DESIGN AND EVALUATION OF ANIMATED 3D USER INTERFACES

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ABSTRACT

With the proliferation of virtual environments in real-world applications effective interface design and usability testing for virtual environments becomes increasingly important. Since 3D interfaces are not based on a set of standardized widgets the tasks of user orientation, interface presentation and interaction feedback require special attention during the design of 3D environments. Animation techniques based on cartoon principles can be used to improve the presentation of 3D environments and their interaction possibilities, thus enhancing the usability of 3D interfaces. In this paper we describe a system for rapid prototyping of animated 3D widgets and evaluate a set of cartoon animated 3D widgets in a simple multi user application.

KEY WORDS: 3D user interfaces, animation principles, usability testing

1 INTRODUCTION

The design of usable 3D interfaces for desktop visualization and virtual reality applications is a challenging task. Probably the most promising aspect of user interaction in 3D environments is to make the interaction more "life like", mimicking realworld tasks as closely as possible and thus enabling users to control an application with their everyday skills. While the potential of 3D interfaces has been largely recognized, technical constraints and the lack of experience have limited their practical application so far.

One central problem is the trade-off between detail and speed that is always involved in real-time 3D animation. To be effective and usable a 3D interface has to inform the user about his location (*user orientation*), current interaction possibilities (*interface presentation*) and changes in the environment (*interaction feedback*). These tasks become even more important in collaborative multi-user environments, where the user has no means to anticipate actions of other users. Adding more detail and better animation may seem like the obvious answer, but graphics performance is still a severe limitation and will limit the complexity of scenes and thus the amount of detail in interfaces for the foreseeable future. The second obstacle is that additional detail is not cost effective. The design of 3D environments is already a time consuming task and the addition of detail increases this cost even further. This is only warranted if usability increases at least proportional to the additional cost.

The above suggests to look for alternative ways for providing additional cues to the user and for increasing the "appearance" of life-likeness (as opposed to closer emulation of reality through more detail) in order to make 3D interfaces more understandable and thereby improve their usability. Cartoon animation provides interesting insights on how the appearance of "life-likeness" can be improved without a large amount of detail or actual realism. Cartoon animation uses exaggeration and decidedly "unrealistic" techniques or tricks to reinforce the illusion of reality. The user is not consciously aware of these tricks. They work in a subliminal way to make the animation more understandable and thereby seemingly more realistic or life-like. Techniques borrowed from cartoon animation have been successfully applied to 2D user interfaces and with state of the art 3D animation tools it is also possible to apply them to 3D environments.

This paper is based on our current effort to design usable animated 3D user interfaces and to develop adequate tools for the rapid prototyping of animated 3D widgets. Our goal is to combine sophisticated 3D techniques with well known scripting approaches for 2D user interfaces. To evaluate the effects of cartoon animation principles on usability we have designed a usability test of animated 3D widgets in a simple multi user scenario

The remainder of this paper is organized as follows. The following section describes animation principles in traditional cartoon animation and shows how to apply these ideas to the area of 2D and 3D graphical interfaces, including a discussion of related work in this area. The next section describes Ishell, a high-level 3D animation library embedded in the well known scripting language Tcl/Tk. We apply Ishell in a direct manipulation editor that allows us to design animated 3D widgets. The resulting 3D interface elements can be used alone. Section 3 gives an overview of research in 3D interaction. In the following section we describe our test setting for the evaluation of cartoon animation principles in a multi user scenario. The results of the first pre-test indicate that cartoon techniques can clearly represent important actions in 3D world. The paper concludes with a summary and a description of future activities.

2 PRINCIPLES IN TRADITIONAL ANIMATION

Early cartoon animation was mainly concerned with the exploration of a new media - a situation similar to realtime 3D animation and 3D user interfaces today. It was the development of believable characters by the animators of Walt Disney's studio in the 1930's that enabled cartoon animation to evolve from a technical novelty into an art form. Apart from technical advances in cartoon production it was mainly the "discovery" of a number of animation principles that enabled Disney's artists to create more life-like characters (Johnston, 1981). In (Lasseter, 1987) Lasseter explains these principles and how they can be applied to (non realtime, keyframe) 3D computer animation. These principles are well known among traditional animators and include:

