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The Three-Dimensional User Interface

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1. Introduction

This chapter introduced the three-dimensional user interface (3D UI). With the emergence of Virtual Environment (VE), augmented reality, pervasive computing, and other "desktop disengage" technology, 3D UI is constantly exploiting an important area. However, for most users, the 3D UI based on desktop is still a part that can not be ignored. This chapter interprets what is 3D UI, the importance of 3D UI and analyses some 3D UI application. At the same time, according to human-computer interaction strategy and research methods and conclusions of WIMP, it focus on desktop 3D UI, sums up some design principles of 3D UI. From the principle of spatial perception of people, spatial cognition, this chapter explained the depth clues and other theoretical knowledge, and introduced Hierarchical Semantic model of "UE", Scenario-based User Behavior Model and Screen Layout for Information Minimization which can instruct the design and development of 3D UI.

This chapter focuses on basic elements of 3D Interaction Behavior: Manipulation, Navigation, and System Control. It described in 3D UI, how to use manipulate the virtual objects effectively by using Manipulation which is the most fundamental task, how to reduce the user's cognitive load and enhance the user's space knowledge in use of exploration technology by using navigation, and how to issue an order and how to request the system for the implementation of a specific function and how to change the system status or change the interactive pattern by using System Control.

Finally through the case analysis, it highlighted the experience and interactive of 3D UI. And then it analyzed elements affecting 3D UI interactive mode from the Psychology, interactive design and information show.

3D UI has come to the transition time from the technology-driven to the design-driven. This section gives the readers a basic understanding of 3D UI. It focuses on the basic concepts, advantages and limitations between different latitude UI, its applications and the studying contents.

1.1 Concept of 3D UI

1.1.1 Definition of 3D UI

With the development of computer hardware and software technology and the increased demand of application, digital terminal equipment diversification, such as cell phones, PDA (Pocket PC) terminals spread, and so on, that the time of Pervasive Computing has arrived.

Currently the shortcomings of the WIMP interface occupying the mainstream position are also increasingly reflected.

From a technical perspective, WIMP interface used "desktop" metaphor which restricted the human-computer interaction; imbalance of computer input/output bandwidth; complex operation grammar and the small-screen effect; used the ordinal dialogue mode; only supported precise and discrete input; can not handle simultaneous operation; can not use the auditory and tactile; all of these make it clear that WIMP interface is unable to adapt to pervasive computing.

Since the 1990s, researchers proposed the idea of next-generation user interface. As one of the main forms of interface, three-dimensional user interface is attaches importance for its natural, intuitive features. The increase of the dimensions brings about a qualitative change to the user interface, as shown in Fig. 1.

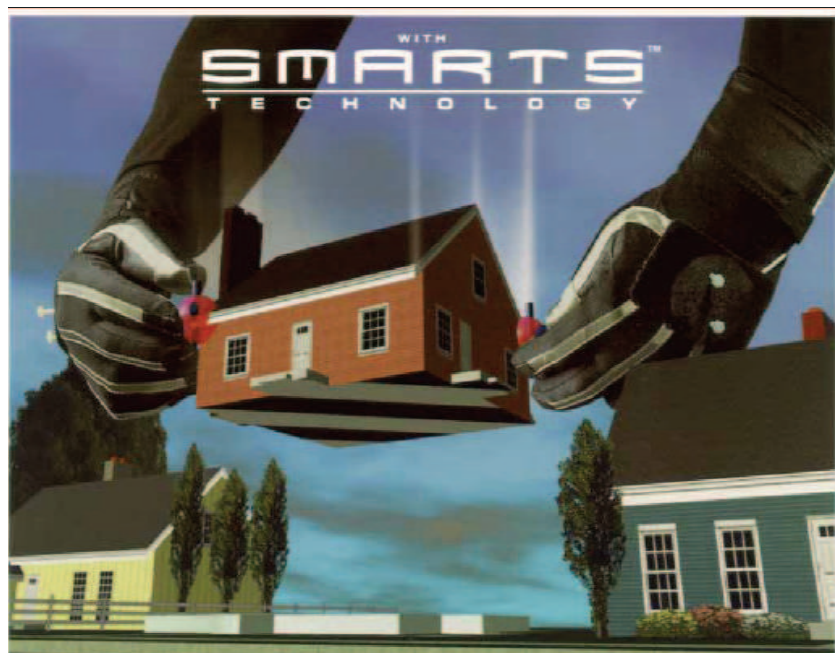


Figure 1. 3D UI

User interface can transform the user's behavior and state into an expression that computer can understand and operate, and then transform the computer's behavior and state into an expression a user can understand and operation. The three-dimensional user interface is a human-computer interaction that users can directly carry out the tasks in the 3D space. Its visual angle is like a free camera angle lens, which users can self-control the direction of visual angle.

3D virtual environment is a new human-computer interaction, using this mode the user can enter to a cyber space that virtually unlimited, and interacting with inner objects in a natural harmony way. This cyber space can describe things existing in the real world (that is, "real things to virtual"). It can also describe the things that entirely imaged or things that existing in the real word but people can not touch (that is, "virtual things to real"). It may also known as virtual reality environment.

3D virtual environment system has three features which are Immersion, Interaction and Involvement, which is called 3I characteristics.

The current 3D virtual environment system included: Desktop, Half-physical, Visual Immersion, Augment Reality, and Distributed Virtual Environment, in Fig. 2. Shown.

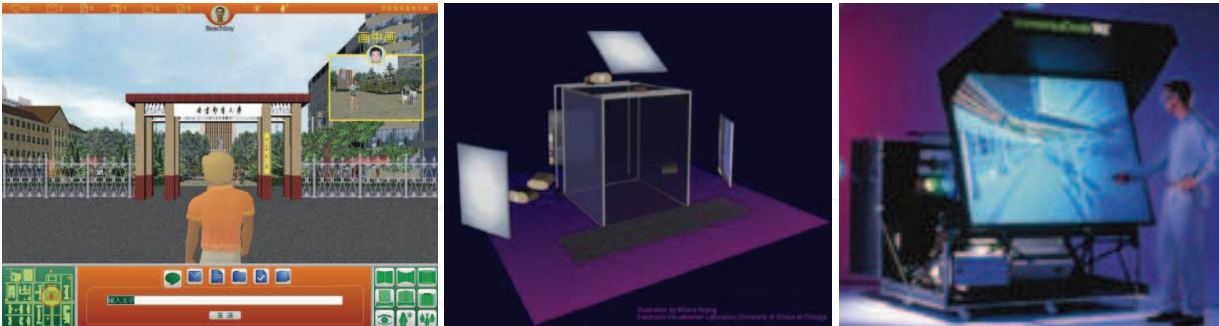


Figure 2. 3D Virtual Environments

These systems not only need the technology of viewpoint transform, but also need the system control technology of choice, move, rotate of objects. These systems can not become a mainstream application because of the immature of peripheral hardware, the naturalness of interactive technology and lower usability of these systems. The three-dimensional user interface under the desktop environment is more mature.

1.1.2 Advantages and disadvantages of 3D UI

3D UI does not replace the traditional 2D graphical user interface paradigm, but solves the poor performance of the traditional mode in interaction. Compared with the 2D interface its advantages are as follows:

- Scenario context

3D scenario enhanced the users' comprehensive capabilities of dealing with information, including awareness, perception, learning and memory.

- Information architecture and layout

3D UI provides a new space for the organizing, bearing, showing a more complex information. More importantly, with the trend of the high-capacity and high complexity of the future industrial information platform, there is an urgent need for a new interface presentation, which can not only carry information, can also performance the relationships and differences between different types of information. 3D UI shows great potential in this area.

- Information visualization

3D information visualization makes information shows more directly and more easily to understanding. In essence, graphics and representation can make the users easier to understand and identify the information.

- Interaction Experience

On one hand, 3D interaction can introduce many more natural and rich actions in the real world to traditional human-computer interaction; On the other hand it can show a more attractive new interactive way through breaking the world restrictions.

However, 3D UI also has some own shortcomings which is inevitable, such as got lost in a complex map in the 3D scenario which can bring disorientation, spending more time to learn the navigation, slow study being the cost of rich visual experience, and s unable to get the users' desired view.

- Offer new different structures

3D seems to provide the possibility for representing many dimensions of information and meta-information in a compact way and various structure (3D Navigation).

- Do something which 2D couldn't realize

3D structure / environment are helpful for certain tasks. So we have to explore the best place 3D used in.

3D UI's characteristics inherent present us with new challenges. So far, there has not been summed up a 3D fixed interface paradigm similar to WIMP. On the other hand, 3D UI related to many other subjects such as cognitive psychology, human-computer ergonomics, and so on. And the study of perception and psychological mechanism of processing is not yet mature which also limits the 3D UI research in a certain extent. Although we are living in a three-dimensional space, but in reality the rich three-dimensional objects clues such as the space layout, the human feelings, physical restraint and so on, have not been a unified expression. The existence of these problems gives many challenges to 3D UI research.

1.2 The Content of 3D UI Research

1.2.1 Related Research Fields of 3D UI

3D user interface related to cognitive psychology, human-computer ergonomics, and other disciplines of study. But the research of the perception and mechanism of psychological processing is not yet ripe, and it limited the 3D user interface research to some extent. Although we are living in a three-dimensional space, but the rich three-dimensional cues in reality, such as the objects space layout, the human body feelings, physical restraint and so on, do not have a unified expression.

