HANNAH: A Vivid and Flexible 3D Information Visualization Framework

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Abstract

In this paper we describe an adaptable multi-purpose 3D user interface for complex heterogeneous information. The framework allows to create visualization instruments by hierarchically combining small visualization widgets. We integrate well known 3D visualization tools in our system and also present new metaphors like the RotaryDiagram. Due to the modular architecture and the underlying ontology we are able to build intuitive visualizations that allow direct manipulation, that directly and vividly respond to user actions and adopt to changing needs. The visualizations provide the user with multiple perspectives on the data and semantic relations between items of various perspectives.
The effectiveness of our proposed concepts for 3D information visualization systems is being proven by applying them to an user interface for monitoring, controlling, and optimization of a complex wastewater treatment plant.

Keywords— **HCI, Semantic Information Visualization, 3D Interfaces, Information Visualization Framework**

1 Introduction

1.1 HANNAH

The presented 3D interface is called HANNAH, which stands for "Here And Now, Near At Hand". The name accounts for the claim for creating an HCI-framework which is context sensitive, adaptable, ergonomic, intuitive, vivid, allows direct manipulation and provides direct animated feedback.

1.2 Application area: Process Visualization

The KOMPLETT-project ("komplett" is German for "complete") is engaged with the development of a small unmanned Waste Water Treatment Plant (WWTP) with two distinct water circles and resource recycling ambitions. The final goal of the information visualization system for this complex plant is the intuitive representation of large amounts of heterogeneous data (e.g. process data, optimization suggestions, expert knowledge, maintenance instructions) depending on the user profile. The visualization should provide detailed and revealing information for the remote expert as well as intuitive access to relevant instructions for the non-expert on site. In this context multiple semantic perspectives are essential. The development of the WWTP as well as the visualization are still in progress.

1.3 Motivation

In the first years of Information Visualization research, the focus mainly was on isolated and specialized visualization metaphors for specific data sets. Now, there is more and more interest in the visualization of more complex, heterogeneous and semantically interconnected data. Moreover, single visualization metaphors are being combined to Information Visualization systems or frameworks that link multiple perspectives on the data. E.g. Seo et al.[11] and Jern et al.[7] developed systems with linked 2D visualizations like scatter plots, color coded maps, hierarchical clusterings, and parallel coordinates. This development is also driven by the fact that the amount and complexity of the data we have to manage and analyze today increases steadily. This is true for researchers, journalists, artists, politicians, and many others.

In our specific application area, the visualization of industrial processes, the plant operator has access not only to some timeworn filers and few measured parameters but to numerous on-line and off-line parameters that characterize the current state of the plant in detail. Some WWTPs are already provided with Decision Support Systems (DSS), which suggest problem solving and process optimization strategies to the operator. Moreover, expert databases and specific support pages of plant manufactures are accessible through the World Wide Web. Thus, the operator is overwhelmed with predominantly unstructured data. He is overstrained with the task of finding relevant information, spotting important trends, and detecting optimization potential. In the worst case the operator is even overloaded with irrelevant information and consequently no longer able to respond adequately to exceptional circumstances on the plant.

Considering the fact that in our case the plant is unmanned and thus even non-experts have to cope with the system, it has to meet diverse requirements: It has to visually and intuitively indicate trends and irregular behavior of quantitative data. Depending on the context, it has to show semantic relations between currently relevant qualitative data like the technical process or the physical layout of the plant and textual data like plant documentation.

In order to identify the drawbacks of current industrial process visualization systems (see section 1.4.1) and the requirements for a new system, we questioned a worker, who daily interacts with such a system about his practical experience and his wishes. He was able to quickly navigate through the different views of the plant and understand the meaning of symbols and colors that are quite unintuitive to non-experts. Even experts need some time to understand the arrangement of information and the interaction possibilities. As the system does not allow to view multiple perspectives on the plant, our interviewee used multiple monitors. What he lacked most was a possibility to adapt the system to changing needs – the static system can only be configured by system-experts. As a wish for a new system he mentioned animations of process parameters changing over a time period.

1.4 State of the Art

1.4.1 Process Visualization

Most process visualization systems, that are in use in industrial plants only provide a fixed number of static process views which contain some animated elements like color changing symbols and value displays to indicate the state of the plant.

E.g. SIEMENS[12] develops SIMATIC WinCC, an HCI for the visualization and control of industrial processes. They create hierarchical 2D maps of the processes as well as partly animated 3D models with attached information labels. These visualizations often use unergonomic color combinations, poor graphics, and unintuitive overcrowded interfaces. To some extent this might be due to the fact that they want to provide the domain experts with interfaces similar to conventional drawings, that were developed before the information age, instead of making use of innovative information visualization techniques. The most apparent drawback of these conventional process visualization approaches is, however, that the static process views can not be adapted to changing needs.

