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# Interactive Data Annotation in Virtual Environments

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**Abstract**

*Note-taking is an integral part of scientific data analysis. In particular, it is vital for explorative analysis, as the expression and transformation of ideas is a necessary precondition for gaining insight. However, in the case of interactive data exploration in virtual environments it is not possible to keep a pen and pencil at hand. Additionally, data analysis in virtual environments allows the multi-modal exploration of complex and time varying data. We propose the toolkit independent content generation system IDEA that features a defined process model, a generic annotation model with a variety of content types as well as specially developed interaction metaphors for their input and output handling. This allows the user to note ideas, e.g., in form of text, images or voice without interfering with the analysis process. In this paper we present the basic concepts for this system. We describe the context-content model which allows to tie annotation content to logical objects that are part of the scene and stores specific information for the special interaction in virtual environments. The IDEA system is already applied in a prototypical implementation for the exploration of air flows in the human nasal cavity where it is used for data analysis as well as interdisciplinary communication.*

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## 1. Introduction

Currently available computational power is able to produce data far more quickly than scientists can analyze and understand it. In their progress report, [van00] argue that Immersive Virtual Reality (IVR) will be a possible solution to what they call the accelerating data crisis. As such, VR has become a common means for scientific visualization but its use is mostly focused on presentation purposes. It is not fully integrated into the process of data analysis. A trivial, yet immanent, logistical problem is that VR display systems and interaction hardware are often part of specialized laboratories and its utilization means additional effort to the user.

An integrated process model with open data storage facilities and an open framework for the integration of application specific interaction metaphors can lead to a better motivation for the utilization of VR technology in the scientific data analysis process. On a software level, the lack of widely accepted metaphors, tools for true three dimensional interaction, and the weak integration of VR applications in current workflows is wasting much of the potential that VR has in the field of scientific visualization.

In [Spr92], the authors present a data analysis process, that identifies the expression of ideas during data maneuvering as an obligatory precondition for the gaining of insights. During the undirected search process, which characterizes interactive data exploration, the transformation of observations to a written or spoken form enables cognitive preprocessing of these ideas. [Spr92] encourage to provide a tool that allows to store and link records from different stages of the analysis. We follow this idea and propose that a generic method for the annotation of ideas during interactive VR visualization sessions will provide a true benefit for the use of VR technology in the data analysis process. So far, there is little common knowledge established about the foundations of such a system, although many implementations utilize basically the same methods, but name them differently. In addition to that, most systems are application specific or cover a fixed set of content types and lack a gen-

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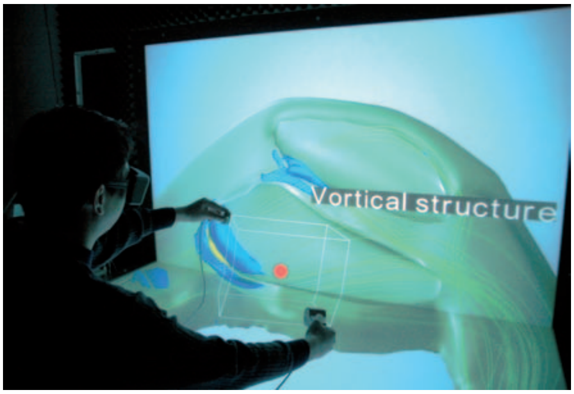


**Figure 1:** *A user annotating a flow field inside the human nasal cavity in a workbench environment. He is currently marking a region of interest, employing two handed interaction.*

eral, extensible model. No system seems to be embedded in a process model that is defined beyond the borders of the VR application. Although many implementations are mentioned in the literature, almost none seems to be currently developed or available. Many are tied to a specific VR toolkit, although the idea of annotation support is rather generic.