- Squash and Stretch defines the rigidity and mass of objects by distorting their shape during an action. Soft objects - like most living things - are deformed by external forces during movement. Exaggerating this deformation increases the perception of object "softness".
- Timing refers to the speed at which actions in an animation occur. Timing of object animation is essential to convey properties like mass and size and also to create a sense of realism by emulating physical effects like inertia and friction. Timing between actions is essential to focus the viewer on important actions and to avoid loss of attention.
- Anticipation is used to prepare the viewer for an action by catching his eyes and directing his attention to the area where the action will take place. Typically an action occurs in three parts: the preparation for the action - this is anticipation -,the action and the termination of the action. A typical device for anticipation are small preparatory moves.
- Slow In and Out refer to the timing of object motion. Objects don't move with a uniform velocity but accelerate and decelerate. In cartoons slow in and out timing is not only used to achieve a sense of physical realism, but also to spend more time and detail at important actions and to "fast-forward" through less interesting sequences.
- Exaggeration means to accentuating the essence of an idea through design and action. Exaggeration is commonly used as an attention getter and to illustrate the central idea or action in a scene. Most animation principles discussed here can be thought of as some form of exaggeration of reality.
- Secondary Actions are actions of an object that result from other actions, for example through collisions or friction between objects. Secondary actions can be used to heighten interest and add realism and complexity.

Other principles include staging, follow through, overlapping action, arc movement and appeal (Johnston, 1981). Summarising, all these animation principles are used in concert to communicate an idea clearly and unambigusly by making the content of the animation more apparent than the animation techniques themselves.

Similar to cartoons, virtual worlds must not necessarily obey the physical laws of the real world. Therefore "cartoon physics", based on the animation principles described above, can be used as a metaphor for object behaviour in virtual worlds since animation based on "cartoon physics" is familiar to users from TV and computer games, has great expressive power and possibly leads to more understandable animation.

3 ANIMATION IN USER INTERFACES

Typical user interfaces rely on two forms of interaction: navigation and manipulation. In conventional graphical user interfaces (GUI's) manipulation, based on the windows, icons, menus, pointer (WIMPS) metaphor, is the central form of interaction. An application is controlled and data is manipulated through standard interface components called widgets. Widgets (e.g. buttons, scrollbars) have a uniform appearance, feature simple functionality and tend to be similar in appearance and behaviour across applications and platforms. The layout of the widgets that constitute a user interface is relatively fixed and can thus be "designed for usability" by the interface designer.

Navigation in conventional GUI's is often limited to switching between applications, arranging the layout of windows and scrolling window content.
Interfaces for 3D environments, on the other hand, are often based on a spatial "world" metaphor that relies on navigation as the primary form of interaction. Much of the intuitivity and potential of 3D interfaces stems from the use of a spatial "world" metaphor that enables the user to navigate through information spaces and use his everyday skills for interaction. However, navigation in 3D environments is not without problems: While occlusion of important information (for example through overlapping windows) can be problematic in conventional WIMP interfaces, the problem becomes significant in 3D environments where the interface is much more dynamic and the visibility and recognizability of interface components differs between different viewpoints, on which the application designer has little influence. It is therefore not sufficient to provide animation support in 3D user interfaces, but the animation techniques must also include the necessary functionality to ensure that the user is actually able to see and identify the animation. Manipulation in 3D interfaces is often simple direct manipulation of objects in the virtual world or the use of application specific 3D widgets. Due to the spatial nature of 3D "worlds", interfaces have to provide adequate answers to a number of questions concerning user orientation, interface presentation and interaction feedback:

- To improve user orientation the interface needs to answer to the questions "Where am I?", "Where have I come from?" and "Where can I go from here?".
- Interface presentation should primarily aid the user in recognizing interface objects and their functionality ("What is that object?", "What can I do with it and how?"). A more advanced function of interface presentation is to provide hints or suggestions for future actions ("What can/should I do now?").
- Interaction feedback informs the user about changes in the environment caused either by the user himself, the system, or other users ("What is happening and why?", "Where did that object come from?").

The potential benefits of animation in user interfaces have been recognized for quite a while, see Baecker and Small (1990). Hudson and Stasko (1992) describe how animation techniques have been integrated in a 2D user interface toolkit. Chang and Ungar (1992) give a detailed account of how cartoon animation techniques have been used in a 2D WIMP interface. The use of squash and stretch to enhance expressiveness in direct manipulation editors was recognized by B. Thomas (Thomas, 1995). He used a special warp algorithm to continuously animate transformations applied to 2D widgets. Recently, this idea was extended to 3D (Thomas, 1998). Based on Conner's pioneering work in 3D widgets (Conner, 1992) the extension of 3D interface elements to the fourth dimension using high level animation libraries is currently an increasing area of research. Geiger and Paelke (1998) encapsulate visual presentation techniques (e.g. cartoon principles) in agents to enhance 3D user interfaces with animation. While traditional animation principles have been applied to 3D film animation in general and to a number of graphical interface presentations in 2D and 3D, there is currently no conclusive evidence that they improve usability (Gonzales, 1996).