When considering the requirement of multiperspective visualization, not only the process visualization but also the visualization of the physical layout of the plant have to be addressed. Agrawala et al.[1] described an approach for visually explaining the construction of 3D objects with the help of explosion views.

1.4.2 Information Visualization

Brown et al. [3] visualized network performance with various animated 3D metaphors like 3D surfaces and 3D bar charts. Moreover, they emphasized the importance of animations in visualizations with large data volumes: *If a picture is worth a thousand words, then an animated visualization is worth a thousand static graphs.*

Although there is still a controversial debate on the usefulness of 3D Information Visualization, some results like that of Ware et al.[14] are often quoted and commonly accepted. Ware studied graph perception, which is quite important as graphs are generally useful for many visualizations. They found that the ability to decide if two nodes are connected is improved by the factor 1.6 when adding stereo cues, by the factor 2.2 when using motion parallax depth cue, and by the factor 3 when using stereo as well as motion parallax depth cues. (The motion parallax depth cue is the depth information we gain when moving in front of a 3D scene or moving the scene itself.)

As mentioned in section 1.3 Seo et al.[11] and Jern et al.[7] developed 2D information visualization systems that provide various views on the data with diverse visualization techniques in separate windows. The separated visualizations are visually connected by direct feedback and brushing techniques. Pretorius et al. [9] presented a 2D visualization for large transition graphs that combines two visualization techniques in one window, namely hierarchical clustering as well as graph arcs between cluster elements.

In our previous work[4] we developed a 3D information visualization environment for documents, called DocuWorld. In this approach 3D representations of documents were automatically organized in 3D space depending on search results, similarities and context. Qualitative evaluation indicated that most users intuitivelly understood where to look for imported or similar documents.

Many of the 3D visualization and interaction concepts developed in the context of DocuWorld like the ThoughtWizard metaphor, the Shake Metaphor, Structure on Demand, TacticalZoom, animated feedback, or ThoughtFlashes are also leveraged in our recent project, the HANNAH-framework for KOMPLETT. Other concepts are and will be added or improved. The exciting question of future 3D information visualization interface research will be, which of these concepts have the capability to exploit the immersive and intuitive potential of 3D HCIs and finally become conventions.

2 The HANNAH-Framework

2.1 System Requirements and Architecture

In order to develop a system that instantly adapts to changing user-, task-, and device contexts and that allows the user to intuitively configure the interface depending on his or her needs by simply plugging together virtual 3D components, the system architecture has to be highly modular. The needed 3D support is made available by the use of the graphics library OpenGL. All visualization items are instances derived from the base class VisObject. This class provides basic positioning, material, labeling, and drawing functionality. The next class in the class hierarchy is AniVisObject, which supplies the functionality needed to create animated slow-in/slow-out transitions between various states. From this class simple DiagramObjects, objects in the the ExplosionView, control-elements, and nodes in the ontology visualization can be derived. More complex objects must be derived from the class CompoundVisObject, that is also a child class of AniVisObject. CompoundVisObject can be used to combine lower level VisObjects to more complex higher level VisObjects like control menus, Ontology visualizations, or ExplosionViews. This modular and hierarchical architecture allows to consecutively develop more complex visualization objects in multiple levels of abstraction, handle them consistently, and plug them together easily. It also allows to intuitively implement the previously mentioned (section 1.4.2) concepts: Individual VisObjects or CompoudVisObjects can be rotated or shaken (ShakeMetaphor) to offer motion parallax depth cues. They can be moved along animated paths, they can be moved in and out of view (Structure on Demand concept), and scaled depending on the current focus (TacticalZoom).

2.1.1 Databases and Ontology

The data resulting from measurements on the plant is stored in databases. The goal of the KOMPLETT-project is, however, not only to visualize process data and static process views, but to efficiently, intuitively, and visually organize more information about the process and to interconnect these heterogeneous information items (see section 1.3). For this purpose, we decided to collect the information as an ontology. The process ontology modeled in Protégé[10] contains process steps, the process sequence, reactors, measuring instruments, links to diverse information material, table names of measured data, many other information items, and the semantic links between all these items.

2.2 Processdata Visualization

Most conventional process data visualizations only consist of simple two-color line graphs for one parameter in a specific time interval. Considering the findings of Information Visualization research concerning perception, visual scales, and intuitive metaphors, our approach strives to provide the user with more efficient visual analysis tools.