The contribution of this work is to present a general foundation for an annotation system. It defines a basis that can be used as an extension point for custom types of annotations and their embedding in virtual environments (VE). The system is comprehensive, it covers the meta modeling of the data, ties objects and annotations in the context-content model, defines a basis for different types of content, and is embedded into a scientific data analysis process that includes VEs.

The annotation data that is collected during a session is to be represented and possibly revised in future sessions. The system has to be minimally invasive, meaning, that the integration of the annotation system to a custom application or software environment has to be without too much effort. Moreover, there have to be specific interaction metaphors which allow the user to take notes without interfering with the analysis process itself. In addition to that, the recorded annotation data has to be accessible in a desktop environment, e.g., to be used for reports. In order to reflect the supportive nature of the system, we use the acronym IDEA for **I**nteractive **D**ata **E**xploration and **A**nnotation for the prototype implementation of the concepts we propose.

The rest of this paper is structured as follows. First we will give a brief overview of the related work in this area. Then we will focus on the foundation of our annotation system IDEA and its architecture, describing the overall process, the context-content model and the currently supported content types. We will finish this paper with the description of a prototypic application of the IDEA system in the field of flow visualization, see figure 1.

## 2. Related Work

One focus of the previous work is on creation and manipulation metaphors or the description of special types of content. Most authors provide specific solutions in their application domain, e.g., medicine, virtual prototyping in automotive design or general mechanics, such as [Son04], [Tre04] or [Tsa02]. Other applications focus on architecture, city navigation for tourists or E-learning systems, as in [Jun02] or [Rei03]. These specific applications usually give little information about the general nature of either the process or the technological foundation. Not all of them are used in immersive VEs.

With respect to the different types of annotations, the content-marker model [Lou94] is common, as well as the recording of voice based annotations. The latter is often used due to the lack of keyboard support in fully immersive VEs, see [Ver93] or [Har96]. [Jun02] present a system that is capable of changing the virtual world by sketching, an extended interpretation of an annotation, but the system uses a **W**indows **I**cons **M**enu **P**ointer (WIMP) metaphor based environment. In [Tsa02] a broad variety of interaction methods is presented for content generation, but the authors utilize a custom non-immersive display and interaction hardware. Their content types comprise 2D/3D sketching, taking screenshots, voice and text annotation. The annotated data can be inspected by an off-line browsing tool in a desktop environment.

The most fundamental part of the data annotation process is the modeling stage, where annotation types, possible objects of reference, handling of variance in time, and the exploration process are defined. The scientific exploration process is seen as a multi-step interactive process in which data, ideas and insight to a specific problem approaches the scientist [Sch00]. Especially [Spr92] rates the act of note taking as a fundamental element for gaining insight. They line out a microscopical process that is claimed to be genuine to the scientific data analysis process, but do not mention the embedding of this process step in a larger context. An aspect that we consider very important is the preprocessing step, where the model data for the virtual world is created, partitioned and classified by the user. This step is rarely mentioned by other researchers, as it is a manual procedure that produces system specific results, e.g., meta information about the objects or content of the virtual world. [Lou94] present a prototype implementation for a desktop based annotation system, and consider a VR extension as a future challenge. A more formal work on the variation of visualization parameters and their impact on the insight to a visualization is described in [Jan02]. [Bow03] and [Raj04] present recent work on the general nature of content browsing in annotated virtual worlds. They define taxonomies and dis-

