tablet users, was understood quickly. Some users even stated that, now working with a pen, they would expect scribbling and paper-like annotation functionality. The experts reported a very precise feeling with setting points, related to the physical support and sensor precision. The ratings confirm these impressions: The pen sketching in general was rated very positively ($\mu = .86$; $\sigma^2 = .04$; $\tilde{x} = 1.00$), and also separated into aspects of precision ($\mu = .89$; $\sigma^2 = .02$; $\tilde{x} = 1.00$) and ergonomics/comfort ($\mu = .86$; $\sigma^2 = .02$; $\tilde{x} = .75$).

Slice interaction for alignment of volume slices was rated also positive overall (μ = .67; σ^2 = .12; $\tilde{x}$ = .75). It was widely accepted as a concept, despite of the fact that the prototype had some flaws according to users: The most impeding factor was reportedly the heavy weight of the 3D Sketch Slice. Two users regarded this as personally unacceptable which was reflected in the ergonomics rating (μ = .54; σ^2 = .11; $\tilde{x}$ = .5). With a weight of about 0.8 kg, our current prototype weights about 1.1 kg in total with the handle attached. The direct alignment of slices was commented positively. Sometimes, the 1:1 mapping seemed to prevent a user from reaching all areas within the workspace without taking a step to the side or re-clutching the 3D Sketch Slice. Thus a scaled mapping of the tablet translation should be considered. Another comment was that re-clutching into an already aligned slice would suddenly switch slice rotation towards the tablet's rotation, making it hard to add only slight adjustments to a prepared data view. Still the possibility of directly holding a slice as a tangible object was commented very positively, mostly to high technical precision through tracking. A neutral rating of precision in slice control reflects these rather mixed comments (μ = .54; σ^2 = .07; $\tilde{x}$ = .5).

The multi-user marker was appreciated in general, without being formally evaluated. Users never asked on what sketch they were currently working, even with other users around, working on multiple sketches. The real-time animation of the small tubes towards other users evoked a comment that it made the virtual items appear more real, or the other person more virtual, respectively.

6. Discussion

The 3D annotation solution presented was primarily designed for a rather narrow-focused application, uncertainty sketching. However, it explores the general task of 3D volume annotations in a novel, yet simple way. Currently, this task and the underlying problem ("how to precisely describe a volumetric region in a simple way") is not broadly addressed. There are only a few possible applications of spatially arranged data, each being very specific such as medical data, possibly requiring their own specific solutions. Increased usage of 3D information visualization and developments in the visual analytics application domain might require more general approaches in the future.

Our approach offers a simple way of creating 3D annotations according to specific data points combined with very precise, physically supported 3D input, that should be evaluated more broadly in general selection tasks. The main current weaknesses are related to the clutching functionality, where clutching overwrites current slice orientation, hence not meeting the requirement for easy management of multiple slices. Relative orientation mapping or snapping functions with visual feedback for the original slice orientation could help here. In addition, the slice cursor, which indicates the mapping orientation dependent on a user's view, is hardly noticeable in regular sessions since the orientation of the slice was rather rarely rotated on the view axis. At a 45 degree slanted orientation, the mapping sometimes switches back and forth caused by slight head movements, which can be very irritating. A hysteresis function could help out here.

Sketching itself through 3D alpha shapes seemed to be fairly easy to use. Although one might issue slider control of the convexity to be a rather indirect method of form manipulation, it offered a satisfactory outcome most of the time and should be much quicker than manipulation of single vertices of a mesh. Possible improvement to our approach could be gained by extending to weighted alpha shapes. Furthermore, pen interaction offers additional opportunities related to pressure sensitivity when interacting with the points: moving a point with high pressure could have an impact on the weighting of the adjacent points in the alpha shape. Pen input for real scribbling in 3D should be further explored, as several users actively proposed this feature.