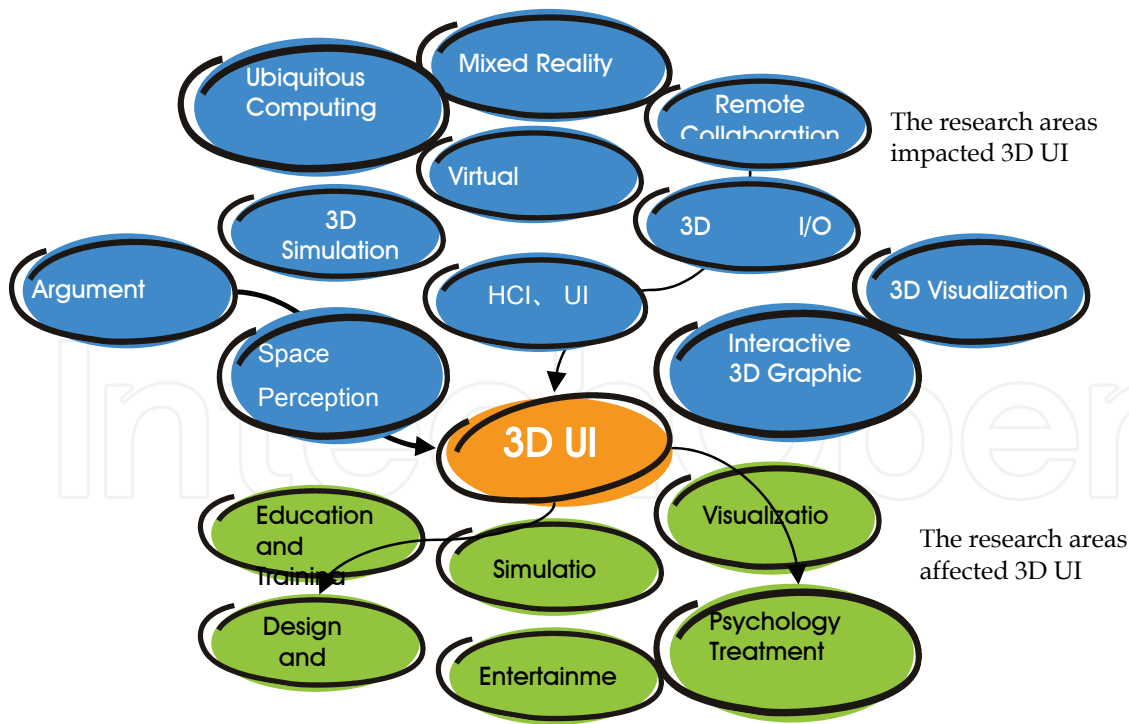


Figure 3. Related Research Fields of 3D UI

3D user interface is an intersecting research area related to multi-disciplinary, it is impacted by many research area, such as space perception, cognitive psychology. And at the same time, it also affected many research areas, such as information visualization, entertainment

and education training, etc. The relationship between these parts and the related research areas can be shown by Fig. 3:

1.2.2 The content of 3D UI

3D UI can be studied from two aspects: Technology Elements of 3D UI and Design Elements of 3D UI.

(1) Technology Elements of 3D UI include: Human Factor, 3D Interaction Technique and 3D I/O Device. As shown in Fig. 4:

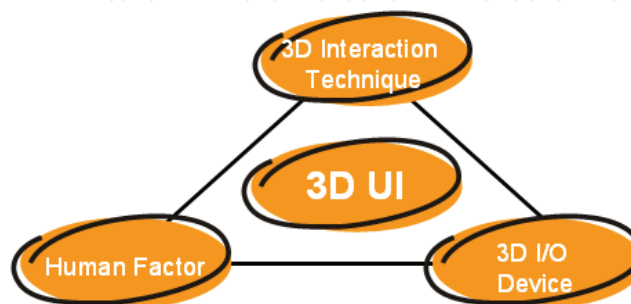


Figure 4. Technology Elements of 3D UI

Human factor mainly studied on visual perception and 3D depth cues, human spatial capabilities and the differences of individual ability, structure spatial knowledge of 3D environment, sound perception of space, manually picking and dragging characteristics, behavior cognitive planning, on-site and other aspects. Among all aspects above, on-site is a phenomenon which has been done a large number of exploration but not yet understand entirely, it was assumed that has a certain effect to the space knowledge. This means that the stronger on-site users were feeling in the virtual world, the more effective his search path done. Many factors affect the on-site feeling, such as the sense of immersion.

3D Interaction Technique mainly researched on navigation, selection and operation, system control. The navigation is mostly about on physical movement technology, driving skills, path planning, and the technology based on the destination, spatial knowledge, procedural knowledge, global knowledge, user-centered path searching and environment centered path searching. Selection and operation researched on pointing technology, virtual hand, world miniaturize technology, 3D desktop operation technique. System Control mainly include the adjusted 2D menu, 1 DOF menu, TULIP menu and 3D Widgets.

Input devices include the mechanical input devices, electronic input devices, optical input devices, voice input devices, inertial input devices and omnibus input devices. It has six aspects of usability problems: speed, accuracy, ease of learning, fatigue, cooperation, sustained and obtained of devices. Output devices include visual output devices, image output devices and mixed-output devices.

□2□Design Elements of 3D UI include 3D Scenario, 3D Widget and Interaction Devices. As shown in Fig. 5:

Relative with the traditional 2D system, 3D interface use its own three-dimensional scenes, it allows the users live in a shared virtual environment by the incarnation, it provides users the channels to understanding others, communicating and cooperating with them, and provides a context environment with different type of sharing object. 3D Widget is a conception extended meaning from 2D graphical user interface, similar to the button and icon in WIMP, the main purpose is to assist users finish complex tasks with low degree of

freedom devices, user will be able to transform objects freely by indirect operating widget using mouse. 3D Widget is frequently used to data accessing of entity, such as zoom, rotate, stretch, and so on. Since the degree of freedom of one Widget is limited, so it also was known as limited manipulation technology. Excessive use of widget will occupy the screen space, and require users to remember the mapping relationship of each Widget at the same time, so it is commonly used in desktop environment of 3D interaction.

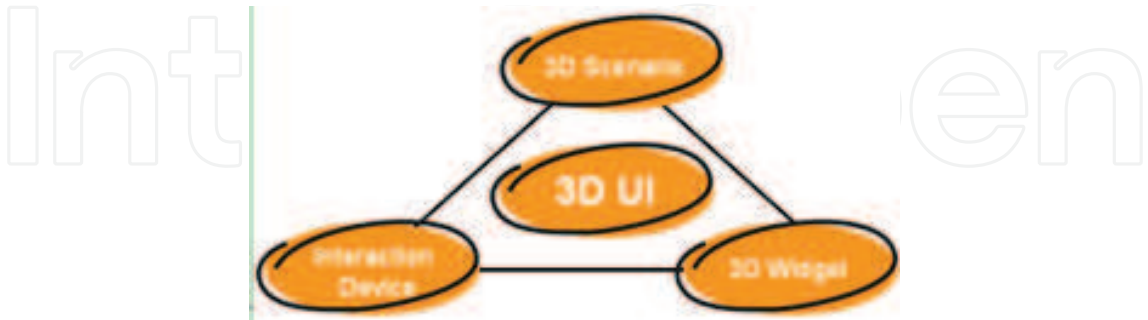


Figure 5. Design Elements of 3D UI

1.3 Application of 3D UI

Along with the improvement advance and falling price of hardware, the demand of application is increased, 3D UI gradually penetrate into lots areas of application. From the beginning of the data browsing to the interactive design, from the massive information visualization to the immersive entertainment, from military to civil parts, the extension and maturity of an increasing number of application system makes people aware the superiority and huge market potential of 3D interface. Overall, we can divide the application to several areas followed: simulation shows, real-world metaphors and 2.5D UI adapted from 2D.

(1) Simulation Shows



Figure 6. Simulation Shows

As shown in Fig. 6, the simulation shows have a typical application in simulation systems, PC games such as Sims™, prototype construction, etc. The main feature is that users have been known how to use the interface from their Day-to-day experience of life, so the time spend on interface learning is the least.

In the field of product design, the use of simulation shows is able to let the multi-designer self participate in the product design process, carry on the virtual assembly and virtual test, so it can save both time and costs.

The goal of simulation shows is to promote the intercommunions and cooperative works. Through the intercommunion, can promote the work flow, personnel arrangement, resource information optimization; provide more natural and interesting operant behavior.

(2) Real-World Metaphors

The use of real-world metaphors is shown in Fig. 7. The typical application of this area is 3D desktop management system, its main feature is that the whole area of human activity can inspire and guide the design of 3D UI.

For example, the construction and the virtual world are based on the shape and style of the arranged and organized space, thus the principles of architectural design can be transferred to the 3D UI designing. In some 3D desktop management system, some elements of architectural are used, such as the wall, desktop, they allowed users to obtain the operation knowledge quickly.

Metaphor is just a starting point, the interactive technique based on metaphor must be designed carefully, to match the application demand and the restriction of the interactive techniques.



Figure 7. Real-World Metaphors

(3) 2.5D UI

2.5 D has a typical application in real-time strategy games, as shown in Fig. 8. The main feature is that the well mode of interactive had been established in 2D interface, can make the 3D interface design easier to find suitable interactive technology; learning process can also become the shortest. The interactive in 2D is obviously easier than in 3D, users just have to operate 2 degree of freedom but not 6, so 2D interactive can let users carry on some tasks with a higher accuracy (such as selection, operation).

We can apprehend the 2.5D UI as a limited 3D UI, the interface objects is three-dimensional, but they all “grow” on one plane. 2.5D user interface is a transitional stage between 2D GUI and 3D UI, it is an imitated 3D interface display mode, appeared with the progress of the game three-dimensional technique. The visual angle is no longer the overlook or side-view as traditional 2D view, but fixed the user’s perspective at a certain angle in the air (it’s usually the

axonometric view), so it can present a virtual 3D effect. But this is only a visual on 3D, because our visual angle fixed at the certain angle, so we can just move on a plane or zoom the view range, but never see the other sides of these object on the screen. It is just like you paint a jar on canvas, but no matter it looks like a true one, you will never see the back of this jar.

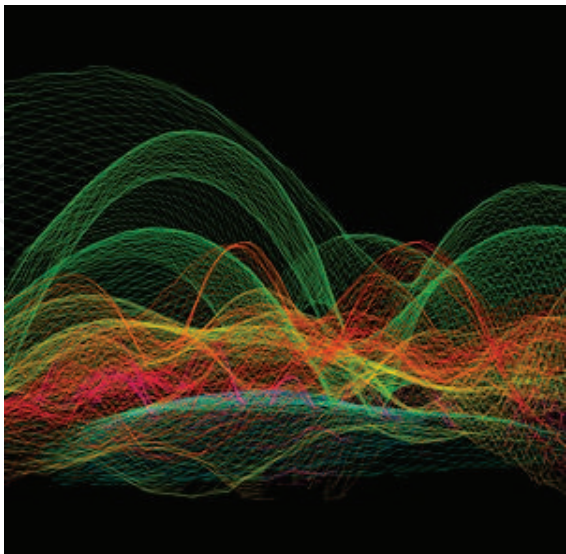


Figure 8. 2.5D

2.5D UI at such a preceding position connects link 2D and 3D, it put forward an innovative integration strategy on all levels of cognitive perspective, interactive and information expression.

