Action Spaces – A Metaphorical Concept to Support Navigation and Interaction in 3D User Interfaces

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Abstract
There is the obvious necessity of navigational support in virtual environments. Beside exploratory virtual worlds a new class of three-dimensional applications is evolving, where 3D objects are manipulated as documents within a three-dimensional interface. With this kind of applications the task of the spatial arrangement and integration of 3D interface elements becomes evident. Due to the increasing complexity of three-dimensional software these elements must be grouped in a certain way. This paper therefore suggests a metaphorical approach called *action spaces* to structure three-dimensional user interfaces. To switch between different action spaces navigational support is needed. The idea of task-centered navigation between predefined viewpoints is introduced. The approach is illustrated by examples. Various metaphors for the realization of this approach are explained and classified.

Keywords
3D User Interface, Virtual Reality, Desktop VR, 3D Graphics, Virtual Environment, 3D Widgets, Metaphors, Navigation.

1 Introduction

Efficient navigation through virtual environments is an important goal to achieve in applications like architectural walk-throughs or distributed virtual environments. Beside this type of virtual reality (VR) environments new applications will be built in the near future, where the focus does not lie on navigation through more or less realistic worlds, but rather on 3D objects as documents in an interactive three-dimensional user interface. Consider applications in the fields of 3D-modeling, CAD, product presentations, electronic commerce, virtual training and many more. In all these areas interactive manipulations of 3D objects dominate the application, whereas navigation does not play a role at the first glance. By now there are only few experiences and no standards on how to design an realize this new class of three-dimensional applications. In order to construct a 3D environment the developer would probably rely on experiences with 2D solutions in the first place.

If we look at typical WIMP (*windows, icons, menus, pointing*) applications we usually find one application window with one or more documents being worked on with the help of interface elements like menus, icons or toolbars. Due to their complexity menu systems are to a certain degree contradictory to the demand for minimizing the search time while looking for specific functions or tools. Tool palettes are more suited, which can be arranged around a document to have quick access to desired functions. That is why common toolbars already contain tools and functions to fulfill specific tasks like for example a toolbar with icons to modify graphical objects in a word processor.

These experiences can be transferred to 3D user interfaces. The main part of a 3D application will be a spatial environment, where 3D-documents can be modified with three-dimensional interface elements. The tools should be designed three-dimensionally to be tightly connected and integrated with the objects to work on and to avoid the discontinuity between 2D and 3D [9]. Interaction with the three-dimensional objects happens through either direct manipulation or the use of 3D widgets, which encapsulate geometry and behavior [4]. Given a 3D modeling package with a completely three-dimensional interface one can imagine, that the multitude of widgets should be arranged in widget subsets within different task-oriented spaces. The question arises how to arrange tools and application controls in space and how to activate the various action zones. This again turns out to be a question of navigational support.

This paper proposes the *action space* approach to solve that problem and to also answer the question, how users can switch between different spaces. The next chapter is devoted to related work in this field. After that the concept of *action space* is introduced in detail. The fourth chapter presents a possible application scenario and a product presentation prototype. To effectively apply *action spaces* structural and navigational metaphors are needed, which are introduced in the last chapter of the paper.

2 Related Work

Whereas research on navigation and interaction in virtual environments exists, there is not much research on the design and visual structure of more complex three-dimensional interfaces. Earlier (non 3D) research on the level of operating system interfaces suggested multiple desktops (*virtual workspaces*), each providing icons, tools etc. according to a certain task [2]. Later the *Information Visualizer* project [3] investigated arrangement and access of information objects with the goal of minimizing the retrieval costs. The architecture introduced information workspaces on the base of the 3D/Rooms metaphor. The user can freely navigate between information rooms. Although techniques for an accelerated navigation were developed, the problem of orientation still remains. Moreover, the system was only aimed at the information visualization and retrieval domain.

Several techniques were developed for an improved navigation in virtual worlds, basically for immersive virtual environments. Among them are *Worlds in Miniature (WIM)* [10] or *Worldlets* [6]. The focus of this research rather lies on efficient navigation and orientation, being independent of the specific activities and tasks in the virtual environment.

With the *Virtual Venue* application [1] the *flying chair* metaphor was introduced. It allows a limited and animated navigation between predefined places. Considering the mere navigational support our approach resembles the flying chair. The virtual venue however is a specific information retrieval system and does not investigate more complex virtual tools and 3D documents.