An interesting aspect was that, despite of the highly visual task and the so-called indirect pen input through a pen tablet, no user asked for adding display functionality to it. One reason might have been the heavy weight of the tablet alone. We also think that spatial relations between data points and dynamic visualization objects are crucial for such tasks involving spatially organized multi-dimensional data.

7. Conclusions and Future Work

In this paper, we addressed the concept of 3D volume annotations, by focusing on an actual use case scenario: uncertainty sketching within volumetric seismic data sets for the oil and gas industry. Within this scenario, we identified a list of requirements that should be met to provide an efficient interface design for 3D volume annotations.

As our main contribution, we presented the concept of the 3D Sketch Slice, which consists of a prop for a visualization object that also serves as sketching interface, to combine 3D data exploration and annotation. We elaborated this concept in our implementation based on 3D alpha shapes, which allows to iteratively focus on distinctive data combined with adjustable implicit 3D sketch completion.

The implementation offers a new approach to volume annotation that facilitates precise spatial interaction through the combination of 2D and 3D interaction. Compared to existing solutions the main advantages are the physicality and the sensor precision. This allows for precise 3D interaction-which remains constant regardless of distance to the model. Furthermore, the system offers direct alignment of viewing objects and sketching interaction at the same time, which overcomes indirect feel on existing WIMP-applications. We further presented a new view-related automatic mapping function and the concept of multi-user markers (MUM), which provides awareness for co-located collaboration on the same sketch.

We have explored this new 3D annotation solution within the targeted scenario in an informal user study. Overall positive feedback validates the identified requirements according to the expertise of the geologists. Shortcomings related to clutching and heavy weight will be addressed in ongoing work. We further plan to extend this approach to other, broader applications related to 3D volume annotations, especially concerning the research field of visual analytics.

8. Acknowledgments

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References

[BBK*06] Bornik A., Beichel R., Kruijff E., Reitinger B., Schmalstieg D.: A hybrid user interface for manipulation of volumetric medical data. pp. 29–36. 2

[BBMP97] Billinghurst M., Baldis S., Matheson L., Philips M.: 3d palette: a virtual reality content creation tool. In *Proc. of VRST '97* (New York, NY, USA, 1997), ACM, pp. 155–156. 2

[BBS08] Bae S.-H., Balakrishnan R., Singh K.: Ilovesketch: as-natural-as-possible sketching system for creating 3d curve models. In *Proc. of UIST' 08* (New York, NY, USA, 2008), ACM, pp. 151–160. 2

[BWHA98] Bowman D. A., Wineman J., Hodges L. F., Allison D.: Designing animal habitats within an immersive ve. *IEEE Computer Graphics Applications 18*, 5 (1998), 9–13. 2

[CGA09] CGAL: Computational geometry algorithms library. http://www.cgal.org. 4

[CVM09] CVMLCPP: Common versatile multi-purpose library for c++. http://tech.unige.ch/cvmlcpp/. 4

[dHKP02] de Haan G., Koutek M., Post F. H.: Towards intuitive exploration tools for data visualization in vr. In *Proc. of VRST '02* (New York, NY, USA, 2002), ACM, pp. 105–112. 2

[EM94] Edelsbrunner H., Mücke E. P.: Three-dimensional alpha shapes. *ACM Trans. Graph. 13*, 1 (1994), 43–72. 2, 4

[FBZ*99] Fröhlich B., Barrass S., Zehner B., Plate J., Göbel M.: Exploring geo-scientific data in virtual environments. In *Proc. of VIS '99* (Los Alamitos, CA, USA, 1999), IEEE Computer Society Press, pp. 169–173. 2

[FI09] Fraunhofer-IAIS: Twoview display system. http://www.iais.fraunhofer.de/index.php?id=645&L=1. 4

[Hal09] Halliburton: Geoprobe volume interpretation software, March 2009. http://www.halliburton.com. 3

[HPGK94] Hinckley K., Pausch R., Goble J. C., Kassell N. F.: Passive real-world interface props for neurosurgical visualization. In *Proc. of CHI '94* (New York, NY, USA, 1994), ACM, pp. 452–458. 2