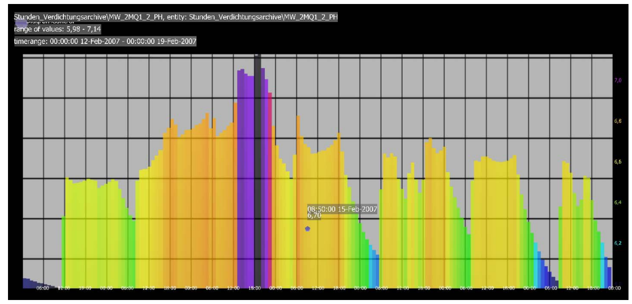

Figure 1: Processdata in a single diagram

Figure 1 adds the visual scale color to the concept of simple graphs. The value of the process parameter is mapped to y-position as well as to a continuous color gradient. The color gradient can be interrupted at one or more points (in this case between cyan and green and between orange and red) to represent that the value is below or above a certain limit. The small sphere on the diagram is moved following the mouse pointer and continuously displays the exact value under the sphere.

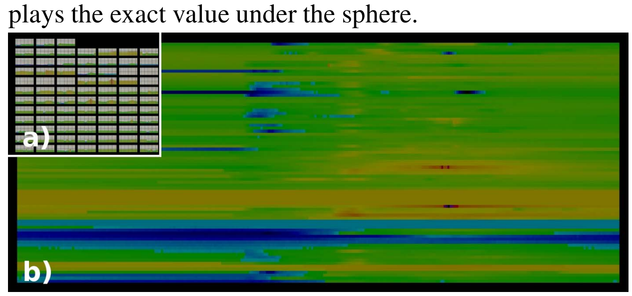

Figure 2: a) Space multiplexing b) ColorPlane

When more than one parameter has to be displayed or the time interval is enlarged, the user usually has the possibility to choose between time multiplexing (displaying one diagram after the other) or space multiplexing (all diagrams are scaled down and displayed simultaneously, see figure 2 a)). Thus, the user is in the dilemma of having to decide whether he or she wants to abandon the possibility to compare diagrams or to perceive details. The idea of representing large series of values with few color coded pixels, the pixel based techniques, has a long history in Information Visualization research. E.g. Ankerst et al.[2] proposed CircleSegments and Kincaid et al.[8] developed the Line Graph Explorer. In our system we use ColorPlanes to visualize the value of one parameter in multiple time intervals. The ColorPlane in figure 2 b) shows temperature measurements in our office. Each row represents on day. Comparing the rows easily reveals certain patterns: At about 9:00 a.m. the temperature falls due to the opening of the windows and at about 1:00 p.m. the temperature rises as the door is closed during lunchtime.

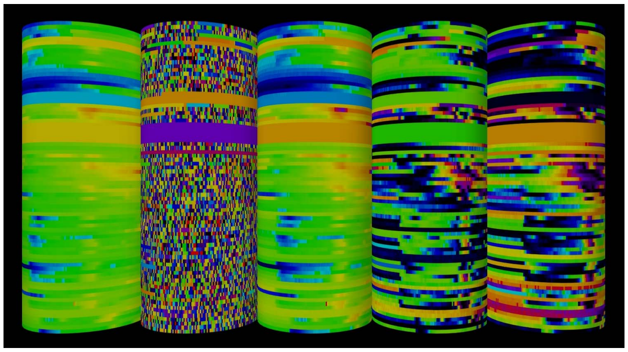

Figure 3: ColorRolls

Making use of the third dimension, multiple ColorPlanes with data from different process parameters can be visualized as ColorRolls. The rolls can be simultaneously rotated in order to move the time interval of interest to the front. Due to perspective projection a natural focus & context effect is created. Weber et al.[15] proposed a similar approach for visualizing time-series on spirals.

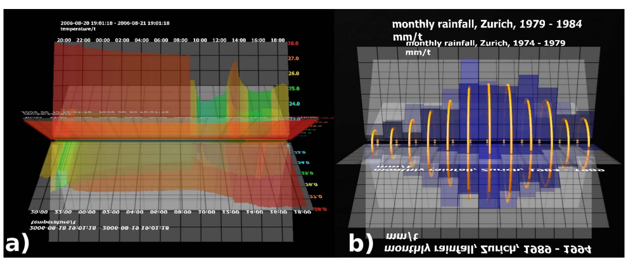

Figure 4: a) RotaryDiagram b) RotaryDiagram with AverageRings

Another new 3D process data visualization metaphor that serves as a good compromise in the time vs. space multiplexing dilemma is the RotaryDiagram shown in figure 4. Similar to the cards in a rotary file known form daily life, the diagrams can be rotated by the user forward and backward around the center. The rings in the center (figure 4 b)) are not only used to enforce the rotary file metaphor. They visually indicate the average value of each column from all diagrams. These average value rings help to spot irregularities in the rotated diagrams. Moreover, the semi-transparent style of the diagrams allows to directly compare consecutive diagrams.

