TimeTube: Introducing Haptics in a 3D Visualization Technique for Grasping Time-Related Data in a Human Computer Problem Solver

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Abstract

In an analytical laboratory, the scheduling of which assays are analyzed in which order and on which laboratory resources is a good example for a task that cannot be solved by a computer system alone. A computer system implementing scheduling algorithms, however, can be used to support the laboratory staff in order to find suitable schedules serving in a sense as an intelligence amplification tool for the human user. For this, the user interface is crucial and we employ a novel visualization technique we call TimeTube in order to enable the user to easily grasp the current state of the scheduling process and to facilitate decisions on how to optimize the schedule. In order to interact with the 3D visualization that we have conceived, a pen-shaped force-feedback device, the commercially available "Phantom Omni", is used. It serves not only as a means for 3D input but is also able to provide haptic guidance. And it makes constraints on the schedule intuitively perceivable, by realizing a "haptic visualization". We present a prototype system that implements the TimeTube technique and integrates it with a sophisticated scheduler. First test results show that completing tasks and navigating through time is intuitive for the users. As such, the system is a best practice example for a problem solver that takes advantage of the strengths of humans and computers.

Keywords: Haptic Visualization, 3D Visualization, Temporal Visualization, Human Computer Interface, Human Computer Problem Solver.

1 Introduction

The dynamic scheduling of analytical processes (e.g. in pharmacy or bio-chemistry) in a way that laboratory resources are used to capacity and workflow constraints for analyzing assays are met is a complex problem. For example, the duration of cleavage in general is hard to predict. Thus, an according analysis step may take between 30 minutes and 4 hours. A computer scheduler has to take the worst case into account and reserves a device needed for analysis for 4 hours although the task may be finished within half an hour. Prediction errors like this accumulate over time and make computer schedules useless - apart from the problem that the time for finding an optimal scheduling solution grows exponentially with the problem size. Laboratory staff, on the other hand, possess vast knowledge about bio-chemical processes (which cannot be modeled in a computer properly) and may predict that in an individual situation the duration for cleavage may take only 2 hours at most. Judging the schedule - the probability of violating the schedule and the consequences in that case - a person may take the decision that it is safe to reserve a device for an analysis step only for 2 instead of the usual 4 hours. The human is also able to take the responsibility for this decision. Moreover, a human can provide hints for finding a complex schedule, thus reducing the time needed for scheduling significantly [Sch04].

As a consequence, the scheduling problem cannot be solved by a computer. The computer can provide significant support, though. For this, exchange of information between human and computer is crucial. Using interactive visualizations is an established way to accomplish this. Common visualization techniques used to illustrate such scheduling problems are Gantt charts [Gan03, 1903]. Yet, these charts are not suited well for these tasks. With increasing complexity of analytical processes it becomes difficult for the viewer to understand and overlook the whole process. Time or conditional constraints between analysis steps increase the complexity. If scheduling results have to be manipulated manually it has proven to be difficult for the laboratory staff to modify these complex charts. Another visualization technique originally designed to view changing values that avoids some of the disadvantages of the Gantt charts is the Circle View [KSS04]. In a Circle View visualization, different segments provide information concerning time-related interdependencies between different values. These values are visualized in a linear way beginning in the center of the circle and ending at the circle's border. This becomes a disadvantage, however, if a visualization of a long period of time is needed as the size of the Circle View limits the viewable time.

In this paper, we present the TimeTube, a 3D visualization technique that combines the advantages of Circle Views and Gantt charts in order to support the laboratory staff in complex scheduling tasks. In the TimeTube, visual representations of analysis steps are no longer spread over many columns and rows but are visualized in a linear alignment instead, with the time being displayed as a distorted tube centered around an axis perpendicular to the screen. Focus and context techniques such as Rapid Zooming [MCR90] or Multiple Windows [CPM94] help the user to maintain the orientation in large sets of analytical data. The "Phantom Omni" [Sen] as a pen-shaped haptic 3D interface device (see fig. 1) makes sure that the navigation in the TimeTube is manageable by the user. Since common 2D input devices like a mouse are not suited well for interacting with the 3D TimeTube, we use the Phantom as a true 3D input device which also allows making use of haptic constraints by exerting forces on the pen.