4 DESIGN OF ANIMATED 3D WIDGETS

While the potential of (animated) 3D widgets in interactive 3D applications has been widely recognized and demonstrated in many applications, the design of 3D widgets still faces a number of conceptional and technological problems. These difficulties include the lack of classification of 3D interaction tasks, lack of standardized 3D widgets, technical constraints (e.g. frame rate), and visual distinction from non-interface objects. Techniques and tools from 2D WIMP GUIs are of little help because 3D widget aspects are fundamentally different compared to 2D widgets. Since little solid design knowledge is available 3D GUI development typically follows an iterative design approach. Rapid prototyping is a design technique especially suitable to address the problem of 3D GUI design. It follows an iterative approach of consecutive specification-modeling-evaluation cycles. The principle idea is to start with a rough approximation of 3D geometry design, define the interaction behavior and feedback representation (e.g. by means on animation sequences) of a 3D widget and to test this widget in the application. Based on the test results new iteration cycles are then possible. Such an approach is best supported by interactive design tools based on a layered high level 3D animation library that allows a quick development of widgets, e.g., by providing a scripting interfaces.
For the design of animated 3D widgets we use AAL, a custom animation layer put on top of the well known 3D graphics library OpenInventor (Wernecke, 1994). AAL is a hierarchical 3D animation library and was originally designed as a system for rapid prototyping of interactive real-time 3D animations (AUTHOR PAPER 1, 1998). It is organized along different levels of abstractions and uses a construction kit metaphor for designing interactive animated 3D applications. The first level, L1, above OpenInventor provides all necessary static objects for prototyping animations. We only use lights, cameras and primitive shapes and external objects as static animation elements but encapsulate them in completely object oriented way. Unlike OpenInventor, Java3D or VRML, properties like position, material, or transformation are attributes of the corresponding element and not a substructure in the complete scene graph. Abstract animation methods like keyframe animations (move, rotate, scale, colour) and algorithmic animations (pendulate, shuttle, inverse, rule-based) can also be defined at this level.

At the next level, L2, animated objects are composed from elements of the lower levels. Objects are manipulated by predefined and user-defined animation methods that allow us the generation of complex animations based on animation lists and message passing. An animation list can start other lists on the same animated object or other objects. Multiple lists are processed concurrently allowing to generate complex animated behaviour. The highest AAL-level, L3, provides concepts for agent-based functionality (e.g., states, transitions, handling of events and simple constraints).

For rapid development of animated 2D/3D user interfaces we have integrated this 3D animation functionality into the scripting language Tcl/Tk 8.0 with the Ishell system. Tcl/Tk is often used for prototyping 2D-WIMP-user interfaces and is well suited to be extend by new commands. Ishell extends a Tcl/Tk shell with arbitrary 3D graphics functionality. The designer specifies the desired classes and methods of a 3D graphics library and Ishell automatically generates a library that can be dynamically loaded into a standard Tcl/Tk shell. After loading, the defined 3D elements are available as additional Tcl/Tk-commands. We have integrated a large proportion of Open Inventor as well as several extensions of OpenInventor developed by other researchers. The current version of Ishell runs on SGI and WinPC and is available at our web site. A direct manipulation editor for animated 3D widgets was developed using Ishell and AAL. 3D widgets consisting of 3D primitives and external 3D objects can be generated and their animation and interaction behavior can be easily defined using animation lists. Such animation list can be defined, saved and loaded independently from animated objects. Interactive events like mouse clicks, mouse over/enter/leave, etc. can be assigned to widgets and start the widget's animations and user defined callback functions. These functions are containers whose content is defined by the programmer in the final application. A widget can be saved as a Tcl object and is then available for reuse in any Tcl/Tk application that uses Ishell. Figure 1 shows a screen shot of the design of a chair widget that executes a stretch-animation when the user tries to move it in a locked state.