Tool palettes with 3D tools and objects are employed in many VR applications and authoring tools. The *Toolspaces* approach [9] addresses the problem of arranging 3D widgets and objects in containers attached to the virtual body of the user. They are activated on demand with the *glances* technique [9] and are only visible and in reach for a short time. 3D objects can be taken through the virtual environment with *toolspaces*. The number of widget-containers and their arrangement are nevertheless limited by their position close to the user. In addition to that problem the paper does not cover the design of the virtual space itself, nor the overall structure and content.

3 Action Spaces

The concept of *action spaces* was introduced for the first time in [5]. It will be explained here in further detail and will be illustrated with application examples and supporting metaphors in the next chapters.

3.1 Mental Model

By manifold human activities people have created certain rooms or places for special associated tasks like labs, offices, kitchens etc. These established working places are highly specialized and allow an enormous efficiency of actions due to optimized tools and a good spatial layout of furniture and tools for a particular task. Moreover, the spatial specialization allows efficient, pragmatic navigation. Four abstract features can be identified for working places. Firstly a metaphoric and visual framework (e.g. *house*), secondly the scenes of action (e.g. *workshop*), thirdly tools and their containers (e.g. *drill, workbench*) and finally the objects being worked with (e.g. *workpiece*).

This mental model can be adapted to three-dimensional interactive applications. The basic application metaphor could be some geometric structure like a city or building, thus serving as a spatial framework for orientation. A number of possible structures and metaphors are introduced in chapter five. Action spaces can be found as parts of spatial metaphors or geometric structures. The scenes of action as well as the tools and containers are described in more detail in the following concept. The fourth feature, the objects to be manipulated, are 3D-documents, e.g. 3D models or products displayed in those spaces.

3.2 Definition

For scenes of actions we define ***action spaces*** as virtual 3D spaces with interface controls serving an associated task. A number of tools, interface controls (3D-widgets) and their containers are laid out around a predefined viewpoint to fulfill sub-actions of the task. Their position and the position of the 3D documents to be viewed or manipulated is fixed within defined constraints. So like in real life important objects and tools usually have their well established and constrained place. Thus obscuration of objects and visual clutter is avoided as opposed to world-in-miniature widgets or other floating controls causing obscuration of objects and visual clutter in typical VR applications [8]. The figure shows an annotated snapshot from a three-dimensional application based on action spaces.

Action spaces do not have to be rooms in a geometric sense. They are rather defined by the position of the user in the virtual environment and the interface objects inside the view frustum. That means walls, shelves or other framing geometry may just have a decorative or demarcating function. Although the number of 3D widgets is already reduced due to the task-oriented spaces, the developer might still face a space problem given the limitations of the user's view in a desktop VR application. This problem can be solved in conjunction with the *toolspaces*-approach [9], where additional tools and interface controls can be chosen from temporarily visible tool-palettes.

3.3 Navigation

Typical applications have many action spaces for different main tasks. How can navigation through space be achieved? The user does not have to navigate actively through space, for example using a fly or walk metaphor. Instead she or he triggers the change of places according to the intended action. This triggering might be caused by interactions:

- with widgets like buttons representing the next space or the direction towards it (e.g. doors in the 3D/Rooms metaphor [3] or icons displaying the main task of the next action space)
- with miniaturized views of the other spaces or the overall structure (e.g. using *WIM's* [10] or *worldlets* [6])
- with visible parts of neighbouring spaces (like in detail/context techniques)
- using natural voice or gestures

Orientation and navigation is simplified with this *task-centered navigation*, since the user only has to trigger change of places and not to move in some way. This is very helpful especially with desktop-VR systems, because of limited freedom and support to move around like in immersive VR applications. The transition between action spaces should be animated to facilitate orientation. Changing the current viewpoint is not necessary between two different action spaces. Take for example the theater metaphor described in chapter five, where the user's position stays the same and many action spaces share the same viewpoint. Only the 3D widgets, their arrangement and number changes within the view frustum, all in an animated manner. This way the action spaces approach is different to just interpolating different viewpoints like in common VRML browsers.

4 Application Scenarios

To illustrate the potential of the action space approach this chapter firstly introduces a typical application scenario in the field of electronic commerce and afterwards presents a prototype of a product presentation environment.