(4) Developing visualization information

Today there are various sophisticated methods to locate sound, but known visualizations still strongly remind of thermographic images. Acoustic shapes, unlike thermographic ones, differ from the contour of the measured object. Image overlays make it even more difficult to read and compare the results. The diploma thesis “Digital Acoustic Cartography” is an interactive experiment in mapping sonic events into a concrete visual language. Source material for the visualizations are image sequences recorded by the “acoustic camera”, developed by GFaI, Berlin. Both, acoustic and photographic images are analyzed by processing. The color spectrum of the acoustic images is used as distortion matrix to warp the original picture into a three-dimensional relief. The color code is replaced by the photographic data.



NaturalHazards.info is an information-graphic elaboration of the topic of natural disasters – a java-applet. Here, place markers (cubes) of great natural disasters are arranged in space

according to geographic and temporal location. They can change in colour and size according to their figures. The user can navigate in space freely, head for individual cubes and continents and get textual information. Further functions include an individual filter as well as a map of the world which can be moved in time. The result is a readable reflection of the facts changeable interactively.



2. Theories and Principles of 3D UI Design

This section explained some theoretical knowledge such as the depth cues, and reaction time, dynamic Vision domain based on the principle of the space perception, spatial cognition and behavior. And it also introduced design concept of “Bottom—Up User Experience”, and scenario-based user behavior model—GSOME. Eventually we conclude valuable principles and guidelines about screen layout, navigation, selection, feedback and etc. All of this will guide the design of 3D UI systems.

2.1 Introduction

Any of 3D UI needs export information to users through output devices. They provided information to use's one or more sensory organ through the user's perceptual system. Most of these were used to stimulate vision, auditory and tactile; a few can stimulate the sense of smell and taste. This part mainly mentioned the devices based on the Vision. How can the computer's digital content change into the information that users can understand? It mainly depends on the perception of the human eyes. Understanding of three-dimensional imaging in the human eye and static/dynamic visual characteristics contributes to the 3D UI design.

2.1.1 Depth cues

Users need to understand the structure of 3D UI scenario, particularly the visual depth. Depth information can help users interact with 3D applications, in particular to manipulation, navigation and system control in 3D system. The visual system extracts 3D information using many depth cues provided by visual devices.

Three-dimensional visual is the three-dimensional sense when observed objects, that is, the human eye has the depth perception ability of the objects. The perception about the distance and depth is called depth perception, also known as distance perception. It includes absolute distance (the distance between observers and objects) and relative distance (the distance

between two objects or the distance between different parts of one object). It is very important for judging the spatial relationships between objects. Perception depth comes from the external environment extracted from the human eye and depth of the many Depth Cues extracted from internal body. In the visual, these cues can be divided into monocular and binocular clues cues.

(1) Monocular Cues

Monocular cues are the cues that are provided by only one eye. Monocular cues are mainly static, such as the environment and the physical characteristics or phenomena of objects. It also included some sportive cues of one eye. In painting, the pictures can show 3D stereo effect in the two-dimensional plane by using of static monocular cues. So Monocular Cues is also known as graphic cues.

Monocular static cues include:

Size. If the distances between the user and the objects are different, it will form different size images on the retina.

Obscured. If an object is obscured by another object, the obscuring object looks near to us, the other one looks far more.

Perspective. There are two objects having the same size. The perspective on the proportion of the object which is near to us is large, the video also big; vice versa. In railways you can see that, the two tracks near the distance between the two rails near to us are broad, far narrower.

Air Perspective. As the effect of blue-grey color air, when we look at distant objects, we will feel that, the more far from us, the less details we can see, such as more blurred and the color more light. The disintegration phenomena that appear in details, shape and color is known as the air perspective. According to such cues people can also guess the distance between the object and us.

Light and Shadow. We live in a world of light and shadow. Darkness and shadow look more far from us; but bright and high-light part look near to us. In the arts of painting, the part far from us uses dark colors, and the part near to us uses vivid color. This method can create the sense of distance and three-dimensional effect.

Relatively High. If other conditions are equal, the object relatively higher looks far more.

Texture Gradient. It means the projection size and projection density of the objects in the retina change orderly. According to texture gradient in the retina change, the small and dense objects are far from us, and large and infrequent objects are relatively close.

Monocular Movement-Produced cues:

When the observers have a relative movement of the surrounding objects, far and near objects will have a difference of velocity and direction. The mainly character is motion parallax.

Motion parallax is caused by the relative movement between the viewer and object. Such movement changes the size and location of object show on the retina, to bring a sense of depth.

When the objects with different distance have different motion range on the retina at the same time, motion parallax is engendered. Once rotating head slightly, the relationship between vision and objects has changed the activities of head and body caused the changes.

When we watched the scene through window on a move forward train, the poles nearby go backward rapidly, some of the remote fields, buildings moved backward more slowly. The difference of velocity among the objects in view, is an important indicator to estimate the relative distance of them.

(2) Binocular Cues

Binocular depth cues are referred to the depth cues provided by binocular vision. Although monocular cues can provide people lots of depth cues, help people to finish the operation

tasks with the visual guidance. However, some depth information must be provided by both eyes.

Binocular Parallax

Since the existence of two eye space between (average being 6.5cm), the two eyes look the object from different perspective actually, the line of sight has a bit different. So for the same object, the relative position of eyes is different, which caused the binocular parallax, that is, the image in each eye is different. The binocular depth cues is changing with the distance increasing, when the distance over 1,300 m, as visual axis parallel, binocular parallax become zero, so it will not work to the distance judgement.

Oculomotor Cues

Accommodation is the eye initiative focusing action. The focus can be accurate adjustive by the crystal body. The adjustment of crystal body is realized by the muscle working, so the feedback of muscle move information helped the three-dimensional sense establishment.

Convergence is that the visual axis gathered to the regarded object with the distance changing. Convergence is a binocular function, to get a clear video.

2.1.2 Vision and Reaction Time

(1) Vision Feature

Human beings obtained at least 80 percent of the important information of outside world by vision, such as size, brightness, color, movement, which is the most important feeling. After years of experiments, we know that the process of human visual perception has the following feature:

When we observe objects, the visual line are conditioned to the path from left to right, top to bottom and clockwise movement; eye movement in the horizontal direction priority in vertical direction, the estimated of horizontal direction size and proportion is accurate and rapid than the vertical direction.

When the observation of objects deviation from centre in the same conditions, the sequence of observation is: the left upper quadrant is optimal, and then are the right upper quadrant, the left lower quadrant, and the worst is the right lower quadrant.

There is a relationship between color contrast and the human eye capacity for differentiating colors. When people distinguish a variety of different colors from afar, the extent of how easily identifying is followed by red, green, yellow and white. The two-color match case is, black on the yellow background, white on the black, white on the blue, black on the white, and so on.

(2) Reaction time

Reaction time is the elapsed time between the presentation of a sensory stimulus and the subsequent behavioral response. First the stimulation act on sensory, aroused the excitation, then the excitation spread to the brain and processed, and next it spread through the channel to the locomotor organ, locomotor bioreactor receive nerve impulses, produce a certain reaction, this process can be measured with time that is the reaction time.

F.C.Donders had divided the reaction time into three categories, simple reaction time, choice reaction time and discriminative reaction time. Simple reaction time is usually defined as the time required for an observer to detect the presence of a stimulus. Choice reaction time tasks require distinct responses for each possible class of stimulus. Discriminative reaction time is usually stimulate more than one, but only asked for one stimulus to act a fixed response, and others didn't reaction. The factor impact on the reaction

time is in four areas, respectively: stimulated sensory organ, the intensity of stimulation, the time and space characteristic of stimulation, last one is the adaptation state of organ.

2.1.3 Motion Vision

The photoreceptor cell of human eye need a course of time, to identify the signal showed on the retina since imaging. When the view point moving, the objects image show on the retina would also move with a certain angular velocity. When the objects move slowly, it can be accurately identified, but if the speed to a certain extent, people would not accurately distinguish the objects.

The visual feature have a lot of difference between the observation of moving objects and static objects, the mainly aspects is the following areas: visual acuity, visual field, space identify range. And the visual acuity is acuteness or clearness of vision, especially form vision, which is dependent on the sharpness of the retinal focus within the eye and the sensitivity of the interpretative of the interpretative faculty of the brain. The visual field is the space or range within which objects are visible to the immobile eyes at a given time. The space identify range is the ability of identification, such as the size of object, the motion state and the spatial distance. For the moving object, the shorter distance it off observer, the bigger angular velocity it got, the more difficult to distinguish it clearly. And the impact factor of motion vision concluding the relative velocity, age, the color and intensity of the target, and so on.

2.2 3D UI Interactive Principles

2.2.1 Hierarchical Semantic model of “UE”

User experience is widely affecting all aspects of the user’s experience when they using a product (or a service). It refers to users’ pure subjective psychological experiences. UE in 3D UI is more important than in 2D UI. The designer should meet the users’ spirit needs after the psychological needs by effective design strategy. UE mainly come from the interactive process of 3D UI. The purposes of visual design about the 3D UI is to convey some information to attract users. Visual means can improve the quality of experiments. Shneiderman and Nielsen, two research pioneers of HCI domain, respectively conclude design goals of interactive systems from the consideration of user interface design and usability engineering (e.g., see Table 1).

No.	Ben Shneiderman	Jakob Nielsen
①	Learning Time	Learn ability
②	Executing Time	Efficiency
③	User Retention	Memo ability
④	Error Rate	Errors
⑤	Subjective Satisfaction	Satisfaction

Table 1. Interactive System Design Goal

Actually, user experience may be influenced by all these factors above. Experience is the result of interaction between human and artifact (or other creature) in specific context and accommodated by intrinsic、 psychological and individual surroundings which is

composed of motivation, experience, habitude and a variety of cognitive factor. In order to measure user experience's level and compare it with different kinds of interactive system, a new concept---EQ (Enjoyment Quality) is introduced and a hierarchical semantic differential model based on EQ is established (e.g., see Fig. 9).

