MULTIPLE DYNAMIC PERSPECTIVES TO INDUSTRIAL PROCESSES

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ABSTRACT
The efficient operation of complex industrial processes requires the organization of large amounts of heterogeneous data. We explain that both, these data characteristics as well as the need for context sensitive information interfaces, require the design of visualizations with multiple dynamic perspectives on the data. The benefits of animated 3D information visualization are stated and an efficient motion parallax technique is proposed. Additionally, a navigation concept for information rich semantic 3D environments that frees the user from part of the mental load is described. We present new metaphors for visualizing the data in those perspectives like Cone-View, animated 3D Explosion View, and Rotary Diagram. Moreover, a labeling technique for dynamic 3D environments is explained.

Although still at an early state of development, our implementation of this toolbox of concepts, metaphors, and techniques promises to indicate an new generation of industrial process visualization systems.

KEY WORDS
Visual Information Systems, Environmental Sciences, Process Visualization, Multiple Perspectives, Information Visualization Metaphors, Labeling

1 Motivation

Due to advances in process engineering, process data acquisition, and more rigorous water protection legislation, the management of Waste Water Treatment Plants (WWTP) becomes more complex. Nowadays, 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. Few WWTPs are already provided with Decision Support Systems (DSS), which leverage artificial intelligence methods to suggest problem solving and process optimization strategies to the operator. Moreover, distributed online general 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 in the plant.

This is a typical application situation where intelligent information systems as well as state of the art information visualization user interfaces are needed to cope with the requirements of the information age. The intelligent information system has to collect the raw data from distributed and heterogeneous sources and accumulate it with semantics. This step transforms unstructured data into processable information. The second step that is needed to transform information into user insight, knowledge, and cognition can be enormously facilitated by information visualization techniques.

In our paper we discuss how information visualization techniques can be leveraged to make complex semantic information environments intuitively operatable for domain-experts as well as newcomers. We present an information visualization system with multiple dynamic perspectives which is applied to WWTPs but is flexible enough to be easily adapted to other application areas like software visualization, document spaces, or ontologies.

The remainder of this paper is structured as follows: First we analyse the requirements of current process visualization systems in section 2. After that, the state of the art in Process Visualization (section 3) as well as Information Visualization (section 4) is described. Section 5 elaborates on various aspects, concepts, and metaphors of information environment design and section 6 draws some final conclusions.

2 New Process Visualization Requirements

When larger amounts of heterogeneous data are assembled and required to manage more complex industrial plants new methods are needed to organise data. In our case we have to organise online- and offline data from a small WWTP, external expert knowledge, optimization suggestions from the DSS, descriptions and maintenance instructions of the plant, and other data. In order to enable someone to make use of this data collection the system has to meet diverse requirements: It has to visually indicate trends and irregular behavior of quantitative data or show semantic relations between qualitative data like the technical process or the physical layout of the plant and textual data like plant documentation. Thus, new information visualization tech-

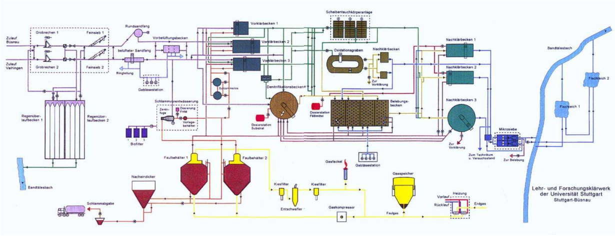

Figure 1. Conventional process visualization

niques have to be used to transform such heterogeneous, but strongly connected information items into knowledge. As the described characteristics of the data (heterogeneous related items) resemble those of ontologies, ontology-like representations have to be considered.

Due to the fact that information systems like that of a WWTP often have to be accessed by diverse users like experts, caretakers, or newcomers, they moreover have to adapt to different user needs. The expert has to be provided with detailed technical information and extensive interaction possibilities while the caretaker needs less confusing representations, intuitive information navigation facilities, and restricted interaction possibilities for security reasons. These users have to fulfill different tasks as plant observation, plant maintenance, or plant optimization. It is required from the system that it adopts to the different tasks. As it should be possible for experts to log into the WWTP information system from the distance and to walk around the WWTP with mobile devices, the system additionally has to adapt to various client devices. To sum up, the system is required to be user-, task- and device-context sensitive.