4.1 3D-Shopping

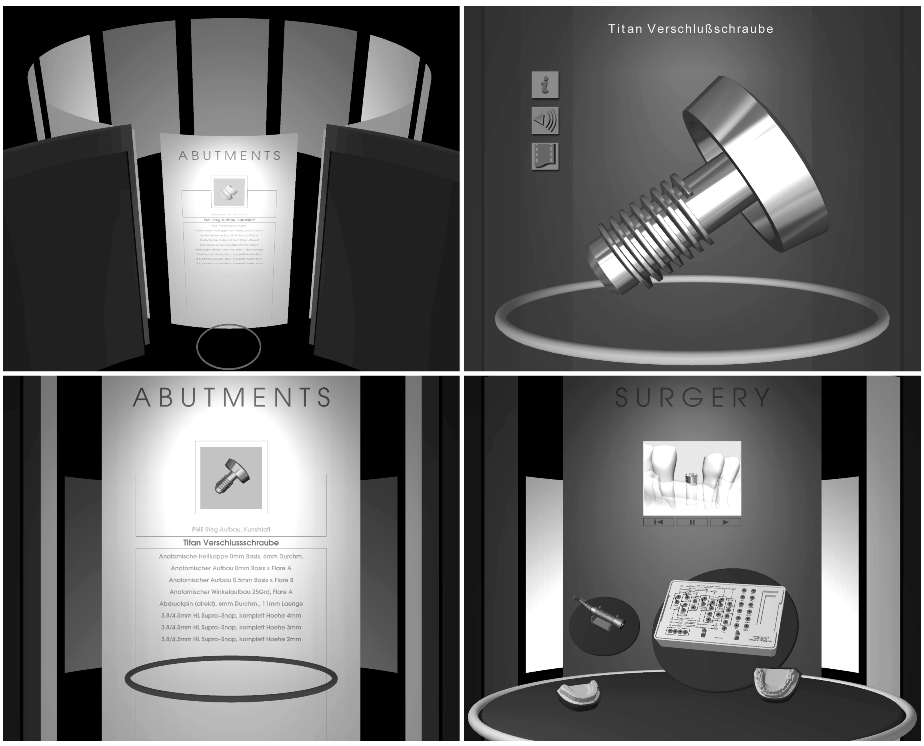
Current 3D-shopping solutions in the web are either difficult to navigate realistic 3D-Malls or just normal HTML shopping pages with small 3D product views. Malls of the first category: often try to imitate reality and thus make it difficult to navigate. There are questions arising like: Why do I have to go a long way to the next shop? Why do virtual shelves have many copies of the same product? In addition to that in most cases the products themselves are not displayed in 3D. The more traditional electronic shopping solutions are quite efficient, but only offer small 3D-windows or views. Since the 3D-products are very small and often of a poor quality, 3D views are no added value to images. Moreover, by now only rotation or zooming are the typical interactions, but not interactive product usage. So we suggest to combine the efficiency of 2D-e-commerce solutions with the impressive possibilities of the third dimension. A 3D-shopping solution of this type could have the following action spaces, which are connected via some geometric structure (see figure on next page for a bird's eye view of a possible arrangement).

- *Browsing and selection of products*
  Product search, browsing of intuitive categories and within associative product scenarios (For example a beach, where sports and swimming products are displayed together)

- *Product examination and configuration*
  Detailed exploration of products. Display of additional information. Configuration of colors, modules, accessories etc. Simulation of product usage.
- *Shopping Cart*
  Central space of the application. Display of selected products with 3D product miniatures. Number of product may be changed.
- *Order center*
  Display of prices and special offers, discounts, payment information, terms of business. Shipping options.

4.2 Product Presentation Environment

The product presentation prototype IMPLANTORIUM has been an interdisciplinary development at the College of Art and Design Burg Giebichenstein Halle (Germany) [7]. This non-immersive, OpenInventor-based system not only allows the presentation of the product range of an implant dentistry company, but also the interactive demonstration of product usage in surgery. The basic application metaphor are two virtual revolving stages facing each other. The front stage can be rotated between the *product presentation* and *virtual surgery* state. The user always faces the back revolving stage, the *Product Store*, an action space consisting of presentation columns and serving the product selection task. Each column contains products of one particular category, like drills or abutments. After the desired product category was selected, the revolving stage is rotated to make the column facing the user. All products are listed on it with a preview picture and short description. The list can be scrolled and products can be selected, which appear in 3D, apparently being emitted by the preview picture.