The paper is organized as follows. We briefly discuss relevant visualization techniques as well as focus and context techniques in the next section. In section 3, we present the basic idea of our prototype application, describe the visualization and the functionality. Section 4 presents first results. Conclusions and future work are presented in section 5.

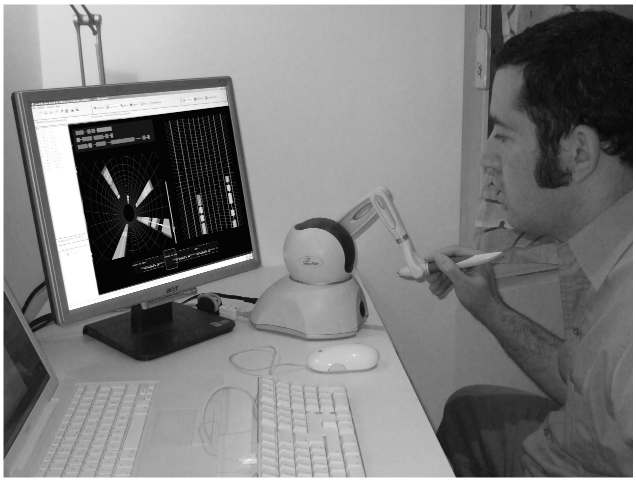

Figure 1: Using the TimeTube with a Phantom Omni [Sen]

2 Basic Considerations

Scheduling results are commonly visualized in Gantt charts. However, this visualization technique is not well suited for laboratory environments since it is not able to express the inherent complexity of such activities and does not foster proper user interaction. Depending on the number of activities a workflow (i.e. a sequence of analysis steps required to analyze an assay) consists of, it is very difficult to follow the several analysis steps distributed over different rows and columns. The user has to scroll down to reach the next activities and has to scroll to the right to see activities which are to be executed in the far future. If there are conditional branches, it is even more difficult to check whether workflow constraints are met.

An advantage of the Gantt charts is that they are able to visualize schedules of arbitrary length - at the cost of having the user scrolling and being able just to perceive a section of the workflow. Other visualization techniques such as the Circle View in figure 2 show the evolution of multiple attributes over time. Each attribute is represented by a different circle segment. In contrast to the Gantt chart, the Circle View visualizes the value of each attribute by colors [KSS04]. The arrangement of the colored pixels starts at the center and

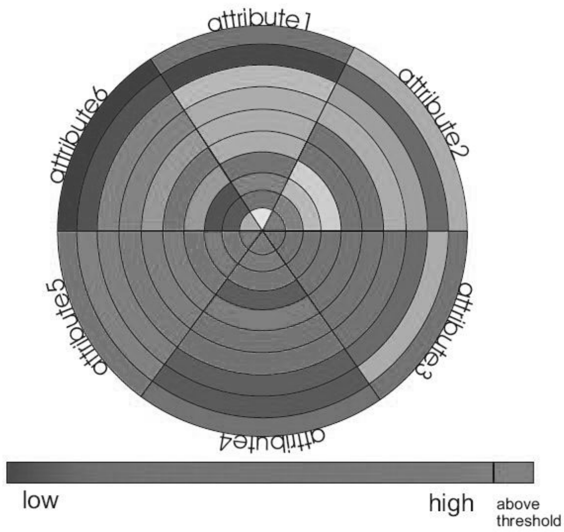

Figure 2: Example for a Circle View. Each segment represents a single attribute. [KSS04]

ends with the outer line of the circle. By slightly modifying this visualization technique it is possible to visualize workflows instead of values. One workflow is represented by one circle segment. By dividing the circle into more concentric circles it is possible to define each of the sub-segments as single analysis step of the workflow. Sub-segments near the center of the circle symbolize analysis steps in the near future; sub segments far-out symbolize analysis steps scheduled in the far future. An advantage of this visualization technique is the linearity of a workflow. It begins in the center of the circle and ends at the border of the circle. Conditional branches are represented by bisecting one sub-segment. Thus, it is easy to look at the whole context of the visualized workflows without loosing the focus on the current analysis step. A major drawback of this visualization technique is that only a limited number of concentric circles can be displayed.