To meet these requirements, it can thus be concluded, that state of the art industrial process visualization systems have to provide multiple as well as dynamic perspectives. This means that the system should be directly responsive to user interaction. Moreover, it must be able to dynamically show the information at different scales and diverse semantic perspectives and the transitions between these views should be smoothly animated to reveal the relations between them.

3 State of the Art in Process Visualization

Most current industrial process visualization systems only provide a fixed number of static process views which contain some small animated elements like color changing symbols and value displays to indicate the state of the plant. Figure 1 [1] shows a typical example of these conventional systems.

SIEMENS[1] 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.

Considering the requirement of non-static process visualization, semantic formalisms for modelling processes have to be used. A complex approach to this problem has been proposed by Estublier et al.[2]. They provide diverse semantic views on the data (control flow, data flow, and state diagrams). The process is modelled with the help of a graphical editor.

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

4 State of the Art in Information Visualization

Storey et al.[4] developed Jambalaya, a 2D ontology viewer originally used for software visualization that is based on SHriMP (Simple Hierarchical Multi-Perspective). They use animated nested (hierarchical) treemaps that provide details on demand and multiple semantic perspectives. Relations are displayed as straight colored lines between individual elements. With complex data sets single relations can only be distinguished if they are highlighted.

Fluit et al.[5] created AutoFocus and Spectacle, semantic desktop- and web search engines with 2D clustermaps visualizations. With the help of the spring embedder algorithm they create clearly arranged beautiful maps. Nevertheless, this non-hierarchical approach is limited to a small number of semantic concepts.

Card's[6] Web Forager is one of the first 3D information visualization systems. It makes use of spatial memory as well as hierarchical visualization via perspective projection. The user is not in danger of getting lost in space since it is not required to move around. However, there are no possibilities to visualize semantic relations between documents.

Kleiberg et al.[7] present a 3D graph visualization that results in "intriguing and stimulating" botanical constructs. It is an example of the visualization possibilities 3D approaches offer. Nevertheless, the authors did not intend to develop a complete information system with multiple semantic perspectives and suitable navigation.

Bosca's[8] OntoSphere is a graph based hierarchical ontology visualization tool that makes good use of different visual scales like color, size, shape, and distance. There are three hierarchical levels but no additional semantic per-

[1] image resource: http://www.iswa.uni-stuttgart.de/lfkw/

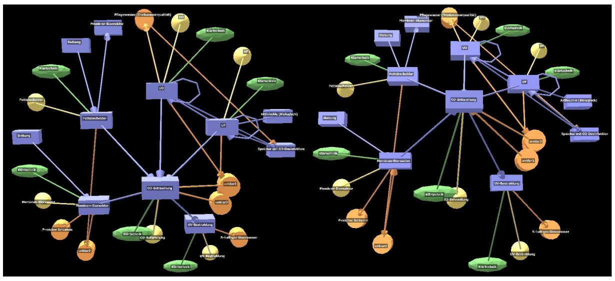

Figure 2. Two States of Shaking Cone-View

spectives. The abstract graph visualization with colored spheres and arrows is probably unmotivating for users not engaged in ontology engineering. Another problem of this system is labeling.

5 New Process Visualization Concepts

Our research is involved in the KOMPLETT-project which is engaged in the development of a small unmanned WWTP with two distinct water circles and resource recycling considerations. ("Komplett" is German for "complete" and hints at the holistic, sustainable, and interdisciplinary approach of the project.) The final goal of the information visualization system for this complex plant is the intuitive representation of large amounts of heterogeneous semantic data. As this project is still at an early stage, no complete information environment can be presented, yet. Nevertheless, we identified the requirements as described in section 2 and developed concepts, techniques and exemplary visualization metaphors, which we present here.

5.1 3D Information Visualization

Although there is still a controversial debate on the usefulness of 3D Information Visualization, some results like that of Ware et al.[9] 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 clues, by the factor 2.2 when using motion parallax depth clue, and by the factor 3 when using stereo as well as motion parallax depth clues. (The motion parallax depth clue is the depth information we gain when moving in front of a 3D scene or moving the scene itself.)