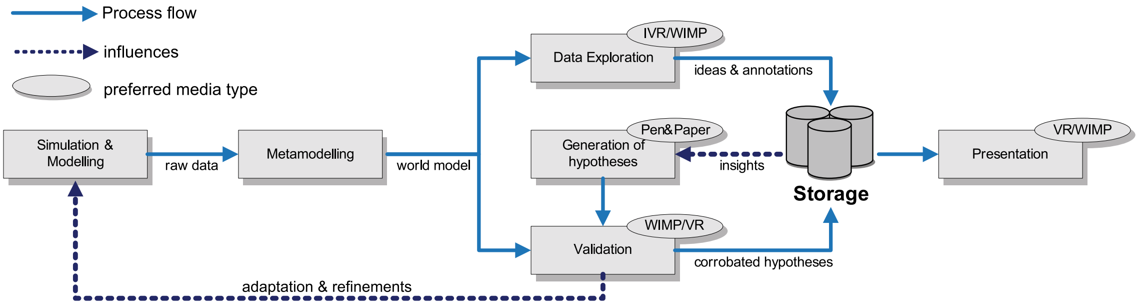


**Figure 2:** *Schematic view of the underlying data analysis process.*

tinguish between abstract information and concrete objects. However, this work does not cover the aspect of content generation, but concentrates on interactive browsing and annotations selection techniques.

## 3. Annotation System Architecture

The annotation system IDEA is supposed to be the implementation of a process, a terminology and a software model. The complete process is interesting, as we try to develop tools that aid the explorative data analysis by providing access to the data and the annotation in different environments throughout the overall process.

### 3.1. Process Model

The partitioning of the process includes ideas of the model from [Sch00], with an extended off-line modeling stage where the data model that is to be annotated. Figure 2 depicts our process model. Beginning with a simulation and modelling step, scientific data is created with application specific features and in custom data formats. This data has to be transformed to a structure that enables IDEA to differentiate between informative and structural components of the virtual scene. Details about this process are discussed in section 3.2. After this modeling stage, either a data exploration step or a validation step is executed. While the first step is ideally performed in an IVR environment, there is often a first control phase in a WIMP environment. However, the core idea of this stage is to interactively scan the data set for interesting phenomena with an undirected search, navigating through it and modifying visualization parameters. The validation stage differs from that step, as this phase is reached once principle ideas about the simulated raw data have been established and a directed, batch-like processing of the data sets where a desktop-based visualization solution is an adequate tool. Of course, interim VR based checks are also valuable at this stage.

We think it is important to realize that at almost any stage of the analysis process, note-taking in whatever form is a most valuable cue for the development of ideas and insights. However, we rate any model that assumes a fully digitized workflow cycle as unrealistic. With respect to that, a very important step in this process contains the off-line browsing of generated annotations in a desktop based environment. In this phase the scientist will probably note portions of ideas and sketches using pen and paper. Any information from this stage is hard to incorporate in a digital environment after its production and thus lost for any automated processing. Therefore we do not propose an expert system that automatically scans the annotation content, but a well structured and open data collection and browsing environment.

An important and well understood purpose of VR technology lies in its expressiveness during presentations of researched insights and the ability to communicate about complex data. As a remark, we would like to state that a well planned path of well placed annotations can be used for presentation or educational purposes. Consider an educational tour of annotations through interesting spots in an air flow simulation, e.g., for students of mechanical engineering.

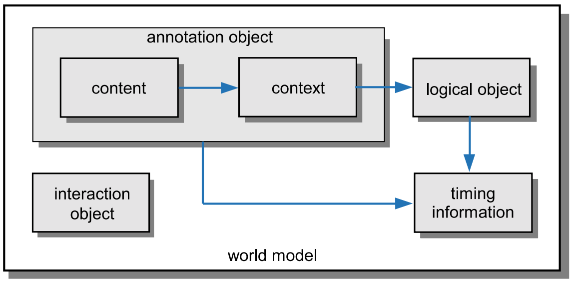


**Figure 3:** *The world model is partitioned into three basic object types: logical, interaction and annotation objects. Context and content are loosely coupled within the annotation object and bound to logical objects.*

### 3.2. Preprocessing of Raw Data

A fundamental requirement of the IDEA system is to apply the framework to a wide variety of application domains, e.g., architectural walkthroughs, exploration of un-