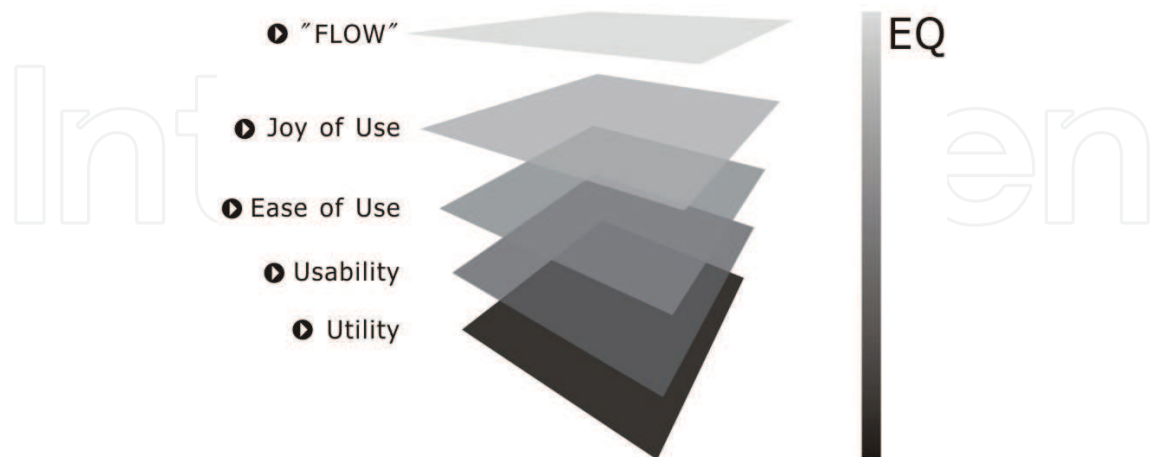


Figure 9. Semantic Differential Model for Measuring "User Experience"

In this model, we utilize five HCI glossaries "Utility", "Usability", "Ease of Use", "Joy of Use" and "the Phenomena of FLOW" to describe user experience, in which the semantic differential is able to represent different level of EQ. Although its scientificness is yet being further proved, the model is able to indicate orientation of user experience in different systems.

With regard to "different systems", we further divide interactive systems into three groups by referring to Shneiderman's theory: key system, everyday application, and computer games. Obviously, computer games are the most representative one.

- Key system

The application of key system includes transportation control, nuclear reactor system, and military operation and so on. Their chief design goal is "Utility". In order to ensure that operators under high pressure manage to operate quickly with no errors, long time training is always necessary. In fact, adding some hedonic factors to these systems may seriously affects the system performance on its reliability and stability, so such issues are supposed to be taken into prudent consideration

- Everyday application

Everyday application includes industrial and commercial application, office application, and home application. Disordered display, complicated and stuffy operation process, incomplete function, inconsistent task sequence, and inadequate feedback information can be seen here and there [3], so "Usability" and "Ease of Use" are emphasized repeatedly.

Benefiting from the twenty years' development with usability engineering, such problems are being paid attention to and being gradually solved efficiently. The design goal of this group is moving: Usability has become an acknowledged quality aspect of a wide variety of technical products, ranging from software to washing machines. However it recently acquired a new associate, the so-called "Joy of Use". Enhances the non-entertainment system the user experience already is the information system design important idea.

2.2.2 Cognitive Scenario-based GSOMS interactional model

A group of influential theorists at Carnegie Mellon University take the views that decompose the user behavior into small acts of measurable steps to analyze layer by layer. They propose an important model: the goals, operators, methods and selection rules. The GOMS model assumes that users begin with forming the goal (edit documents) and the sub target, and then achieve each goal through methods and process (for example move the cursor to destination through a combination of the cursor key). The change of the user's mental state or the task environment should executive the operator, which includes basic sense, movement and cognition action. Selection rules select one control structure from several optional methods to achieve a goal (for example deletes repeat by the backspace key or deletes the select region by delete button).



Figure 10. Cognitive-Based Interaction Model

3D UI adopt mission analysis to describe users' behavior of each step, including identifying task, cognizing scenario, executing action, perceiving feedback, evaluating result. User's cognitive scenario decides the users' behavior. Obviously, this is where the GSOMS come out, although the original GOMS brought up by Card was once considered as the most successful user behavior model. However, if this model is applied in a tri-dimensional environment, for example, because one feature of tri-dimensional environment is "Scenario", some demerits will appear in the 3D computer games. According to Norman, "The basic challenge which people in different areas faced is the output of knowledge, rather than reproduction (copy) knowledge." Scenario is the extremely effective channel for user to form comprehensive cognition of environment, so scenario-based user interface could help user perform exact, reasonable, habitual operation. And the non-entertainment system is out of scenario and convey with symbols. It values the knowledge that is far away from the real situation, which brings difficulties to cognitive. Recently the cognitive scenario has become a theory based on study, which provide meaningful study and promote the knowledge transform to real life. Therefore, it is very necessary to extend the GOMS model into GSOMS

(the Goal, Scenarios, Operators, Methods and Selection rules) model. The interactive model of tri-dimensional information system is based on the users' scenario behavior process (e.g., see Fig. 10).

2.2.3 Screen Layout for Information Minimization

Designer should focus on the layout of the interface to consider the arrangements in the 3D UI, in order to achieve information minimization. We will analyze it from psychology, interactive design, information display and other aspects. In the tri-dimensional environment, users' task is very complicate, from objects accurate movement to the overall situation control. The system offers highly effective resolution, including user behavior process, the design metaphors of the task, information minimization and immediate feedback effect.

3D UI, as a complex system, consists of numerous elements. And more and more information and data user needed to be dealt with appears. Therefore, interactive design should adopt a screen layout with compact and distinct information classification (e.g., see Fig. 11).

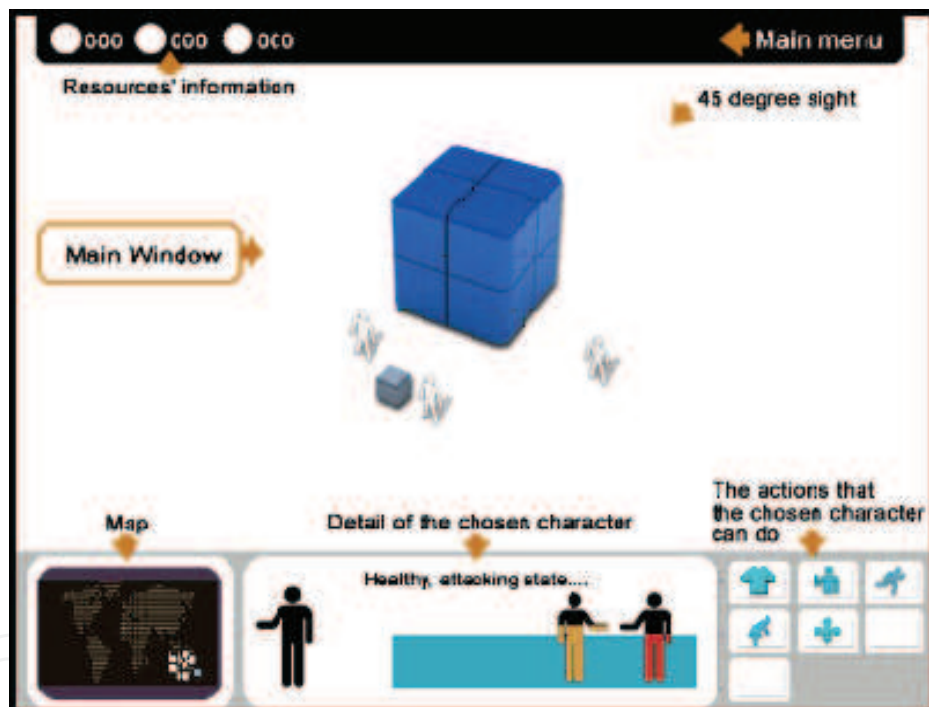


Figure 11. Screen Layout

The screen consists of three parts that are always visible: "Top", "Main Window", and "Bottom".

- Top

The top tool bar includes the scene property of the users, time icon, and so on. Here to provide users for the state and the information directly, so that users can gain the information in need during the shortest time.

- Main Window

The main window shows the detail information with maximum screen. It always shows as god view, and the objects show as rich-information (form, size, shadow, texture, lights and so on). It is called Isometric Projection.

- Bottom

The bottom is the navigation area, including the map navigation, the movement navigation and so on. The narrow sense navigation information refers to the geography object the positional information, the generalized navigation also should include other function readout which the system provided. In the large-scale 3D scene, Navigation is very significant, by which users know their location and the way to arrive the target area. There is a navigation map of a 3D game, as shown in Fig. 12. On the one hand it distinguishes different camps and terrain information through different colors, on the other hand, it reflects the important events through graphical animation. These embody the landmark knowledge, road knowledge and overall knowledge, and the combination of overall navigation and process navigation is another strategy of human-computer interaction.



Figure 12. Navigation Map

Different is in the 3D contact surface needs to unify the concrete mission requirement with the traditional 2D contact surface to carry on the dynamic operation, and to pay the territory the attention to be extremely intense. When basis operation the field of vision region gaze spatial frequency distribution, the gaze the duration, the gaze assigns target and so on sequence, level and vertical glance path scope and number of times examines the appraisal, this kind of three surface layout reasonable has manifested the dynamic sight/attention territory assignment, and is advantageous for the operation.

3. 3D UI interactive technical analysis

This part discussed the interactive technology which is used in most common 3D interactive task. It clearly expounded the basic elements of 3D UI: Manipulation, Navigation and System Control, and the following is arranged in accordance with the user's interactive mission analysis.

3.1 Summarization of 3D UI Interactive Technology

Interactive technology is the manner that performs a specific interactive task by using interactive devices. Users can use the same type of interactive devices, and use different interactive techniques to perform an interactive task. The change of interactive devices, implement methods and algorithms produced a wide range of interactive technology which served interactive services ultimately. Bowman first sorted the existing interactive technology from the three levels which are task, sub-task, and implement technology and proposed this design method based on this classification. As shown in Fig. 13.