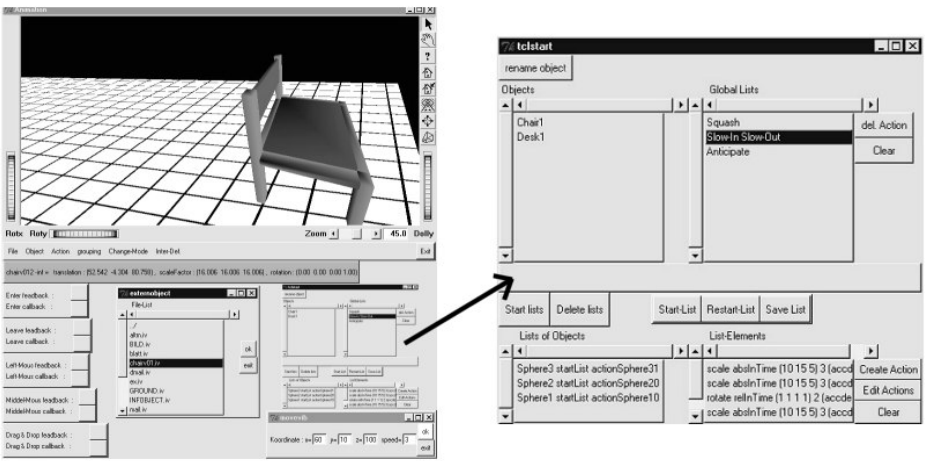


Figure 1: Design of animated 3D widgets using the 4dEdit

The design of animated widgets that use traditional cartoon principles for feedback representation is simplified considerably using Ishell and the 4dEdit editor described above. The editor also allows to test the designed widget in a special 'interaction' mode.

5 EMPIRICAL EVALUATION OF 3D GRAPHICAL USER INTERFACES

Much work in the domain of virtual environments has focused on the creation and demonstration of new technologies with only minimal consideration of usability aspects. At the same time research in human-computer interaction has often constrained itself to single users interacting with a computer through a conventional WIMP interface. Only recently have there been significant efforts to study and improve the usability of virtual environments (Bowman and Hodges, 1997). Such studies have clearly shown that the impressive technology of virtual environments does not guarantee high usability. Like other interactive systems the development of usable virtual environments requires the integration of usability engineering into the development process.

However, most of these techniques (e.g. cognitive walk-throughs, design reviews, model-based evaluation) can not be directly applied to virtual environment interaction because currently only limited design expertise and few design guidelines exist for this domain with its shared, exploratory high-level tasks that are in contrast to the single user, goal directed low-level tasks in typical WIMP interfaces. Existing usability studies in the context of virtual environments and three-dimensional interaction have often been concerned with the isolated study of input / output devices or interaction techniques in specialized test applications. Such results are invaluable to guide the design process of virtual environment interfaces but they often fail to address the complex interdependencies between several simultaneous users, their tasks, the environment and I/O devices that characterize typical virtual environments. These interdependencies imply that the usability of a virtual environment can not be inferred from the devices and techniques employed in its construction alone, but is best established by testing the application itself. This leaves the empirical method of experimental evaluation as the most promising technique for virtual environment evaluation.

One problem of multi-user 3D environments is the feedback representation of user actions. Expressive feedback presentations should inform the user about changes in the environment caused either by the user himself, the system, or other users. Our test scenario we experimented with cartoon animation techniques as a means for feedback representation. As an example for a collaborative multi-user 3D environment that allows to test the use of traditional animation principles, we consider a collaborative office planning application. Users are placed in a virtual 3D representation of our lab where they can manipulate wall elements and place office furniture and equipment. Each user‘s task is to examine different office configurations and select a best fit in collaboration with his colleagues. The resulting configuration must satisfy both external constraints (e.g. space, number of furniture) and be accepted by all colleagues involved. The configuration process will likely lead to interaction conflicts. Some typical conflicts are that a user wants to insert an object into the scene at an already occupied position, wants to move an object to an already occupied position or wants to move an object which is currently held by another user. An object may also be moved (or even removed) by someone other than the user who has placed it.

In order to estimate the usability effects of the proposed visualization techniques, our study covers three different conditions, which allow to compare and assess the relative gains in efficiency, usability, understandability and intuitiveness of actions. Two kinds of criteria are being evaluated: on the one hand performance measures as time to solution, error rate, detection rate, frequency of actions, etc. and on the other hand subjective measures as intuitiveness, understandability, satisfaction, and ease of use. The conditions, to which the subjects are randomly assigned, are: *interaction without animation techniques*, *interaction with straight forward animation* and *interaction with cartoon animation techniques*.