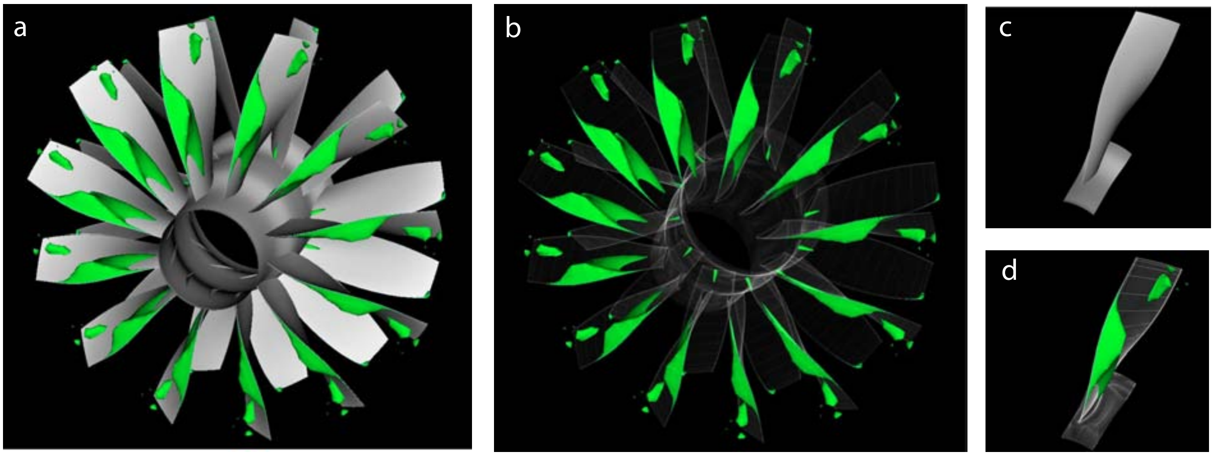


**Figure 4:** *This visualization of a counter-rotating propfan illustrates the problem of context selection. The logical object in the annotation's context defines what part of the world-model the user wants to annotate given scene (a). Possible answers include: the full isosurface over the pressure scalar field (b), a single fan blade (c), or just the isosurface at this blade (d).(Also see color insert.)*

steady flow simulations or virtual prototyping. The incoming data formats that are used in the distinct fields vary much in expressiveness and handling. We therefore need to apply a semi-automated preprocessing step that converts the *raw data* and associated *meta data* to objects of our world model. While raw data can be seen as a collection of files that contain all the data that is to be explored, meta data is any auxiliary information that helps to work with, convert or understand the raw data's structure. On the one hand, this can be information written on a sheet of paper that accompanies the disc with the raw data. On the other hand it can be information that is embedded in the raw data, e.g., labeling or spatial relations in a VRML model file.

Our *world model* basically consists of three types of objects. First of all, *logical* objects define the elements that can be associated with *annotation* objects. Both types of objects are associated with attributes of time. The third class of objects contains *interaction* objects, which are used for application control or cover an informative aspect, e.g., color lookup tables or labeling sheets. A first preprocessing step will have to convert the raw- and meta data to logical and annotation objects, and has to decide the presence of additional interaction objects and their parametrization. Figure 3 depicts these basic terms and their relation. Logical objects define objects with an application specific meaning to the user and an obligatory identification mark, e.g., a name or an ID. These objects can be embedded inside the raw data, e.g., as in medical data, where single objects of interest have to be segmented and labeled in a semi-automated process step. However, from the IDEA system's point of view, only logical objects can be selected and annotated, so the internal structure of the raw data has to be converted to a set of logical objects. In the context of a VR application, a logical object is comprised of a number of rendering primitives, e.g., polygons, voxels or pixels, that define the object in the visual space. Figure 4 illustrates this problem in the flow analysis application domain.

First, there is the context geometry, a counter rotating propfan, which is given here as one coherent triangle mesh. This could be decomposed into several sub-components, e.g. the single turbine blades as dipicted in figure 4(c). Several of these blades make up one rotor. The green spots in 4(a) depict a simple visualization of an isosurface over the pressure scalar field. In analogy to the decomposition of the propfan geometry, the isosurface itself can be split into several connected components. For example, the user might only be interested in the isosurface at one blade, see figure 4(d).