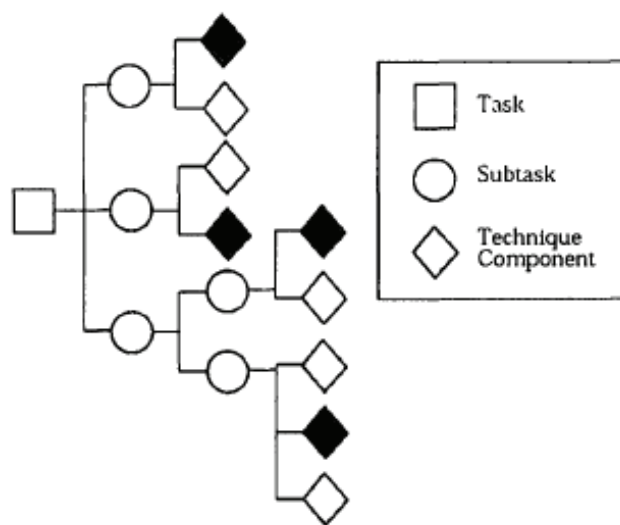


Figure 13. Classification of Bowman

Based on this classification, an interactive task is firstly divided into several sub-tasks, and each sub-task continues to be divided into smaller sub-tasks until there is an interactive technology that can complete this sub-task. These classifications mean can not only discover the affecting variables of interactive technology, but also can guide to design interactive technology. Through the combination the realization technology of different tasks we can easily find new interactive technology. Although it can not guarantee that each combination can get satisfied users' performance, it provides designers a more comprehensive design space. This method is particularly effective when interactive technology options of each sub-task are limited.

3.2 Manipulation

Choice and manipulation are one of the most fundamental tasks not only in the physical environment but also the virtual. If a user can not manipulate and choose the virtual objects effectively, many of the specific application tasks can not be implemented. People's hand is a remarkable device. It allows us to spend less intuitive sense to operate physical objects fast and accurately. The goal of studying manipulation Interface is to enhance the users' capability and comfort, and gradually narrow the impact caused by human inherent habits and hardware restrictions.

3.2.1 Introduction of the concept

Manipulation in reality usually refers to the action that people bring to the objects. In the 3D UI we restricted this action to the rigid objects, that is, the shape of the object does not

change in the course of operation, and only the status of objects is changed. This restriction is the same to the 2D UI. However, even such restrictions, technical manipulation can still have a lot of changes, such as the application goals, the size and the shape of the targets, the distance between the user and the objects, the surrounding environment and so on.

3.2.2 Task analysis

A manipulation can change the location or direction of the objects, or change the appearance (such as deformation, material changes). It is impossible to fully consider the impact of these factors in the process of designing interactive technology. We can only aim at a representative task to design. The basic assumptions of any task is that, under any case all the human needs are composed by the same basic tasks, and these basic tasks composed a more complex interaction scenes. With 3D operation decomposed into a set of basic tasks, we can make interactive technology design only for those small tasks.

According to the task subdivision of two-dimensional graphical interface, manipulation task can be divided into three sub-tasks, Selection, Positioning and Rotation. The interactive technologies of each task are restricted by a number of factors which directly affect the capability and availability of technology. For example, when selected, the choice strategy is not only decided by the size of the target, the distance between the object and the uses, but also decided by the intensity of the surrounding objects. The impact of these factors has led to further refinement of manipulation task, such as the manipulation task is divided into two sub-tasks, the range within the arm can catch up and without it. The existence of these variables constitutes a design space of interactive technology. Poupyrev called these variables task parameters, Table 2 are given the task of those parameters.

Task	Parameters
Selection	Distance and direction to target, target size, density of objects around the target, number of targets to be selected, target occlusion
Positioning	Distance and direction to initial position, Distance and direction to target position, translation distance, required precision
Rotation	Distance to target, initial orientation, amount of rotation, required precision

Table 2. Sub-Tasks and Parameters

3.2.3 Manipulation Classification

There are many relationships between 3D manipulation technologies, and they have public properties. Classification of interactive technology based on the general characteristics can help us understand the relationship between the different technologies and understand the design space of the manipulation technologies macroscopically.

Any manipulation technology can be divided into smaller technology components (Bowman 1999), such as in the choice technology, the first step is to show chosen object, and then issue to confirm instructions, finally provide the feedback when chosen, such as highlights, color changed and so on. Fig. 14 classification is based on this method. Based on

this method, we can design new interactive technologies through the combination of different technology components, and it provides a good foundation for the variables of the assessment.

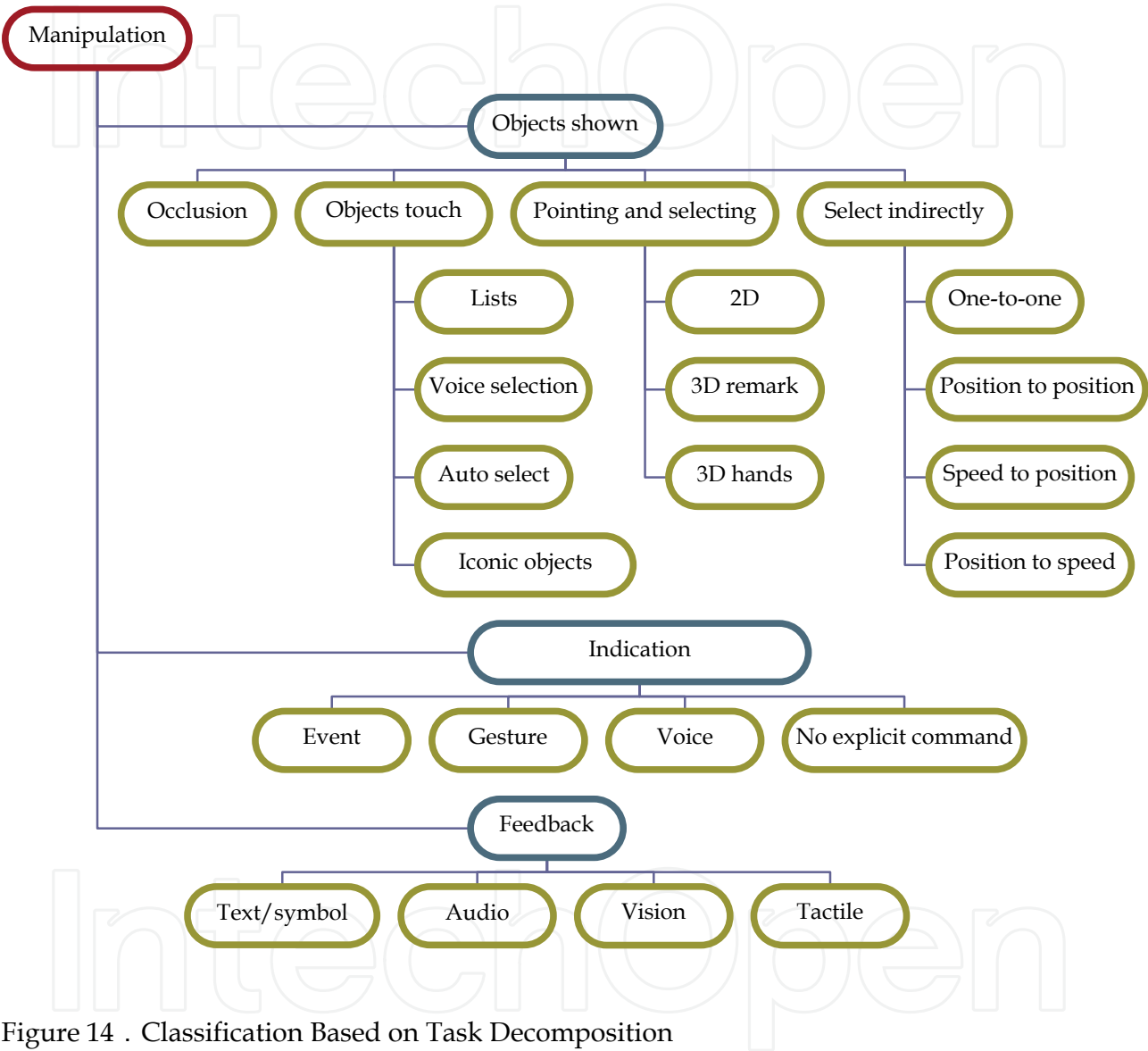


Figure 14 . Classification Based on Task Decomposition

This method based on task decomposition has the advantage that we can make the design space of interactive technology structured. The new interactive technologies are constructed by selecting the appropriate components and assembly together. Most of manipulation technologies in the virtual environment are archived by several basic interactive metaphors or the combination of these metaphors. Each of metaphors forms a basis mental model. Using of such technology users understand what they can do and what can not do. Specific technology could be regarded as the different realization of the basic metaphors.