IMPLANTORIUM system: *Product Store*, *Product Showroom* and *Virtual Surgery*

This product selection triggers the change of action spaces, visualized by two walls closing in front of the product column and behind the 3D product. They expose new interface controls associated with the information/examination task. The change to the *Product Showroom* action space is an example of a constant user's viewpoint with different action spaces. The finely rendered products can be rotated and zoomed using a spacemouse or mouse. Additional product information may be displayed. In the *Virtual Surgery* action space one can configure a surgery table, watch videos demonstrating surgery phases and finally interact with the products to simulate their use.

5 Metaphors for Action Spaces

So far only a definition of *action spaces* as task-oriented scenes of actions was given, where interface controls and 3D-documents are grouped around a predefined viewpoint. An important challenge however is the need for the integration of these spaces in a more general visual application framework, in a geometric and metaphorical structure. First we need *structural metaphors* for the mental connection and geometric integration of action spaces to facilitate orientation. Second we need support for an easy-to-understand and easy-to-follow change of spaces, i.e. *metaphors of navigation*. Sections 5.2 and 5.3 describe appropriate metaphors for each category.

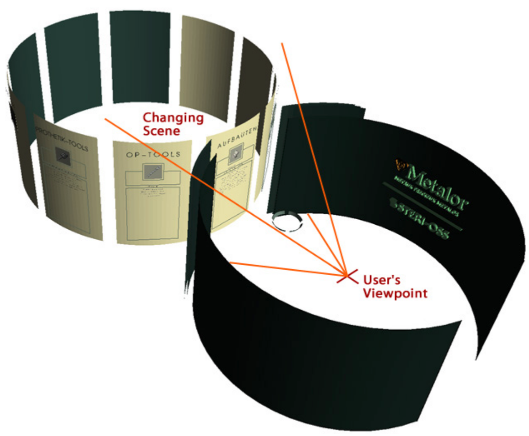
Metaphors should have an analogy in real life but should not try to imitate reality. This follows from the difficulty to achieve a similar experience and to fulfill the user's expectations. In reality it is possible to freely navigate, which is not the case with action spaces. From that it follows that we need more abstract geometric structures, which are still understandable as metaphors. The experiences with the mentioned prototype have shown, that an initial animation showing the overall application structure is of much help for building up a mental model of the basic metaphors. Moreover, good use should be made of the *virtual repertoire*, which consists of transparency, non-linearity, fisheye, hyperbolic or perspective views and similar features. Finding suitable spatial and structural metaphors is basically a conceptual and design problem. That is why we suggest an interdisciplinary development of three-dimensional interactive applications, where computer scientists work together with architects, industrial, interior and communication designers as well as other experts.

5.1 Two Fundamental Metaphors

Our classification distinguishes between two basic structural metaphors differing in terms of the mental model being generated. First the *theater metaphor*, where the user has a static position and viewpoint and the world around changes. Second the *locomotion metaphor*, where the user has a dynamic position and will be moved through a structure.

Theater Metaphor

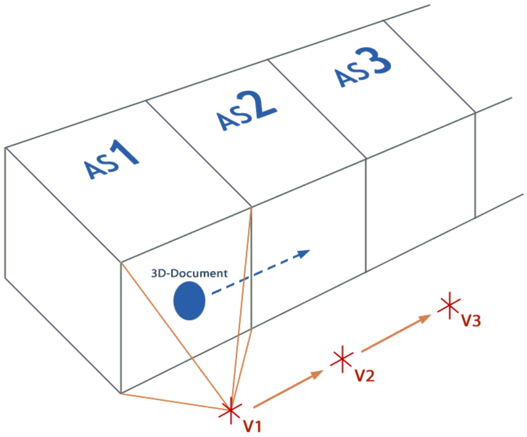
This metaphor resembles typical WIMP interfaces, since the user's viewpoint remains constant. In analogy to a stage portal this is symbolized through a static frame of reference. The 3D-document mainly stays in the center of interest. It does not necessarily have to remain in the field of view, but can also exit and reappear like a real actor. Whenever changing action spaces the "set" (i.e. 3D-widgets, displays, decorative elements...) changes, too. Methods like usage of transparency,



changing the visibility of elements, or change of sizes may be applied. As opposed to a real theater, where changes usually happen on stage, the virtual theater metaphor also allows interface controls, tool palettes and similar elements to be stored beside or behind the user. That means for example, that a tool-palette can be swung into the field of view on demand. The introduced IMPLANTORIUM prototype is based on this metaphor, being realized with two virtual revolving stages. The theater metaphor is especially suitable for building more complex action spaces, where you need many tools at your free disposal, e.g. in a 3D modeling program.