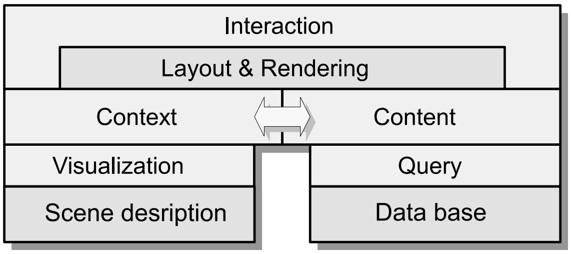


**Figure 5:** *Layered structure of the context-content model.*

### 3.3. The Context-Content Model

Once a set of logical objects is identified and interaction objects are set up, the user can experience the virtual world and generate annotations. The *context-content model* (CCM)

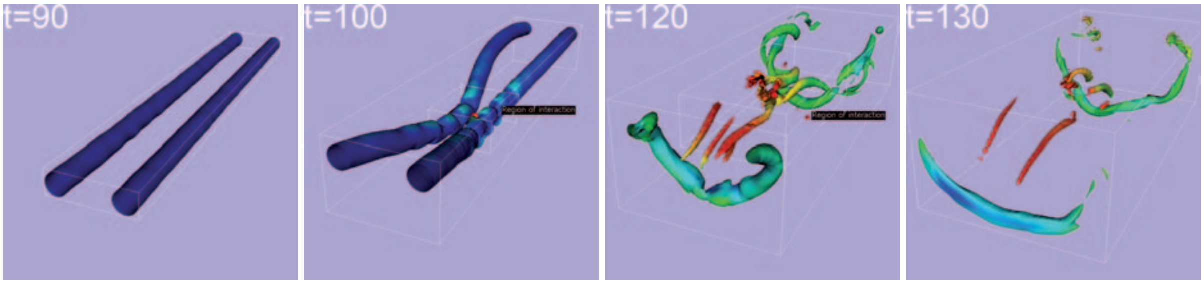


**Figure 6:** *Four Screenshots from a time series showing the interaction of two vortices (Crow-Instability). The entire series consists of 152 discrete time levels. The vortices have been extracted by isosurfacing the $\lambda_2$-value. As such they exist as one logical object in the application's world model. This is indicated by the outward bounding box. Additionally, from t=100 to t=120 an annotation has been added in order to highlight the region of interaction. (Also see color insert.)*

presents a structured and simple view on this process stage. During interactive exploration, the CCM is used to tie annotation information to specific logical objects. It is the very core abstraction of the IDEA annotation system. In a nutshell, the content describes the information or the annotation as itself, while the context contains information about where or to what object the content relates. Figure 5 depicts the overall system's layered structure. The *context* defines the following information.

- the *logical object of reference* and the *geometrical position of the annotation* in the object's coordinate space
- a *volume of interest* that can be used to mark a geometrical subspace of a logical object
- the *user's viewpoint* and *orientation* during the annotation's initialization step
- *timing* information, e.g., for instationary data sets, see section 3.4
- *system control* information, e.g., file descriptors and timestamps
- A collection of associated *screenshots*, 2D still images of a particular view that were taken by the user during the annotation creation process

This view on the context of an annotation allows the lose coupling of the annotation content data to the world model. Storing the user's viewpoint during the recording of an annotation allows the reproduction of the perceived scene in later sessions. The region of interest is an important auxiliary information when logical objects do not have a suitable decomposition or are created as a whole during the data exploration, e.g., isosurfaces of a scalar field in flow analysis.