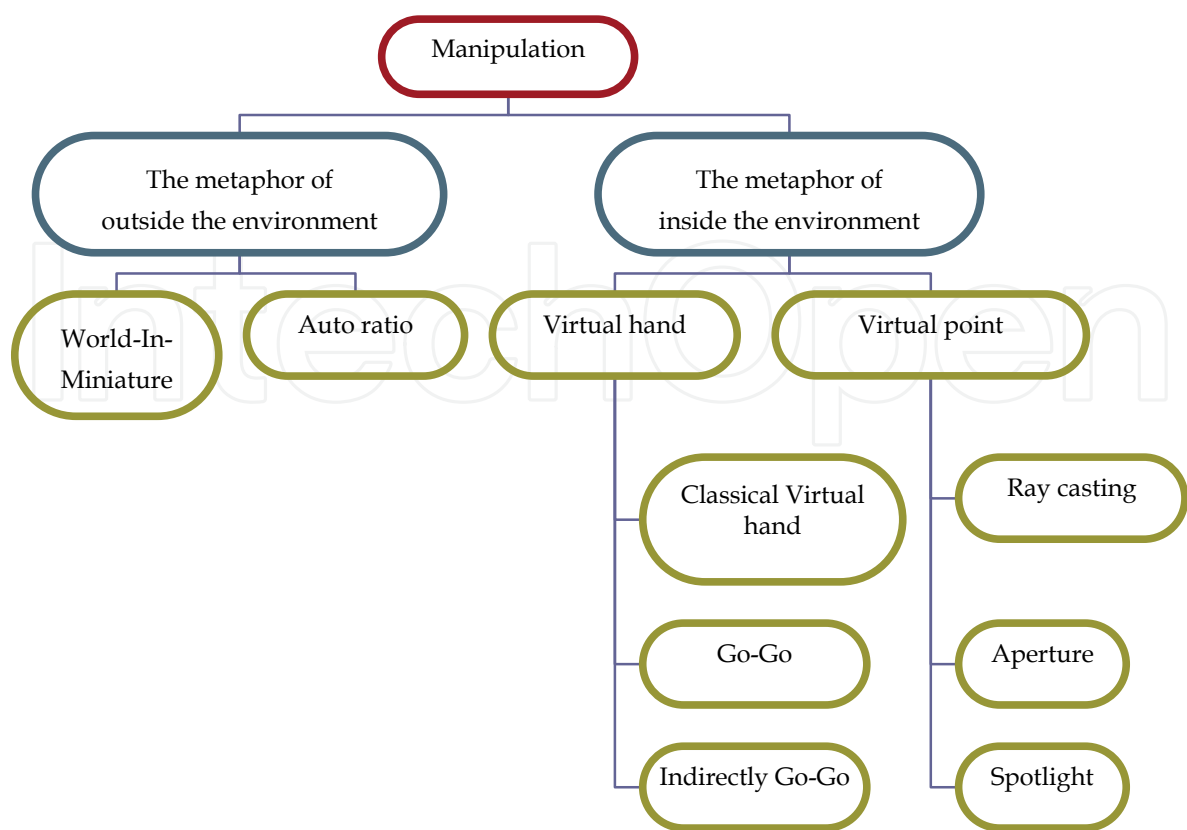


Figure 15. Classification Based on Metaphor

Fig. 15 gives a possible classification of 3D manipulation based on the metaphor in immersion virtual environment. These technologies firstly are divided into two sorts, inside and outside the environment. Classification based on the metaphor provides a readily understandable way to organize interactive technology. For the virtual hand metaphor as an example, the user touch objects through the virtual hand.

3.3 Navigation

Navigation, which is also a basic human task, is an activity in and the surrounding the environment.

3.3.1 Introduction of the concept

Navigation included exploration and path-finding. Roaming is a bottom activity that the users control location and direction of viewpoint. In the real world, Roaming is a more natural navigation task, such as the movement of feet, rotating steering wheel. In the virtual world, roaming allows users to move or rotate the viewpoint and change the speed. Path- finding is an up activity that refers to high-level thinking, planning and decision-making about users’ movement. It includes space understanding and planning tasks, such as identified the current location in 3D system, determination the path from the current location to the target location, the establishment of environmental maps. In the real world, path- finding is mainly by map, direction remarks, path signs and so on. In the virtual world, these elements can also help us find the path.

3.3.2 Task analysis

(1) Roaming

Understanding the different types of Roaming task is very important because the availability of a particular technology often relies on the implemented task. The sub-tasks of roaming are defined as: exploration, search and examination.

In the exploration task, the user does not have clear objectives. He just wants to have a general impression of the whole scene. The process can be assisted to users establish awareness of space. This technology provides the greatest degree of freedom to users. User can change the viewpoint direction and roaming speed at any time, can start and stop roaming at any time.

In the search task, users want to achieve a specific goal in the scene. It means that in this task, users know where he wants to go. But it is not sure whether the user knows how to achieve the goal.

In examination tasks, users should position perspective accurately in a limited area, and implement a small but precise specific task. The roaming technology based on this task allowed very precise movement, such as the head’s physical movement. It is efficient, accurate and natural.

task	goal
exploration	Browser environment, get location information, establishment of space knowledge
search	Goal-oriented, roam to a specific location
examination	In the local area, involving small and precise tasks

Table 3. Sub-Tasks of Roaming and Goals of Them

(2) Path-Finding

Path-Finding is a cognitive process, which defines a path through the environment and uses natural or artificial cues, achieves and uses space knowledge. We introduce three types of Path-Finding tasks which similar to roaming sub-tasks.

In the exploration task, there is no specific target in use’s mind. It helps users build cognitive map, which makes exploration more effective.

In the search task, users need not only achieve space knowledge, but also use it. The searches of known and unknown objects are all search tasks based on the objectives. The difference between them is whether users know the exact location of the objectives.

The examination task, users need to implement many small-scale movements, such as identifying a landmark from a particular perspective, or finding a very small target.

task	goal
exploration	Construction of cognitive map in the browsing process
search	Get and use space knowledge
examination	As the sub-task of search

Table 4. Sub-Tasks of Path-Finding and Goals of Them

3.3.3 Navigation Classification

(1) Classification based on the task decomposition

Like manipulation technologies, the method based on the task decomposition is a classification method which is the most detailed and affects the most variables. Navigation

can be divided into three sub-tasks: Perspective direction or control roaming objectives, control roaming speed and acceleration, control the input conditions. Based on this method, we can decompose roaming technology into the form of Fig. 16. Each task can be implemented in different interactive technology. Now most of the roaming technology can find realization technology of its sub-task from the map. We can also find combination of different technologies.

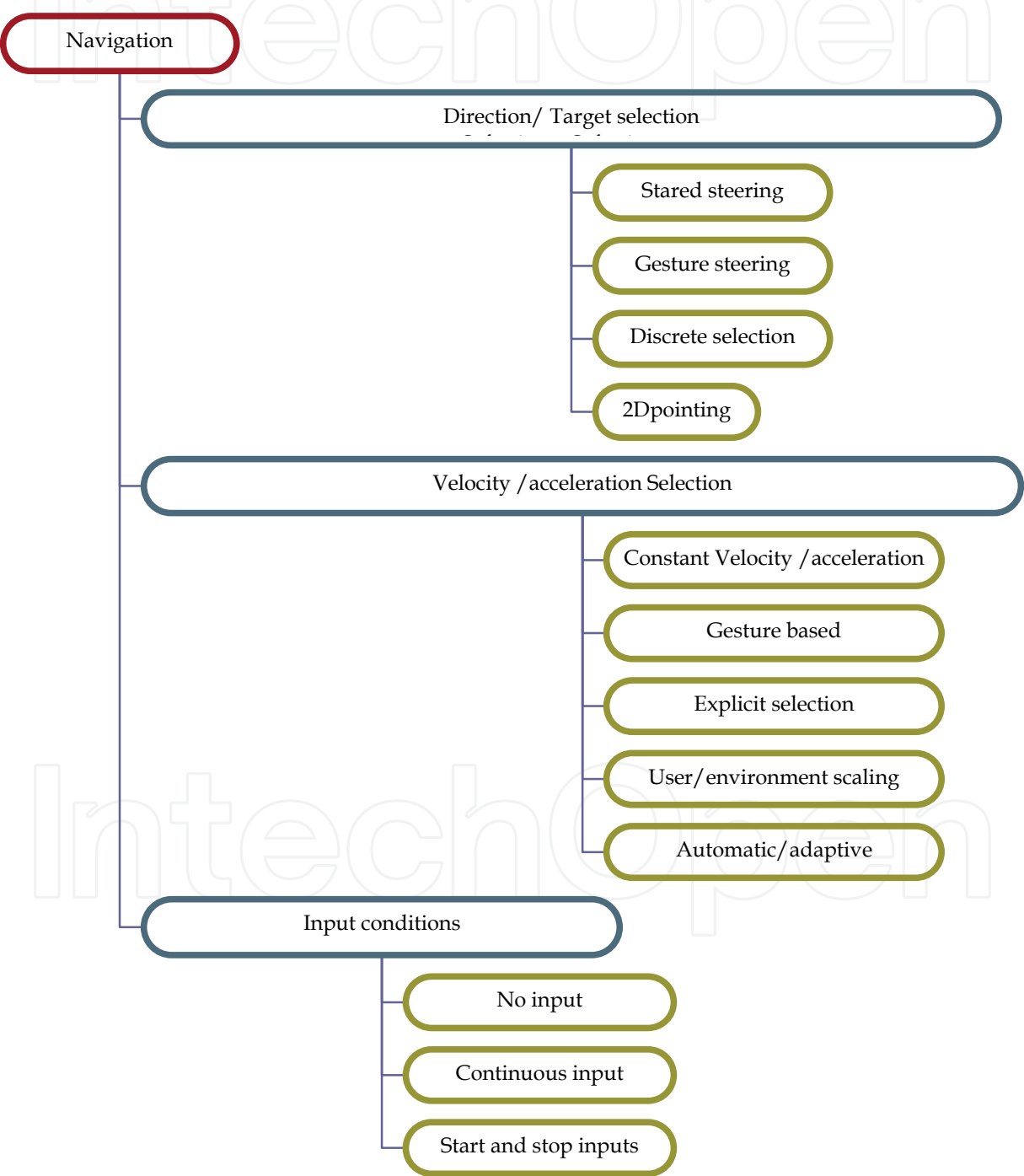


Figure 16. Classification Based on Task Decomposition

Direction or goal choice is the main sub-tasks, where users specify how or where to move. Speed or acceleration descriptions that how users control their speed. Input conditions is that how the navigation to initialize, and to terminate.

(2) Classification based on metaphor

Classification of navigation based on metaphor is easy to understand for users. For instance, if someone told you that there is a special navigation technology used "Flying blanket" as metaphor, you might infer it will allow you to move in three dimensions, and you can use of your hand's movement to drive it. Classification based on metaphor is a useful way of the design space using interactive technology. As shown in Fig. 17, navigation technology is organized through six common metaphors.