2.3 Process Visualization

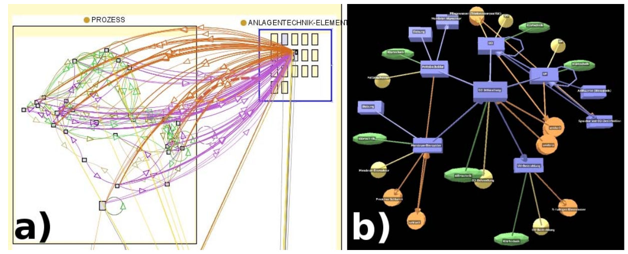

Figure 5: a) Process ontology in Protégé[10] b) ConeView of Process in HANNAH

As explained in section 2.1.1 the sequence of process steps needed for the operation of the plant, the reactors involved, the data measured, and other information are organized in an ontology. Thus, one way to visualize the functionality of the plant is to visualize parts of the ontology. Figure 5 a) shows a cluttered ontology visualization in Protégé.

In the ontology visualization of HANNAH the diverse semantic categories (e.g. process steps, reactors, process data) are displayed in diverse colors, shapes, and at diverse depth levels. The relations of the process steps that are currently in focus are emphasized by animated arrows.

Figure 5 b) shows the ConeView ontology visualization. It can be used when the user wants to focus on a particular aspect of the process. The selected focus element is displayed in the center and front. Process elements that are directly connected to the focus element are rendered in a first circle around the focus point. This circle is more distant to the user than the focus point. The second circle which is even more distant contain items that are connected to those of the first circle. When the user selects another item, it is moved to the focus position and its connected process elements are organized around it in an animated way.

2.4 Process Plant Visualization

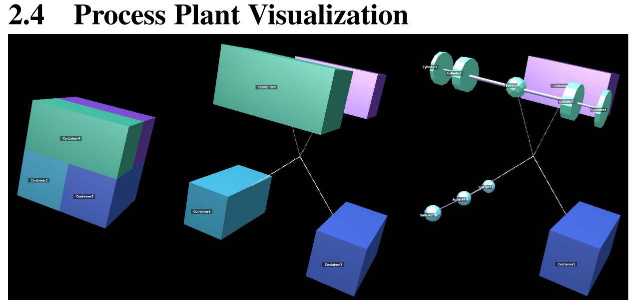

Figure 6: Three states in animated explosion view

Extending the 2D explosion-view metaphor to 3D we created a visualization tool for the physical layout of the plant, that allows to explore it hierarchically. Figure 6 shows three states in the exploration of the example geometry. The 3D ExplosionView tool is implemented by creating a containment hierarchy of elements, for each hierarchy level a graph representing the way in which the elements are connected to each other, and for each element the direction in which it is expected to explode. With this data the geometry can be exploded step by step or automatically to reveal one specific element (e.g. a reactor that has to be inspected).

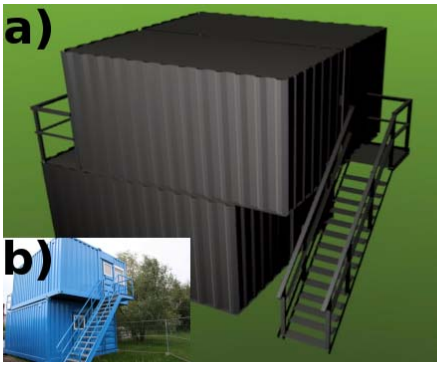

Figure 7: Modeling real plant geometry a) Model rendered with blender[5] b) picture of real plant

In order to transfer this concept the the real geometry of the plant, we started to model it with Blender[5] as indicated in figure 7.

2.5 Interconnected Perspectives

With the help of the process ontology described in section 2.1.1 we are able to visually relate information items from diverse categories or perspectives to each other. E.g. process data can be related to the reactor where it is measured or to the logical process step to which it belongs.