### 3.4. Annotating Time Varying Data

In addition to the three spatial dimensions, transient data introduces a fourth which needs to be incorporated into the system. Here we distinguish two classes of *time awareness* that may apply to an annotation. The first class concerns an annotation's "life time". As stated earlier, in 3D-space an annotation refers to a logical object and a distinct spot or region in the scene. The annotation's content is only valid with respect to this particular spatial extent. Consequently, if the annotated data varies over time, an analogous restriction has to be made. The system models this by including an exact *validity frame*, which may be an interval or a single point in time. Second, the annotation itself can be time-varying. On the one hand this holds for the context. Here it is useful when adding comments to a moving or changing feature in the data set. In this case the annotation's spatial reference should follow the feature in question. On the other hand, the content of the annotation might change in order to comment on specific events or progressions in the scene. This second form of time awareness can be modeled by using different annotations with consecutive validity frames, resulting in a form of key frame animations.

Figure 6 gives an example taken from the visualization of a transient data set showing the interaction of two vortices. During the interaction the vortices desintegrate and the overall shape as well as the topology change drastically. For the time levels $t \in [100, 120]$ an annotation has been included, which comments on the interaction of the two vortices. As can be seen from the images given for t=90 and t=130 there is no point in annotating the interaction here, so an explicit validity frame needs to be defined. Moreover, this scene shows a good example for the usefulness of time varying annotations, since the process of interaction can now be completely described with notes in order to augment the visualization. The pictures for t=100 and t=120 show an adapting region of interest, which surrounds the region of interaction.

### 3.5. Content Types

The term annotation covers context and content. With respect to the expressiveness of the data, we employ an open model that enables different content types, as the CCM does not specify the structure, way of storage and view of content. IDEA currently features different content types that can be generated by the user and are stored in a relational database.

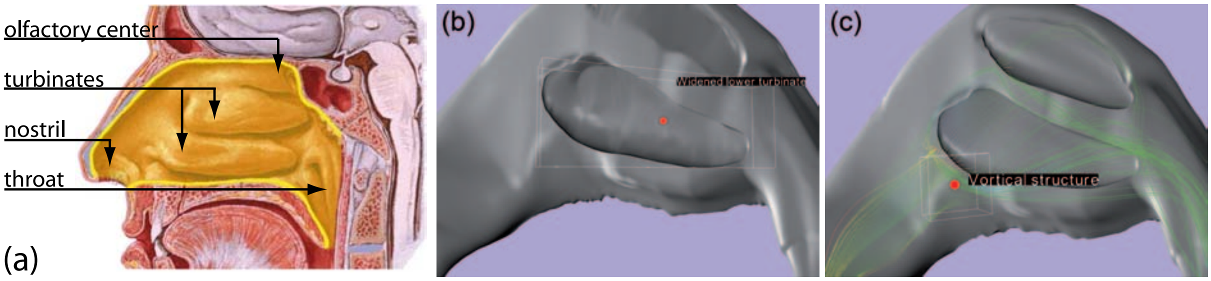


**Figure 7:** *Anatomy of the human nasal cavity (a). Annotated enlarged lower turbinate (b). Annotated streamlines highlighting a vortical structure at the lower turbinate (c).*

- *Voice*. The user can record a message without the use of a keyboard. However, we employ a speech to text system to convert the spoken words to a text string representation. This is more compact and can easily be scanned and edited by the user.
- *Text*. Text can be directly entered using a real or virtual keyboard. The latter employs a point-and-shoot metaphor that can be cumbersome for entering long passages of text.
- *3D sketch*. Using a freehand drawing metaphor, interesting regions can be directly marked in the three dimensional space.
- *Icons*. A pin-point metaphor allows to mark logical objects with distinct icons that represent user definable categories.
- *Virtual Buoy*. A specific variant of an icon, that stores a view on a region of interest in terms of a camera-in-hand metaphor.

Due to the abstract definition of the CCM, we consider these content types only a first basis and new types can be defined, stored and retrieved without a change of the model.