Locomotion Metaphor

The user's viewpoint changes with this metaphor, made visible by a dynamic visual frame of reference (e.g. different rooms or floors). The rooms or action spaces are completely changed along with their interface elements. In some cases 3D-widgets can be shared with other action spaces. 3D-document of the application might remain in the last visited action space or can taken to the next space (see section 5.5). The locomotion metaphor is most suitable for applications consisting of various action spaces with simpler associated sub-tasks.



5.2 Structural Metaphors

This section describes concrete visual or geometric application structures belonging to one of the fundamental metaphors. They serve as basic metaphors of an application.

Rooms

Rooms are a simple, comprehensible metaphor and basic structure. As a basic unit they don't have to be rectangular but can also appear as cells, bubbles or other spatial units. They might be open or closed. In the latter case they can be entered through doors. Rooms are suitable as parts both of the theater and locomotion metaphor and can be applied in many application areas like virtual training, education or electronic commerce.

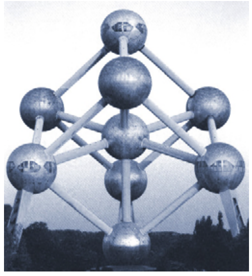
Revolving stages

Revolving stages are also a basic but more complex structure. They contain several action spaces, which are changed through rotation of the stage. Revolving stages are a characteristic example of the theater metaphor, since the user's viewpoint remains constant. The shared use of tools is well supported with this metaphor, because interface controls might be integrated in separating walls, thus being accessible from different sides. For this reason typical applications are those with frequently used tools like 3D modeling packages.

Buildings with floors, corridors, levels

Rooms, revolving stages or similar stackable structures can be part of larger structures. They can be grouped in a vertical way within houses, skyscrapers or towers or in a horizontal way within arcades, floors or tunnels. All these structures are mainly regular and often determined by linear arrangements of the basic units. Thus they are especially suitable for sequential tasks (see section 5.3). Buildings are typical examples of the locomotion metaphor. They can serve as the basic metaphor for many application areas and are easy to understand.

Space stations, molecules, bubble-nets



This group of metaphors allows more "geometric freedom" than the buildings mentioned above. Spheres, rooms, bubbles or 3D-cells are arranged in a (possibly non-linear) geometric raster like a molecular grid, space station or network. Cells are connected by tubes or hallways. Especially molecule structures or bubble-nets allow sub-hierarchies of action spaces, where a main molecule (e.g. selection of a product group) leads to smaller molecules (e.g. choice of product model). These metaphors belong to the locomotion metaphor. They are suitable to realize associative, dependent or connected action space, where certain connections are established, others disabled. Thus dependencies of sub-tasks might be expressed in terms of connections between action spaces and more than just linear structures or sequential tasks are realizable. Typical application areas are entertainment, information / web visualization or data mining.

Urban metaphors

With urban metaphors the arrangement is not restricted, and the layout might be far freer than in the previously mentioned metaphors. Open spaces like streets, places, parks, districts or even cities belong to this group. These metaphors are also examples of the basic locomotion metaphor. Due to the fact, that action spaces restrict navigation to predefined places, urban metaphors possess the disadvantage of high user expectations as far as a free navigation is concerned. On the other hand they are very easy to understand and thus suitable for atmospheric, emotional applications in the field of e-commerce, entertainment, virtual communities or virtual democracy/municipality.

5.3 Navigational Metaphors

The structures belonging to the theater metaphor do not need methods of navigation, since the user's viewpoint remains constant. Most of the structural metaphors however belong to the locomotion metaphor and therefore require methods of movement or navigation. Common navigational metaphors like *fly* or *walk* are not appropriate since the user is transported to predefined places and cannot freely navigate through space. Metaphors of transport suggest themselves as the solution to this problem. We make a distinction between *sequential* and *parallel* metaphors. That means certain metaphors suggest strictly hierarchical sequences of actions whereas others allow the choice between different alternatives.

Elevator / hydraulic ramp

Elevators or hydraulic ramps are well suited for a *vertical* movement between different levels, e.g. of a building. Due to the linear movement these metaphors support *sequential* tasks. With the exception of the lowest and highest level the user can decide between *two directions* (action spaces). Using a paternoster metaphor even cycles of action spaces are imaginable. The elevator doors should be transparent or omitted to better comprehend the animated change of action spaces.