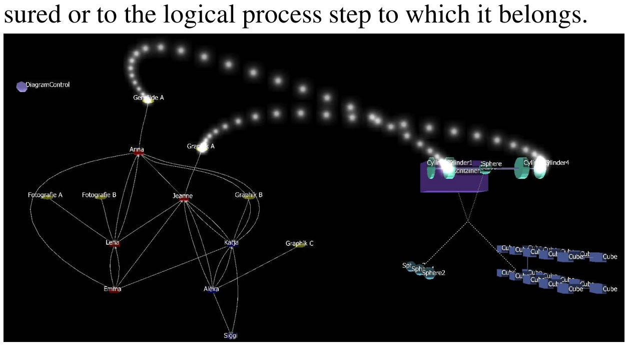

Figure 8: Semantically interconnected perspectives

When navigating through multiple perspectives it is important that the perspectives are linked in order to help the user track her current location in information space. Such a link can be a visual connection between two information items like the curves and arrows connecting process steps or an animated transition between two visualizations. These links should help the user to understand the semantic relation between the linked information elements. Figure 8 shows items two different perspectives, an example ontology visualization and the explosion view, connected by ThoughtFlashes. ThoughtFlahes, that were already used in our last project[4], emerge from the item under the mouse pointer and rise in the form of 3D arcs to related items in an animated way.

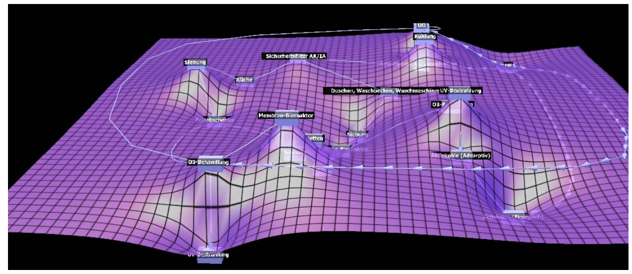

Figure 9: Processdata in landscape-metaphor

One possibility to directly and intuitively connect process data to the process steps in which they are measured is the use of the landscape metaphor as shown in figure 9. The succession of the process steps is visualized as a planar graph (calculated with the Graphviz library[6]). The hight of the nodes is modified depending on the scalar value of the process parameter. On top of this height field, a landscape is calculated with Shepard's Scattered Data Interpolation method. As weight function we used the euclidean distance. This method is often criticized for the fact that distant points take to much influence on the shape of the surface, interpolating local points. In our application, however, this is a volitional effect, as the mean value and the deviation from that value in each process step is easily perceptible. The progression of process parameters over time can be visualized with this metaphor as an animated deformation of the landscape. To give the user an additional hint at the actual value in a process step, we plane to use color as supplementary visual scale.

2.6 Interaction

Due to the fact that "getting lost in space" is a potential problem of 3D applications and that the mental load needed for navigating the viewpoint through the scene could be used for more important tasks we proposed the Thought Wizard navigation metaphor[4]: The user relaxes at a fixed point in 3D spaces and uses simple gestures to move the needed information around him or her.

Our system supports navigation techniques like changing the visualization mode or perspective, scaling, rotating or shaking the objects in the scene, or moving another process element to the focus position in ConeView.

The interaction with the HANNAH framework is to some extend comparable to that of Blender[5], the 3D Content Creation Suite. The scene is directly manipulated (e.g. rotating or resizing objects or object groups) by mouse pointer gestures. There are several keyboard shortcuts that can be used to invoke certain actions or to change visualization modes. As an alternative, there are context menus displayed on demand directly in the scene. Thus, users can choose the interaction method that suits their needs.

As a matter of fact, direct user feedback is guaranteed in our dynamic 3D interface. Moreover, every transition is animated with a slow-in/slow-out movement as proposed by Thomas[13] to reinforce the massive character of the visualization objects and to induce immersion.

3 Conclusions

We presented in this paper a 3D Information Visualization interface called HANNAH. The concepts of HANNAH are a modular architecture, flexibility, adaptability to changing needs, and intuitive access. The proposed toolbox of concepts, visualization metaphors, and techniques that can be used to develop interfaces to information rich environments with large amounts of heterogeneous but semantically related data. Although our focus is on industrial processes, most of the proposed ideas can easily be transferred to other information environments like for example personal information collections or software architecture. Due to the fact that our project is still at an early state of development, an extensive evaluation of our implementation is hardly possible. When comparing our approach to those presented in the section on Process Visualization state of the art 1.4.1 some conclusions can, however, be drawn: Our system is less static than conventional process visualization systems. The animated 3D approach offers, besides more enjoyment and immersion in daily work, new possibilities like the animated 3D ExplosionView and the RotaryDiagram that are not available in todays information interfaces. First feedback from people working with conventional systems reveal that they quickly recognize the potential of our visualization and are eager to evaluate it. Future work will be concerned with the development of more visualization and interaction metaphors, the integration of actual online-data from the plant, and first user evaluations.

4 Acknowledgements

This research is part of the interdisciplinary project KOMPLETT, which is supported by the German Federal Ministry of Education and Research (BMBF).

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