The setting is a simulated cooperative design session, during which the test application (build by means of AAL, Ishell and 4dEdit) is used for interaction. The respective partners are simulated by a multi agent system within the program, which shows controlled actions and reactions to the subjects’ behavior.

When performing the task, the subjects were observed by a video camera. A moderator explained the test task and asked questions on certain behavior or gave information on problems arising. The observational data was coded and analyzed using Noldus™ Observer Video Pro, which allows the assignment of behavioral data to video observations. In addition questionnaires were used to asses the subjective criteria described above, some of which are custom developments (ease, adequacy), others are standardized. The test was performed in our usability lab, which allows usability testing with two digital video inputs and the Noldus software, facilitating analyses across and within participants.

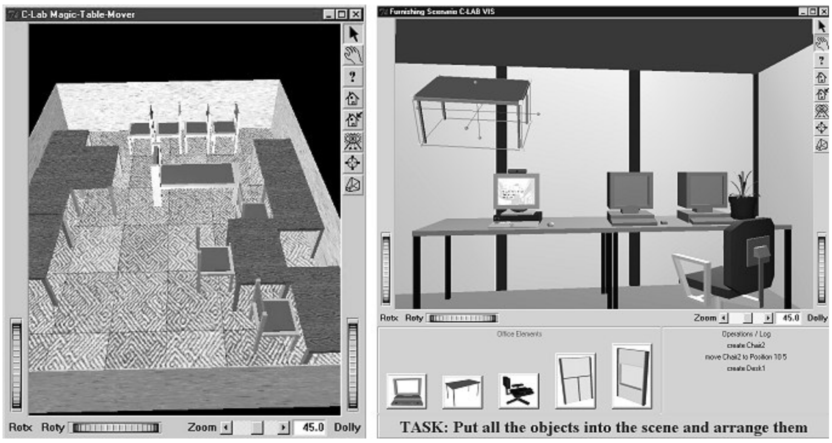
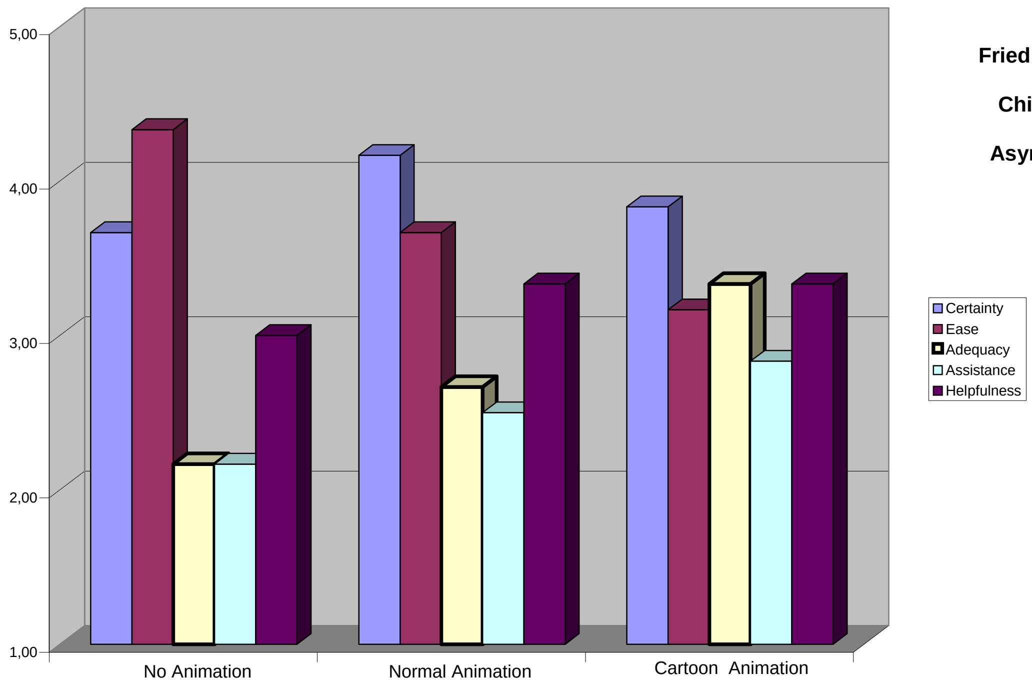


Figure 2: Screenshots of the pretest scenario and the final test application

Test subjects were asked to move office elements to a given position sketched in a 2D overview plan. Subjects were told that another user (simulated by the computer) is also working in the scene. The participants were asked to solve the task three times (A:without animation, B:with straight forward animation, C:with cartoon animation) and to comment on their actions and impressions (think-aloud). During each task the computer randomly moved objects the user had previously selected. The movement of objects caused by the computer is represented in different ways (A:direct positioning, B: linear translation, C: slow-in slow-out with small preparatory move). Some objects moved by the computer could not be moved by the user. This situation is represented by an alert box with explanation (A,B) and a stretch/flip back animation (C).