In order to design successful 3D visualizations various depth clues should be provided. Occlusion and perspective projection are strong depth clues. The motion parallax depth clue, which is of outstanding importance according to Ware, can be provided by allowing the user to move the scene or the viewpoint. This might however result in "getting lost in space" which is frequently criticised problem of 3D applications. Our information system solves

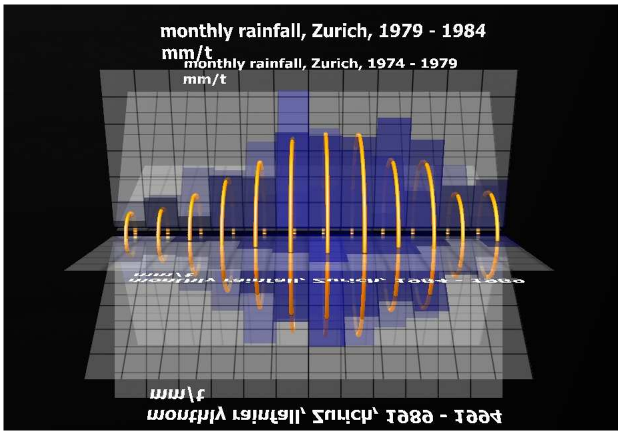

Figure 3. Rotary Diagram

this dilemma by providing the *Shake Metaphor* shown in figure 2: With a simple gesture the user can cause the main visualization area to shake two times around the central horizontal or vertical axis. This frees her or him from the mental load of navigating in space and produces an efficient movement.

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[10] to reinforce the massive character of the visualization objects and to induce immersion. To facilitate to realization of this approach, every visualization object has an animation path and a state variable as attributes. It also has methods to create a slow-in/slow-out animation path from its current position and scale factor to the required destination position and scale factor. When the path is created, the object state is set to "movement". The position of objects in movement are updated after each drawing cycle until they reach their destination.

Of course, there will always be some special visualization with a low degree of 3D-ness that displays certain aspects of the data more efficient than 3D visualizations. In process visualization process parameters are often displayed in 2D diagrams which are a clear and intuitive method of displaying such data. Nevertheless, we developed the *Rotary Diagram* metaphor shown in figure 3 [2] that provides an efficient 3D method for comparing a series of these inherently 2D diagrams. 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 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 semitransparent style of the diagrams allows to directly compare consecutive diagrams.

Figure 4 shows the application of the popular 3D landscape metaphor for our purposes. In the x-z-plane there

[2] data resource: http://www.meteoschweiz.ch

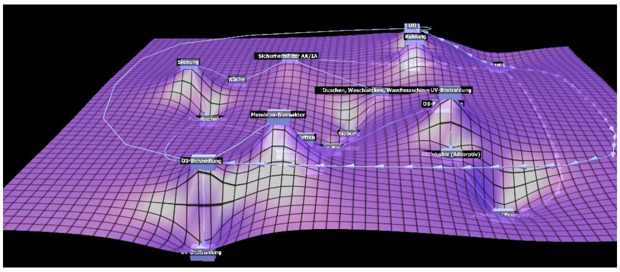

Figure 4. Visualizing one process parameter in Landscape

is a representation of the process similar to that in figure 5. The height of the landscape indicates the value of a scalar process parameter. Thus, this parameter can be instantly and parallelly perceived for every step in the process.

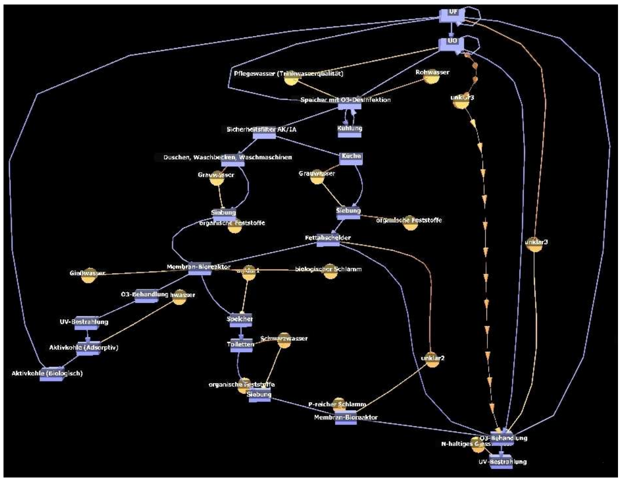

Figure 5. Process visualization

5.2 Multiple Perspectives

Providing multiple perspectives on the data is generally advisable for modern Information Visualization systems. As elaborated in the requirements section 2, this is especially the case when there is a need for a user-, task-, and device-context sensitive system. Considering the visualization of processes, it is thus required that a formal representation of the underlying semantic graph structure together with methods for visualizing this structure is provided. In our approach the OpenSource *Graphviz*-library is used for modelling the graph structure and computing basic layouts. Figure 5 shows a process visualization generated with the help of the *Graphviz*-API. The diverse semantic categories (e.g. process steps, products, reactors, conditions) of the process are displayed in diverse colors, shapes, and at diverse depth levels. (At an early state of information visualization system development there are still many unused visual scales.) The connections of the process steps that are currently in focus are emphasized by animated arrows. When the user decides to enable or disable other semantic categories for gaining insights with other perspectives, the graph layout is recalculated by *Graphviz*.