A desirable feature for any data analysis application is the ability to create screenshots of a noticeable view onto the scene. That is particularly true for VR data exploration applications. In order to bridge the gap between VR based exploration and desktop evaluation, we allow the user to make screenshots of his field of view in every state of the application run. These screenshots are not necessarily tied to an annotation, as they do not have to be bound to a logical object. The viewer's position and orientation during the screenshot in the virtual scene is recorded as well. This can be used to recover views on the scene for later presentations. However, a special state of the application is the annotation recording mode. Any screenshot that is taken in this special mode is stored in the context of the annotation.

## 4. Application

The methods described so far follow from the requirements of a concrete application scenario. We are currently engaged in an interdisciplinary research project whose goal is to understand the complex airflow inside the human nasal cavity, see figure 7(a). This is crucial for the fulfillment of the nose's main functions, i.e. the warming and moistening of inhaled air and the human sense of smell.

During the project a variety of simulation runs are performed. The resulting raw data has to be evaluated by engineers and physicians. The goal is to derive a set of objective measures for the assessment of a given nasal cavity. Both user groups are accustomed to take notes during diagnosis or data analysis respectively. While the medical staff mostly use this device to pinpoint anatomical abnormities, see figure 7 (b), engineers often write down a description of certain characteristic flow features, see figure 7 (c). In both cases annotations are used to highlight several points of interest in order to reconstruct them later. Moreover, annotations form a basis for hypotheses, which eventually should translate into models describing the inner workings of the nose.

In addition the general advantages, in this concrete setting note-taking facilitates the interdisciplinary information exchange and collaboration, because the knowledge of experts from different fields is fused into one single data base. In effect, an engineer can have a look at medical annotations so as to associate the presence of some anatomical feature with a flow feature he just discovered. It is this kind of interdisciplinary connotation, which to our mind is needed to generate usable insights.

Because of the participation of researchers from two different fields the set of possible data content types is quite heterogeneous. Although most of these types could be mapped to free text input, a purely application specific approach would be rather limited. So a more basic design was created resulting in the IDEA process and the CCM as described in this paper. This allows for the inclusion of advanced content types on a common basis. In the near future we strive to implement a scores method which should allow for the assessment of a given patient's nasal cavity. This method could directly be included as an additional content type, so that the user can directly enter his evaluation into the system. Another possibility is the inclusion of 2D-sketches, which are often used by engineers to express first ideas or assumptions.

## 5. Conclusion and Future Work

We have proposed a foundation for an annotation system that is to strengthen the use of VR technologies for the scientific data analysis process. Its core abstraction is the definition of a world model and the loose coupling of annotations in the CCM to objects of the virtual world. Our model is applicable to time varying data sets, which is an important requirement especially for the analysis in scientific visualization applications. We emphasize that the ability to create, transform and access annotations of artificial data sets at every process stage is a key component to the gaining of insight, but that data collection can not be realized in a fully digitized process. Our model is implemented in the system IDEA that features a number of standard content types, e.g., voice annotation and markers. This system is applied in a prototypical development to the exploration of air flows in the human nasal cavity.

Our current work focuses on interaction for content generation, especially gadget free symbolic one and two handed interaction metaphors and the development of new content types. However, much needs to be done in the field of carefully presenting the annotation information to the user, i.e. integrating it into the visualization. Here, common problems such as occlusion, dynamic layout and readability aspects arise frequently and have to be solved in a generic way. This is also true for interactive selection techniques for filtering a great number of annotations, such as parametrized queries. For this aspect we will examine magic lens techniques or geometric queries. Last but not least, desktop support has to be enhanced by providing a WIMP based off-line browsing tool for the annotation content, or the integration into existing approaches, e.g., web-based solutions.