Six subjects performed the same task for each of the three conditions, they were randomly assigned to one sequence to avoid order-effects. The data was analyzed using non-parametric tests (Friedman Test for k related samples), as the sample size wasn't large enough to assume normal distribution of the criteria and errors.
The results concerning the subjective assessment by the subjects showed trends towards the assumptions, i.e. conditions 2 and 3 scored better in the assessments for most of the criteria. However, there was just one significant effect, for the adequacy of the feedback given by the system. For the other subjective measures, the tests didn't show any effects.



Friedman Test "Adequacy"	
N	6
Chi-Square	6,615
df	2
Asymp. Sig.	,037

Figure 3: Mean scores for the subjective assessments

The analyses for the performance and interaction data showed no significant difference between the three conditions, concerning neither speed nor number of conflicts. A time plot for the six subjects is shown in fig. 4.

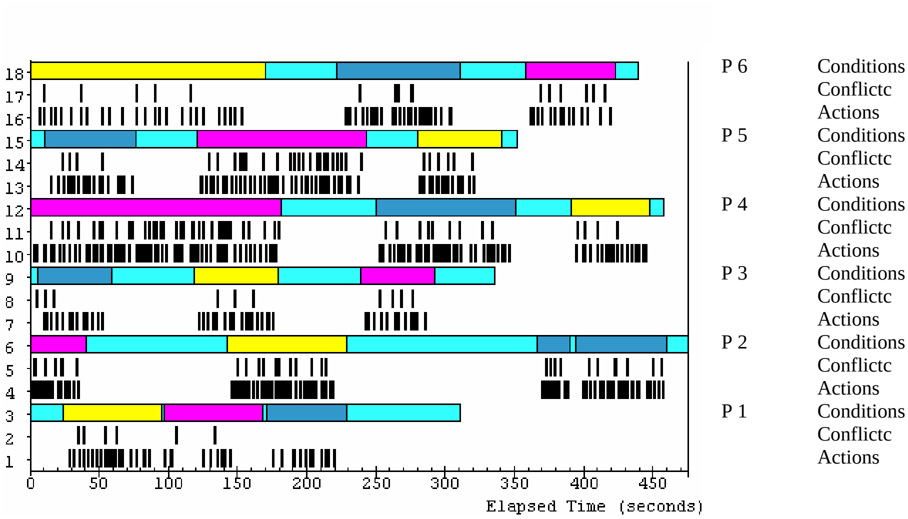


Figure 4: Time-plot traces for subjects 1 to 6

The colored bars show the proportion of time used for the different conditions, the marks below indicate actions and conflicts in the interaction. These data didn't differ significantly between the conditions, mainly due to the fact that the task was not too complex and the interaction rather intuitive.
Post-test interviews and the "think aloud" technique yielded some more qualitative assessments of the systems, which provide input for the future development. Most of the subjects would appreciate a visualization for upcoming actions of the partner/computer by e.g. highlighting the next object to be moved. This would facilitate the selection of a "free" object and avoid conflicts in the interaction. The stretching-visualization for blocked objects brought up

some irritations about whether the type of action was resizing rather than moving the object. This should be reflected in a follow-up version of the system. However, the overall assessment of the interactive system was positive, yet it was perceived too artificial due to it’s prototype character.

6 SUMMARY

In this paper we reported about our on-going work on the design and evaluation of animated 3D user interfaces. It is not sufficient to have efficient tools ready for the design of animated 3D widgets but also necessary to integrate usability testing into the design cycle. Due to the lack of standards in 3D GUI design iterative prototyping and empirical evaluations are presently the best way for user-centred design of animated 3D worlds. Our current work focuses on a qualitative and quantitative empirical study of the use of traditional cartoon principles in animated multi-user 3D user interfaces. The results of the study encouraged further development of cartoon animation as a more adequate feedback in interactive systems, but also showed the need for tests of more advanced versions in real-life settings in order to validate the findings in concrete work situations.

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