Figure 6 shows a close-up view of such a process visualization. This kind of process visualization is suited for gaining overview of the whole process under various semantic aspects. Depending on the size of the process, the use of this visualization might only be advisable for large displays.

When only small (e.g. hand held) displays are available or when the user wants to focus on a particular aspect of the process, another visualization metaphor, the *Cone-View* (see figure 2) should be used instead. This visualization is constructed from the same underlying data structure but leveraging a different layout method: The user-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.

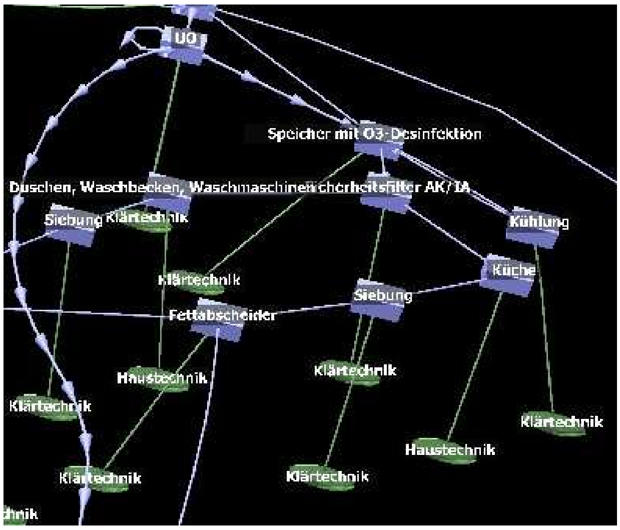

Figure 6. A close-up view of process visualization

Figure 6 also indicates our 3D labeling approach: As proposed by Irani et al.[11] we use semitransparent labels placed directly in front of the object. However, unlike Irani's diagrams consisting of 3D geons our visualization entities can move around and rotate. Thus, we had to develop a labeling technique that maintains the orientation of the label and its position in front of the object while the labeled object moves and rotates. This was done by manipulating the modelview matrix and leveraging the gluUnProject-function in OpenGL.

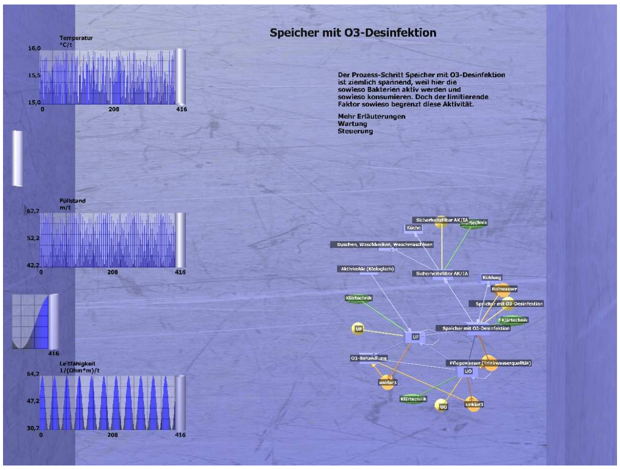

Figure 7. Close-up View of one Process-Step

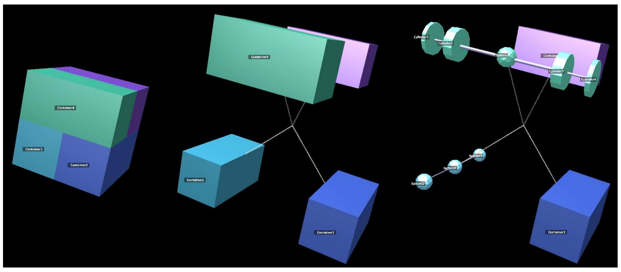

Figure 8. Three States in Animated Explosion View

5.3 Semantic Perspectives

While section 5.2 focused on the need for multiple perspectives from the view of a context sensitive information system, this section focuses on the characteristics of the data and the need for multiple semantic perspectives for adequately displaying large amounts of heterogeneous semantically related data.