Track vehicle / train

Imagine a user looking out of the compartment window or sitting in a ghost train. Track vehicles or trains allow a guided tour of viewpoints (action spaces) like a camera car. This can be a simple panning (linear path) or a more complicated, curved path. As with the elevator *two directions* are possible with this *sequential* metaphor in most cases. In addition to that switches allow choices of directions. Trains can be easily used for automated movements through *horizontal* structures like walkways, arcades or passages.

Cable railway / slide
Being similar to the previous metaphors cable railways or slides allow guided paths through action spaces. Freer forms like spirals winding down are possible with this metaphor, where the user simply stops at action spaces. As opposed to the previous navigation methods this sequential metaphor is a *one-way metaphor*, where only a strict sequence of visited action spaces is permitted.

Flying chair / carpet
The flying chair metaphor of the *virtual venue* [1] or a magic carpet allow a free guided locomotion without a regular path. This causes the danger of disorientation. To facilitate user navigation parts of the chair or carpet should be visible while changing action spaces. This metaphor belongs to the group of *parallel* metaphors, since the user can fly to more than one or two action spaces.

Tele-Portage / "Beam me up"
The well known tele-portage metaphor allows even more freedom of movement due to the possibility to visit arbitrarily distant and unconnected action spaces. User orientation is almost impossible, since change of places is not understandable whenever the current action space dissolves and the new one appears. Despite the disorientation the metaphor is well suited for completely free structures and as a *parallel* metaphor allows the choice of various destination spaces.

While going through the list of navigational metaphors one will notice, that the freedom of movement increases. Whereas the elevator moves strictly linear in a vertical way the train or camera car moves horizontally in a linear way or might also follow a curved path. Slides even allow three-dimensional spirals or other free curves. Next, with the flying chair metaphor one can almost freely move around some structure or terrain, whereas the tele-portage metaphor eventually allows complete freedom of movement.

5.4 Combination of structural and navigational metaphors

Structural and navigational metaphors described in the previous sections can be easily and freely combined. However, it is more reasonable to prefer certain pairs of metaphors, where structural and navigational metaphors result in a more natural fit. The number of plus signs in the table denotes better matches of metaphor pairs. Pairs with the minus sign are less or not at all suited.

	Elevator	Rail Vehicle	Slide	Flying Chair	Tele-Portage
Rooms	++	+	+	+	+
Buildings	+++	++	+	-	+
Space Station	++	++	-	+	++
Molecules	+	-	+++	+	+
Urban Metaphors	-	+++	++	+++	++

5.5 Transportation of objects

Certain tools or interface elements can be used in various action spaces or even should be available everywhere. Using the locomotion metaphor these elements might be taken through the rooms in miniaturized form (as 3D-Icons). As mentioned above the *toolspaces & glances* technique [9] can be used for less important widgets. Using the theater metaphor they should be part of the static visual structure (e.g. portal). Take for example a revolving stage, where a “tools wall” can be accessed from both (or even more) sides.

3D-objects as documents of the application can also be taken with the user to the next action space or processing step. Elevators or hydraulic ramps are especially suited to transport a 3D-document to the next level, where other tools are available to modify it and different actions can be performed on them. The usage of the elevator metaphor allows the display of transported objects in full size. With some metaphors of transport like the flying chair or slide however it is not very meaningful to display 3D-objects in full size. In this case objects should be scaled and transported as icons or in a semi-transparent manner to simplify orientation and visualize change of places for the user.

6 Conclusion and Future Work

For the class of document-based, three-dimensional interactive applications we introduced *action spaces* as a functional subdivision of 3D virtual environments, which allow an automated and task-oriented navigation. An application scenario was sketched and a proof-of-concept demonstrated with the prototypical system. To effectively realize *action space*-based applications metaphors for structures and navigation are needed, which were introduced and classified. The paper did not elaborate on the concrete shaping of action spaces from a designer’s point of view, since this process is difficult to formalize. We consider the development process of virtual environments to be inevitably of an interdisciplinary character. Moreover, the reduced degrees of freedom with action spaces require a careful spatial design especially with desktop-VR, where perceptual aspects and display proportions etc. must be taken into consideration.

There is the need for the development of more sample applications according to this concept, which should be evaluated to answer questions like: Does restricted navigation disturb the user? Can tasks be solved more efficiently with this approach of task-oriented groups of 3D-tools? It is also important to investigate, how multiple 3D-documents can be handled in such a virtual environment.

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