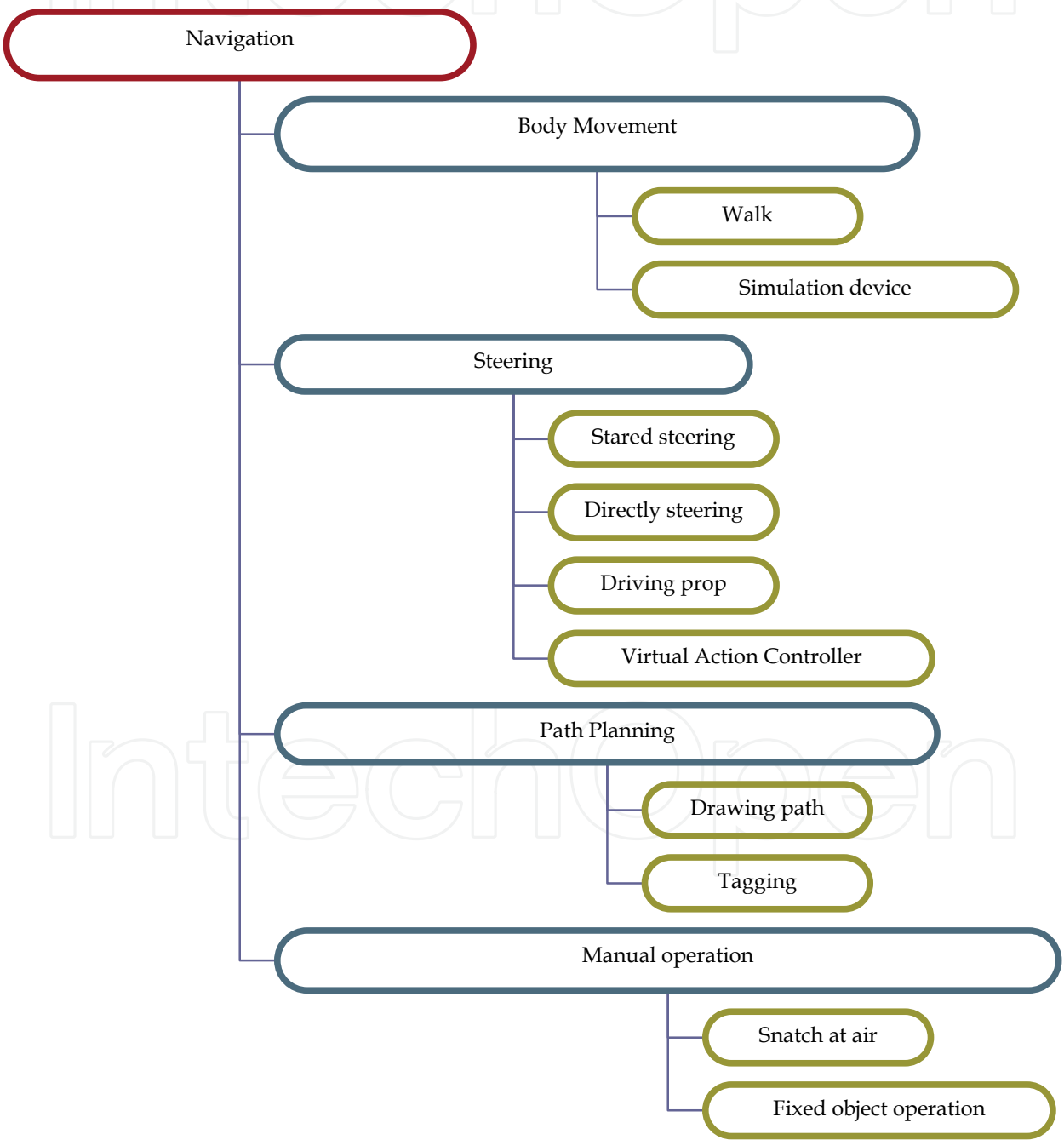


Figure 17. Classification Based on Metaphor

3.4 System Control

In 2D interface, UI elements can be seen everywhere, such as pull-up menus, toolbox, color panels, buoys, radio button and check box. All of these interface elements belong to system control, which allows us to send a command to system, or a mode change, or modify a parameter. Simple imitation 2D desktop devices are not the final solution, so we discuss 3D UI system control.

3.4.1 Introduction of the concept

Although most work in computer application makes up of choice, manipulation and symbols input, system control is still very crucial. When writing in word-processing software, the main symbol interactive input is through the keyboard to complete. These interactions interludes in many small tasks of system control, such as saving the current document through the button to, make the text underline through the shortcut key and so on.

Issued an order is an important way to access to any computer system function, and system control is a user task, which issued an order to complete certain tasks.

3.4.2 Task analysis

Control system is a user task, which issued an order to complete the following tasks:

- Request system for the implementation of a specific task.
- Change the mode of interaction.
- Change the state of the system.

In the manipulation and navigation tasks, users usually not only designate what to do, but also how to do. In the system control, users usually only need to designate what to do, and the realization of details is completed by the system. In the first task, the system has a complete independent feature, such as if user wants the text bold, he just need simply click on the text bold button. The second task is to choose a new tool from a toolbox, such as changing the pencil model for the pen mode. The third task is a click of a button that makes a window the smallest.

3.4.3 System Control Classification

Although the system control technology of 3D user interface is various, but most still use a few basic metaphor or the combination of them, the Fig. 18 is a category based on the metaphor of a control system:

The menu of 3D UI is similar with 2D. 2D menu is rewarded by success in the desktop UI system control, users are known much about it, so the 3D UI could be able to do a attempt. Its biggest advantage is that users are familiar with the style of interaction, almost every user can identify those elements of the menu immediately, and know how to use it. But on the other hand, this type of menu could be shielded by the environment, shielded the realization of users, it may trouble users when they are doing the menu search with the selection technique of 3D. For prevent the menu to shield the 3D environment, it can be designed as a semi-transparent.

The problem of voice commands can be carried out by the simple voice recognition or spoken dialogue system and means of achieving. Speech recognition is a typical application with the simple order which users sent to the system; and the spoken dialogue system concern to improve the session between users and system.

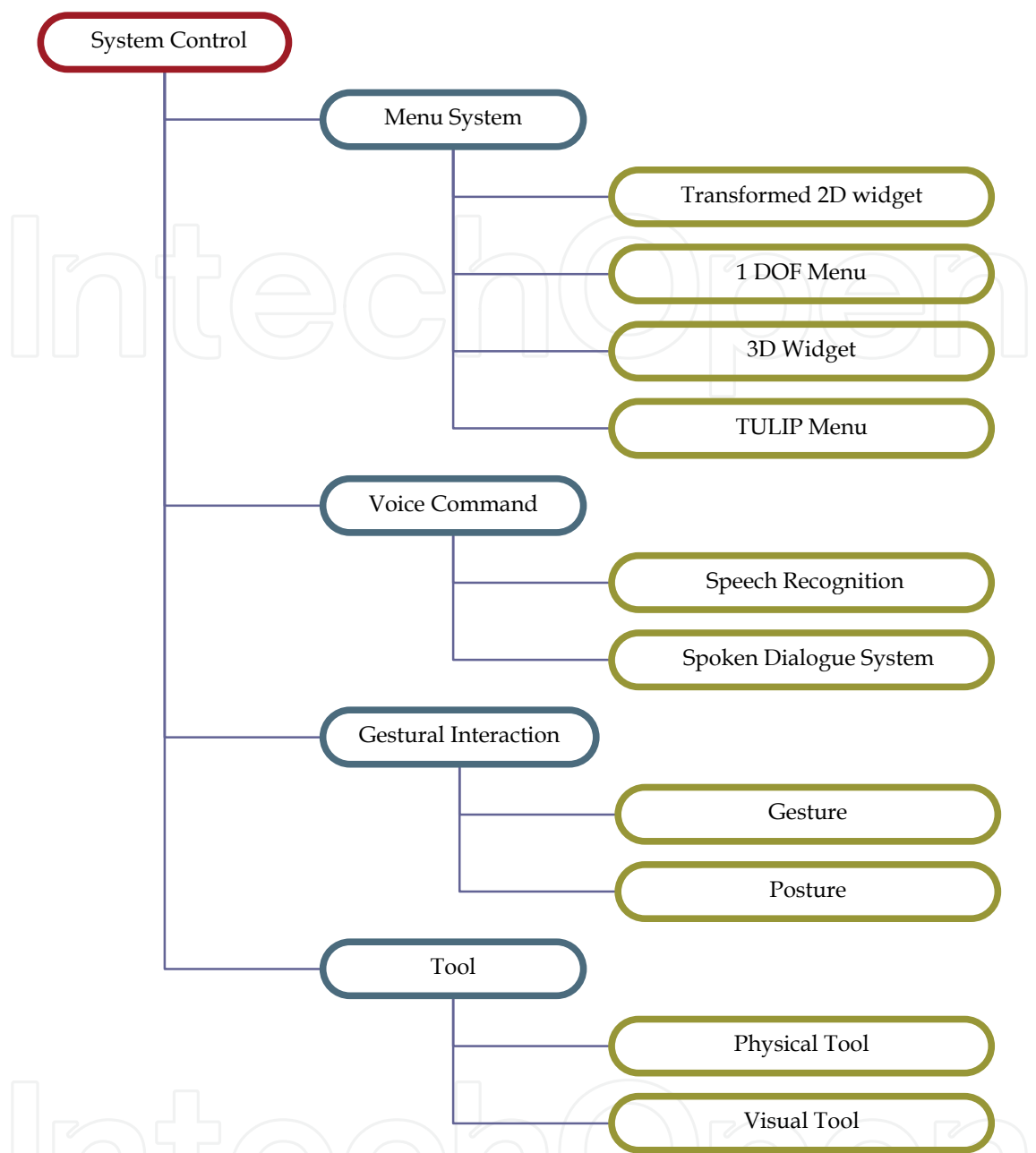


Figure 18. Classification Based on Metaphor

Gestural interaction can be divided into two categories, gesture and posture. Gesture is referred to the shape of hands, and posture is a movement of hand. For example, place the finger into a V-shaped is gesture, and the movement belongs the posture. In many 3D applications, using familiar device to make 3D interactive can improve the usability, these devices become tools, they can provide a direct interaction.

4. Case Analysis

4.1 The Analysis of Software - Rhinoceros

A special category of 3D interactive technology is the manipulation in the 2D input environment. Next part is the analysis of a 3D modeling software – Rhinoceros, the feature

of this software is mapping the manipulation of 2D mouse to the 6 degree of freedom of 3D object.

The analysis of Rhinoceros will divide to 3 parts: the system control region on top, manipulation region of left part, and the intermediate zone of information display region.

4.1.1 System Control Region

As 3D modeling software is still a software application system, it also uses the menu mode of 2D user interface. Almost all users can identify these menu elements immediately, and also understand how to use them. Fig. 19 is the menu part of rhinoceros.

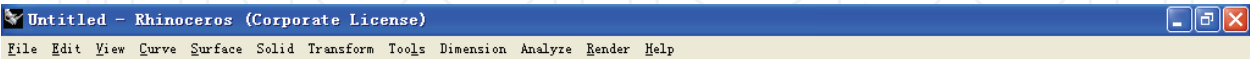


Figure 19. Menu

When in the 3D virtual environment the most simple way to ascertain the position and direction of 3D object is to ask the users, let them input the coordinate of object’s position and the angle degree of direction directly. This approach is usually used in the 3D modeling softwares and CAD softwares which need the accurate position and orientation of the designated object. It’s a very effective technique, as it can adjust the location and direction precise and incremental. Users communicate with system by text typing, such as to defining the distance of movement or the angle of rotation precisely. As show in Fig. 20, it allows users to easily input the related command in order to complete the task want to achieve. A sketchy operating could be able to carry out by a direct technique, but the last value needed to enter.