3 The TimeTube

The main idea of the approach described in this paper is to map time on the z-axis, i.e. the axis perpendicular to the screen. All remaining information is mapped around this axis in a cylindrical fashion forming a tube. Each circle-shaped cross-section represents a point in time. Movement in time is mapped to movement along the central axis of the tube. By pushing the pen of the Phantom forward and backward the user can navigate in time. Because of the perspective projection used, a focus and context technique is realized - points in time close to the current time cursor position are visualized in a high level of detail. The further away information is located in time, the smaller it is depicted. Forces are used in order to allow a smooth acceleration and deceleration in time. When the user arrives at a desired point in time, the Phantom is located on the central axis. Thus, it is easy to reach anything on the wall of the tube since distances to this wall in all directions are the same. As the tube also restricts the workspace naturally, we manage to design a center-of-workspace metaphor which is preferable for the Phantom device [KWP02] as the pen can only be moved in a limited volume and it is hard to relocate the working volume.

The complete visualization is shown in figure 3. In the middle of the visualization two tubes are depicted. The left tube shows information of the future, the right one information of the past considered from an actual reference point in the analytical process. Each of the tubes are rendered as wire frame. The distances between the circles represent constant time periods. These time periods may be scaled by an actuator located between the time tubes. Analysis steps are displayed as bars in different colors symbolizing the varying device types needed for each activity. Two red circles (1 and 2 in fig. 3) define the active workspace for the "Phantom Omni". A highlighted circle (3 in fig. 3) in the workspace signals the actual position of the cursor. The black hole at the end of the tube is used to present additional information about the actual workspace to the user. A static window is positioned at the bottom of the screen displaying a Gantt chart for overview purposes. A red square (4 in fig. 3) is highlighting the workspace actually viewed in the tube visualization. The upper part of the visualization presents status information and allows the user to modify the actual view.

Every workflow for an assay is visualized as a linear arrangement of analysis steps interlinked by a wire. With this first prototype illustrated in figure 3, it is possible to view 40 assays in one tube. However, it is possible to enhance the prototype in order to display several hundred assays easily. The time limitations of the Circle View are solved