[HS07] Hirota K., Saeki Y.: Cross-section projector: Interactive and intuitive presentation of 3d volume data using a handheld screen. pp. –. 2

[IMT06] Igarashi T., Matsuoka S., Tanaka H.: Teddy: a sketching interface for 3d freeform design. In *ACM SIGGRAPH 2006 Courses* (New York, NY, USA, 2006), ACM, p. 11. 2

[Kur94] Kuriyama S.: Surface modeling with an irregular network of curves via sweeping and blending. *CAD: Computer-aided design 26*, 8 (1994), 597–606. 2

[KWRB08] Kuck R., Wind J., Riege K., Bogen M.: Improving the avango vr/ar framework: Lessons learned. 4

[LSH99] Lindeman R. W., Sibert J. L., Hahn J. K.: Towards usable vr: an empirical study of user interfaces for immersive virtual environments. In *Proc. of CHI '99* (New York, NY, USA, 1999), ACM, pp. 64–71. 2

[LSSS06] Lapides P., Sharlin E., Sousa M. C., Streit L.: The 3d tractus: A three-dimensional drawing board. In *Proc. of TABLETOP '06* (Washington, DC, USA, 2006), IEEE Computer Society, pp. 169–176. 2

[Par09] Paradigm: *GOCAD Geological Interpretation*. March 2009. http://www.pdgm.com. 3

[PHF07] Plate J., Holtkaemper T., Froehlich B.: A flexible multi-volume shader framework for arbitrarily intersecting multi-resolution datasets. *IEEE Transactions on Visualization and Computer Graphics 13*, 6 (2007), 1584–1591. 4

[PTW98] Poupyrev I., Tomokazu N., Weghorst S.: Virtual notepad: Handwriting in immersive vr. *Virtual Reality Annual International Symposium 0* (1998), 126. 2

[Sch09] Schlumberger: Petrel seismic to simulation software. http://www.slb.com. 3

[SES99] Schmalstieg D., Encarnaç ao L. M., Szalavári Z.: Using transparent props for interaction with the virtual table. In *I3D '99: Proceedings of the 1999 symposium on Interactive 3D graphics* (New York, NY, USA, 1999), ACM, pp. 147–153. 2

[SG97] Szalavari Z., Gervautz M.: Using the personal interaction panel for 3d interaction. In *Proc. Conference on Latest Results in Information Technology* (May 1997). 2

[SPS01] Schkolne S., Pruett M., Schröder P.: Surface drawing: creating organic 3d shapes with the hand and tangible tools. In *CHI '01: Proc. of the SIGCHI conference* (New York, NY, USA, 2001), ACM, pp. 261–268. 2

[SRS91] Sachs E., Roberts A., Stoops D.: *3-Draw: A Tool for Designing 3D Shapes*, vol. 11. IEEE Computer Society Press, Los Alamitos, CA, USA, 1991. 2

[SSU01] Schwabe G., Streitz N., Unland R.: *CSCW-Kompendium*. Springer, Berlin [u.a.], 2001. 3

[TC98] Teichmann M., Capps M.: Surface reconstruction with anisotropic density-scaled alpha shapes. In *Proc. of VIS '98* (Los Alamitos, CA, USA, 1998), IEEE Computer Society Press, pp. 67–72. 2

[VRG09] VRGEO: Website. http://www.vrgeo.org. 2

[Wes04] Wesche G.: A user interface for free-form shape design at the responsive workbench. *Journal of Computing and Information Science in Engineering 4*, 3 (2004), 178–185. 2

[Wil05] Wilkinson R.: *Speaking Oil and Gas*. BHP Billiton Petroleum, 2005. 1

[ZHH06] Zeleznik R. C., Herndon K. P., Hughes J. F.: Sketch: an interface for sketching 3d scenes. In *ACM SIGGRAPH 2006 Courses* (New York, NY, USA, 2006), ACM, p. 9. 2