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## References

[Bow03] BOWMAN, DOUG A. AND NORTH, CHRIS AND CHEN, JIAN AND POLYS, NICHOLAS F. AND PYLA, PARDHA S. AND YILMAZ, UMUR: Information-Rich Virtual Environments: Theory, Tools, and Research Agenda. In *Proceedings of the ACM symposium on Virtual Reality Software and Technology (VRST)* (2003), ACM Press, pp. 81–90.

[Har96] HARMON, REID AND PATTERSON, WALTER AND RIBARSKY, WILLIAM AND BOLTER, JAY: The Virtual Annotation System. In *Proceedings of the IEEE Virtual Reality Annual International Symposium* (1996), pp. 239–245.

[Jan02] JANKUN-KELLY, T.J. AND MA, KWAN-LIU AND GERTZ, MICHAEL: A Model for the Visualization Exploration Process. In *Proceedings of the IEEE Visualization* (October 2002), Moorehead, Robert and Gross, Markus and Joy, Kenneth E., (Ed.), IEEE Computer Society.

[Jun02] JUNG, THOMAS AND GROSS, MARK D. AND DO, ELLEN YI-LUEN: Annotating and Sketching on 3D Web Models. In *Proceedings of the 7th International Conference on Intelligent User Interfaces* (2002), pp. 95–102.

[Lou94] LOUGHLIN, M. M. AND HUGHES, J. F.: An Annotation System for 3D Fluid Flow Visualization. In *Proceedings of the IEEE Visualization* (1994), IEEE Computer Society.

[Raj04] RAJA, DHEVA AND BOWMAN, DOUG A. AND LUCAS, JOHN AND NORTH, CHRIS: Exploring the Benefits of Immersion in Abstract Information Visualization. In *Proceedings of the 8th International Immersive Projection Technology Workshop (IPT)* (May 2004).

[Rei03] REITMAYR, GERHARD AND SCHMALSTIEG, DIETER: *Data Management Strategies for Mobile Augmented Reality*. Tech. rep., Interactive Media Systems Group, Vienna University of Technology, 2003.

[Sch00] SCHUMANN, H. AND MÜLLER, W.: *Visualisierung - Grundlagen und allgemeine Methoden*. Springer Verlag, 2000.

[Son04] SONNET, HENRY AND CARPENDALE, SHEELAGH AND STROTHOTTE, THOMAS: Integrating Expanding Annotations with a 3D Explosion Probe. In *Proceedings of the Working Conference on Advanced Visual Interfaces* (2004), ACM Press, pp. 63–70.

[Spr92] SPRINGMEYER, REBECCA R. AND BLATTENER, MEERA M. AND MAX, NELSON L.: A Characterization of the Scientific Data Analysis Process. In *Proceedings of the IEEE Visualization* (1992).

[Tre04] TREVISAN, DANIELA G. AND GEMO, MONICA AND VANDERDONCKT, JEAN AND MACQ, BENOÎT: Focus-based design of mixed reality systems. In *Proceedings of the 3rd Annual Conference on Task Models and Diagrams* (2004).

[Tsa02] TSANG, MICHAEL AND FITZMAURICE, GEORGE W. AND KURTENBACH, GORDON AND KHAN, AZAM AND BUXTON, BILL: Boom Chameleon: Simultaneous capture of 3D viewpoint, voice and gesture annotations on a spatially-aware display. In *Proceedings of the 15th Annual ACM Symposium on User Interface Software and Technology (UIST)* (2002), pp. 111–120.

[van00] VAN DAM, ANDRIES AND FORSBERG, ANDREW

S. and Laidlaw, David H. and LaViola, Joseph J. and Simpson, Rosemary M.: Immersive VR for Scientific Visualization: A Progress Report. *IEEE Computer Graphics and Applications 20*, 6 (2000), 26–52.

[Ver93] Verlinden, J. and Bolter, J. and van der Mast, C.: Voice Annotation: Adding Verbal Information to Virtual Environments. In *Proceedings of the European Simulation Symposium* (1993), pp. 60–69.