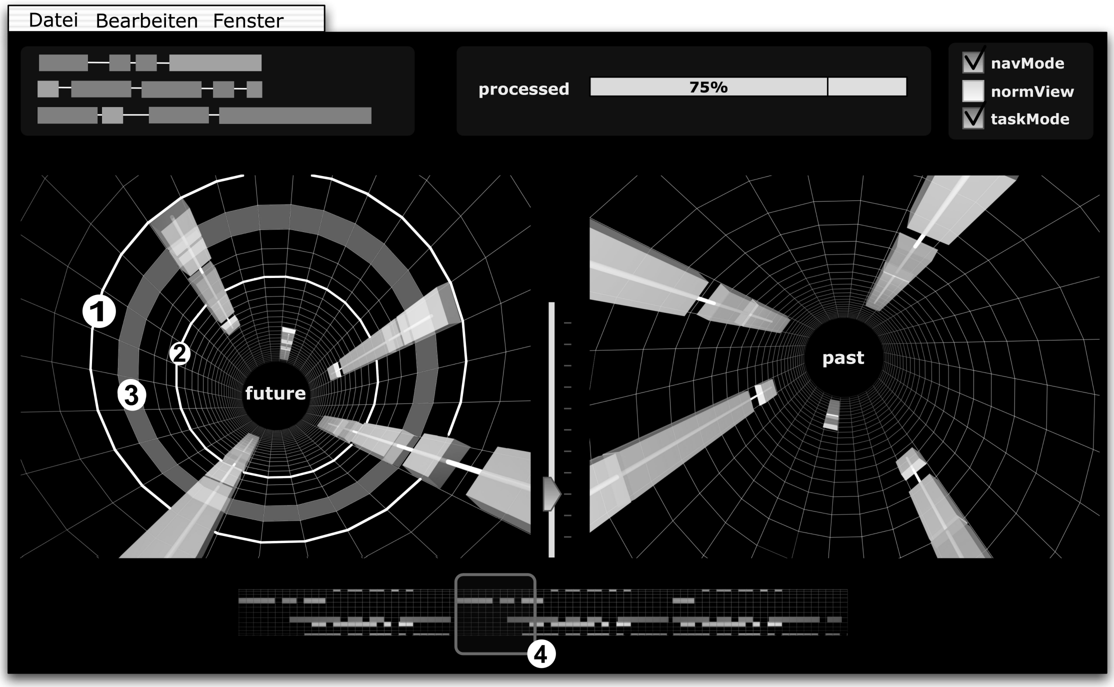

Figure 3: A screenshot of the TimeTube

by integrating an additional dimension. The focus moves from the outer segments into the foreground to the workspace between the two red circles. All other visual information of the whole visualization provide the user with additional context information. The distortion of the tube makes it easy to observe the context of the actual focus in the workspace. In addition we modified the idea of the rapid zooming technique. Instead of picking an object and rapidly zooming in to see more details, we use the zooming for navigating in time. By rapidly zooming into the tube, information of varying points in time is presented in the workspace [Pat07].

Force-feedback is used to restrict the predefined workspace in all directions. If the user moves the pen behind the first red circle (1 in fig. 3) toward him increasing forces exerted from the Phantom signal that the navigation through the time starts. Applying more pressure the navigation speed increases and the user is able to decide how fast he moves backward in the tube. By moving the cursor behind the second red line (2 in fig. 3) away from him again forces signal the motion forward in time. If the user bears away from the tube itself again generated forces guide him back to the workspace. The movements needed to navigate in the TimeTube are intuitive for the user as they resemble movements he experiences in his normal life. If for example the user wants to grasp something in front of him, he only has to move his hand forward. Navigating through the time thus no longer is a matter of moving the mouse left to right or up and down like in 2D visualizations, but only from the back to the front. Analysis steps can easily be grasped by moving the cursor to the activity and pressing the button on the pen. To release the chosen activity the user has to release the button of the pen. Relocating a whole workflow can be done in the same way but the user gets additional haptic information about this workflow. Depending on the number of analysis steps of the overall scheduled time for this workflow, forces are generated by the Phantom: The larger the workflow is the harder it is to move it. Also, collisions with other analysis steps trying to use the same resources can be brought to the user's attention by exerting according forces.

4 Results

To empirically test the TimeTube visualization, we developed a prototype application using Quest3D [Act]. Data I/O with the Phantom Omni input device is handled by Quest3D channels. These channels are implemented in C++ and linked as DLL-files into Quest3D. I/O between the Phantom (which has a timing of 1000 Hz) and Quest3D (with a timing of 60 Hz) is synchronized by a high-priority thread. XML handling is performed by Lua scripts.

In a next step we asked five persons inexperienced in the use of haptic 3D interfaces to test our prototype. Their tasks were to navigate to a specific point in time, relocating one of the analysis steps to another workflow and to move a whole workflow. Specifically, we assessed how the test users evaluate the perceived usefulness and ease of use of the prototype as these two factors are important influences of the adoption of new technological innovations [Dav89]. Moreover, the users were asked to express any problems they encountered (using the Thinking Aloud test method) with the TimeTube visualization and navigation as well as to report if they perceive the new technique as more comfortable and intuitive as common devices.

The test users expressed an overall positive impression of the prototype application. Although the TimeTube appeared unusual to the participants at first, they quickly adapted to it and emphasized its intuitive and easy navigation with the help of the "Phantom Omni". None of the users needed much time to deal with the device. The test persons were at first surprised as they encountered the ability of the "Phantom Omni" to guide them by force-feedback. Yet, they soon learned to appreciate the additional feedback given to them by the haptic constraints [SHH05]. The haptic support was described by the users as particularly helpful with the task of relocating an activity.