Semantic Zoom functionality should be provided for information rich environments. It enables the user to get on demand more detailed information on some part of the data he is currently interested in. Figure 7 shows a high semantic zoom level of one process step. When the user clicks on one process step in the process visualization (figure 5) and calls for a higher semantic level, this process step representation enlarges until it has the size and form of the walls shown in figure 7. In this area more detailed information on the process step can be perceived: Some numerical data is visualized on drawers that can be pulled from the wall, textual information is provided and a small navigation tool allows to move from the close view of this process step directly to the close-up view of an adjacent process step.

Besides the necessity of getting more semantic information or toggeling the display of semantic concepts large heterogeneous information systems like that of a WWTP require completely diverse semantic perspectives. Our system provides up to now two semantic perspectives: The previously described process perspective and the physical layout perspective shown in figures 8 and 9. Although the layout indicated in these figures is not that of the WWTP, they demonstrate our concept of visualizing hierarchical physical constructions by animated 3D explosion views. In contrast to commonly known static 2D explosion views, the user has the possibility to view the object from various directions by rotating it and to explode (or implode) parts of it to a higher (or lower) level of detail when needed.

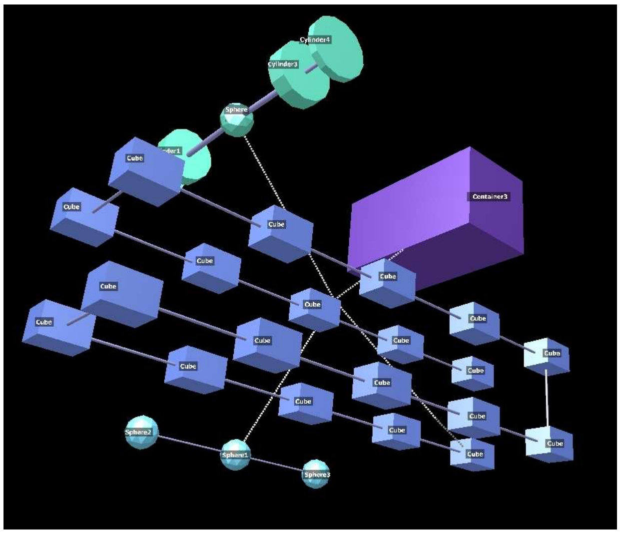

Figure 9. 3D Explosion View

5.4 Navigation in Information Environments

In the original sense *navigation* is the act of finding the position, determining and finally following the course of a ship, an aircraft or a car using maps and instruments. Today, the word navigation is also used in the context of the world wide web or other data bases. In this case the user tries to find his way through often heterogeneous documents using for example search facilities or links between documents. In the context of information systems navigation can also be defined as the pursuing of logical connections between data items. Navigation is a sort of interaction without the possibility of data manipulation. In the same way as it is essential for navigating a ship to know exactly where it is located, the user has to know the context of the currently focused information item or the location in the structure of the information space in order to efficiently decide what information item to choose next.

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 [12]: The user relaxes at a fixed point in 3D spaces and uses simple gestures to move the needed information around him. Until now, our system supports navigation techniques like changing the visualization mode or perspective, changing the zoom level, or moving another process element to the focus position in *Cone-View*. 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, an animated transition between two visualizations, or the enlarging of an item to form a three-wall room as described in the previous section. The links should help the user to understand the semantic relation between the linked information elements. In the case of such visually indicated links the lines between the user deciding where to navigate next and the system directing the user's attention and focus become blurred.

6 Conclusion

We presented in this paper a 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. We already mentioned that some of the concepts have been successfully implemented in our previous project which was concerned with the organization of documents[12].

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 (section 3) and the section on Information Visualization state of the art (section 4), some conclusions can, however, be drawn: Our system is less static than conventional process visualization systems. It can thus provide the user with context sensitive information and functionality as well as semantic relations between information items. The animated 3D approach offers, besides more enjoyment and immersion in daily work, additional possibilities like the animated 3D Explosion View and the Rotary Diagram that are not available in today's information interfaces.

Future work will be concerned with accessing real WWTP data, designing visualization metaphors especially useful for small mobile displays, and developing more semantic perspectives as well as visual links between them.

7 Acknowledgements

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