Every participant mentioned the intuitive time visualization in the z-axis especially with the task of navigating to a certain point in time. Limiting the workspace with force-feedback allowed them focusing on the relevant information. Context information presented by using multiple windows technique was helpful to fulfill the tasks. To identify the free space for relocating one of the visual representations of the analysis steps was the core problem for most of the participants. Thus, we decided to replace the window showing the TimeTube leading to the past with a camera perspective in the tube which nearly shows in 2D the free spaces available in the current workspace as shown in figure 4. A second problem occurred while relocating an activity. For most users the predefined workspace seems to be too small in the number of displayed circles. They had to scroll in time too often. They mentioned that they would prefer a workspace with eight to ten circles, so that movement in time is reduced.

5 Conclusion and Future Work

Dynamic scheduling of analysis steps is one of the major problems in laboratory automation and requires a human computer problem solver. Combining a 3D haptic user interface with a 3D visualization technique that uses the third dimension for representing time, the TimeTube visualizes workflows as linear objects. Haptic constraints guide the users in their tasks and allow them to reschedule workflows. First results show that the navigation in the TimeTube is perceived as easy to use. The limitation of the workspace was helpful to keep the focus on the current task.

As future work, additional concepts could be integrated in the TimeTube for supporting users in finding free spaces for relocating the analysis steps of a workflows. The number of circles in the workspace could be increased, so that scrolling in time is reduced. In addition, more aspects could be analyzed in further user tests for example the effectiveness of the focus and context visualization of the TimeTube. In a next project step, the focus of attention can switch from conceiving the user interface to conceiving a real-time feedback loop integrating the scheduler used. After this additional problem is solved, user testing with real application cases becomes sensible.

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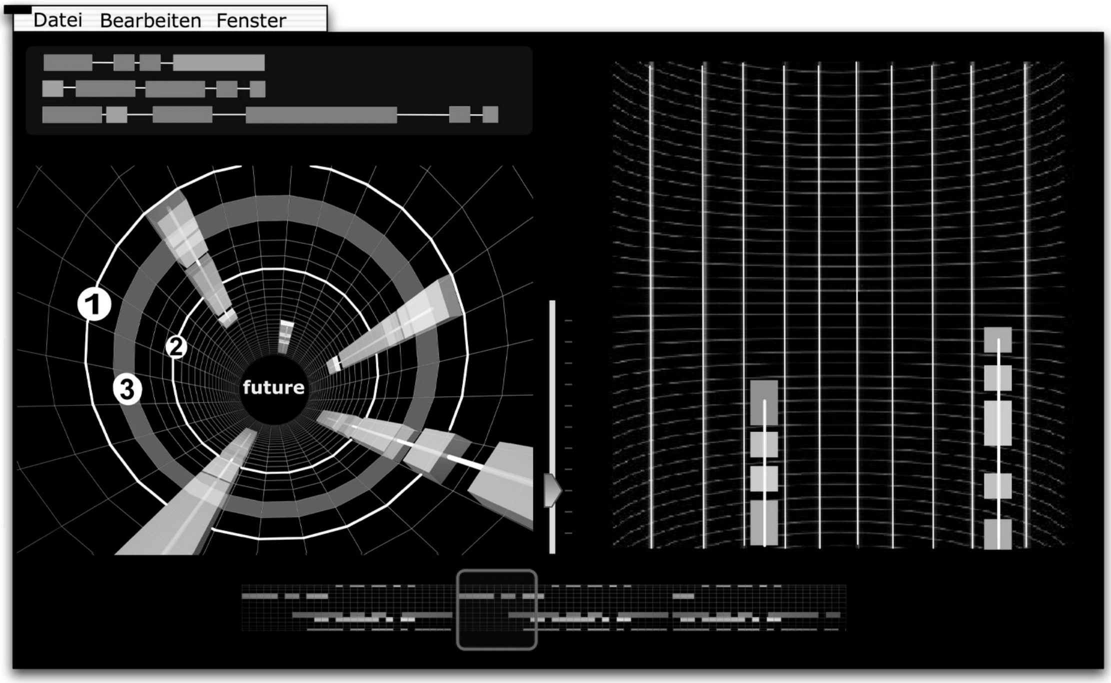

Figure 4: Redesign of the TimeTube visualization technique after the user-test

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