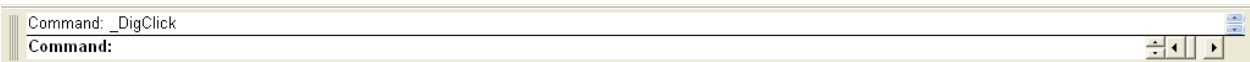


Figure 20 Input Bar

If you want to implement the control of the entire three-dimensional scenes, such as new create, save the file etc, can be convenient realized by clicking the icon on the panel as shown in the Fig. 21. The icon design intuitive understanding to meet the operational needs of users. The icons in this software are very similar with ordinary 2D software interface, so it can reduce the user's learning difficulty. In addition, there are some in common used operating icons, such as movement, rotation and zoom, all these orders have their corresponding shortcuts, which can improve the work efficiency of expert users.

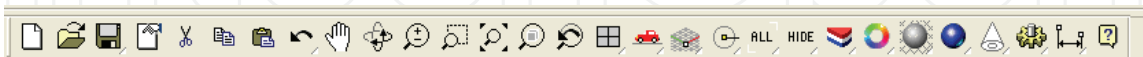


Figure 21 System Control

4.1.2 Manipulation Region :

In the 3D modeling software, some in commonly use operation orders are usually placed in the left of the screen, such as loft, extrude, and other specific orders. It is classified by the way to arrange the operating buttons with common attribute as a group, For example, the similar orders to generate a plane same – surface from 3 or 4 corner points, surface from 2,3 or 4 edge curves and others are in the same group. It’s not only simplified the interface, but also made the system have more level.



Figure 22. Modeling Operate Order

4.1.3 Information Display Region

Rhinoceros used the method of separate the orthogonal view, in each view, users can control 2 degree of freedom at the same time. And in each view in addition, user can specify the manipulation by using the mouse directly to interactive, such as zoom in, zoom out or rotate, and so on. It set up multiple perspectives on the screen, and each perspective shows the same object or scene from a different point of view. Its usually includes a vertical view, front view, side view and perspective

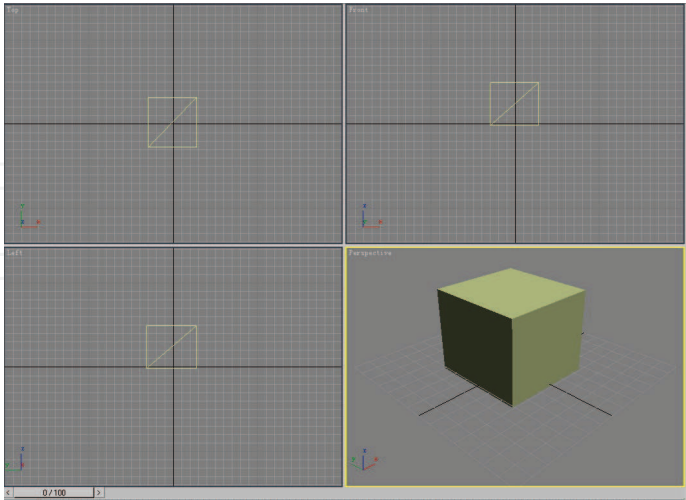


Figure 23. The Orthogonal View

The grid provides a scenario of virtual floor and walls, each axes has a baseline grid, which helps users to locate direction. When the camera view has a freedom motion, the grid will show the particularly use. And the pole is usually playing a role with the grid. When users

choose a target object, there will appear a vertical line from the center and extended to the grid. When user moved the object, the pole moves followed, but always plumbs the grid. Users can understand the position of the object they moved in 3D space, by observing the movement starting point of the pole in the grid (x-axis and y-axis), as well as the distance and direction to the grid (z axis)

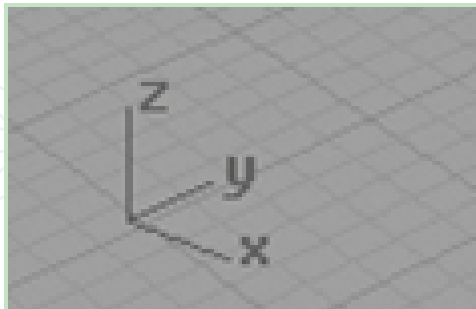


Figure 24. Grid and Poles in Rhinoceros

In the main display area, users can choose the display usage of object, as shown in Figure 1-21 is the wire-frame mode, it solved the problem of objects visualization, while show the internal structure of objects with a faster speed.

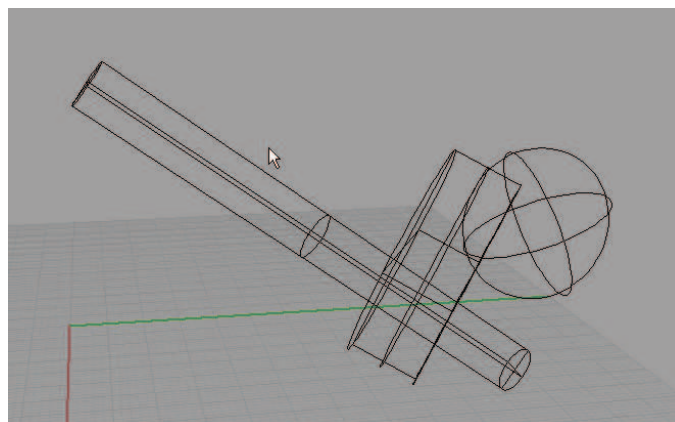


Figure 25. The Wire-frame mode in Rhinoceros

1.4.2 Personal Computer Games

For a long while, computer games attract millions of people. Besides the how games effect he player's ethical behavior, just for user interface, PC game is the summit of civilian sectors at all times. Along whit the upgrade of both software and hardware, PC game also comes through the process of 2D, 2.5D, 3D. Nowadays, 3D computer games became more and more popular all over the world. The naturalness and interaction are attracting hundreds of thousands of players. The important reason of game's success is the advanced design conception, focus on creating the user's experience. As the game can bring people rich experience, when it has a large number of users, and following rich profit, it makes the developers put more and more energy and financial to the interaction research.

As a restricted 3D UI, we would talk about 2.5D UI as the product in the previous development. And the most typical and the most successful applications are computer games. So we will talk about the user interface in 2.5D, with a real-time strategy game Starcraft TM.

The game used the view, this 45 ° angle could make user control the overall situation, and do a orientation from a high level.

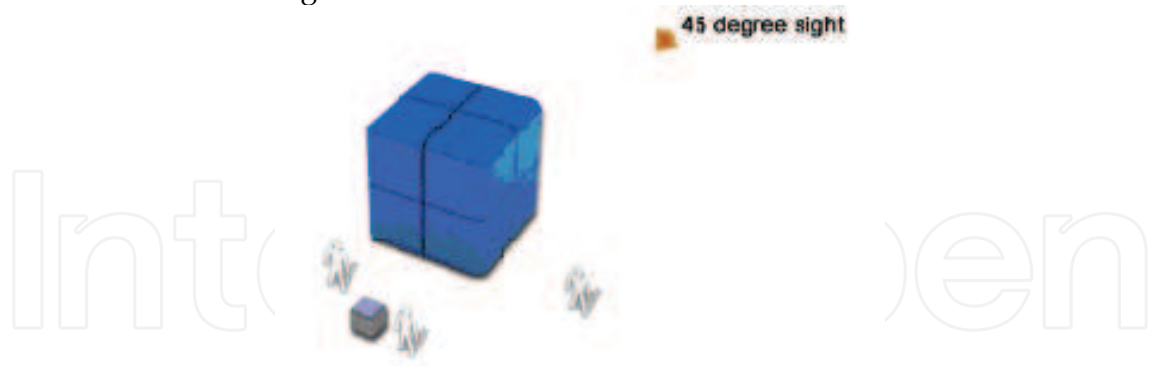


Figure 26. 45 Degree sight

The Screen is mainly divided to 2 parts: The main window and the bottom.



Figure 27. Starcraft™

4.2.1 Main Window

The main window concludes two aspects of information:

①The resources information, are displayed on top of the detailed view and give feedback on the status of your resources. In process control the resources available are usually not critical parameters. It could be replaced with vital information for a specific process. It might be interesting to give the freedom to the operator to set for instance five most important parameters.



Figure 28. The Resources Information

②It shows a terrain with available resources on which your and your opponent’s buildings and troops are situated via 45degree sight (god sight). All these objects have their own animations. Objects can be selected (multi-select possible) and when selected a bar pops up underneath the object that indicates the amount of damage of the object. Moving the cursor towards the border moves the view in that direction. First, the process components can be animated and directly indicate a certain state (e.g. running, on or off or damaged). Second, the multi-select could give an overview of a free selection of process components that are critical at a particular time. The data will be displayed in the properties frame. Third, a bar underneath the process components can indicate the amount of time passed in a process in time.

Cursor is unknown, but plays an important role in the game, such as the choice of location, operation, and other tips. Through the design of the cursor it can be feedback the user’s operation effective at the first time. In the Fig. 29 are part of the cursors’ difference appearance in Starcraft™, appeared in different cases. These not only give the information feedback through the icons, but also help users to achieve accurate selection! They play a decisive role in the real-time strategy games to achieve accurate selection, and the rapid response of current operation.



Figure 29. The Cursors

In Starcraft™, when an object is selected, a green circle emerge immediately, and the cursor changes at the same time as shown in picture. And at the same time, the group, single selection, multi-selection, formation and distribute the different colors to different nation, and so on, will help users do more convenient and efficient select operation of the keyboard and search the targets quickly and make orientation.



Figure 30. Selection State

Selection is an important manipulation behavior in both 2D GUI and 3D UI. In traditional 2D interface, all the components are located on a planar window, so it’s pretty easy to realize the accurate selection. However, due to the existence of the depth of focus in 3D environment, it became difficult for user to select the objects accurately, especially the ones in the distance. This is one of the most important problem make the user often feels confused. Actually although the objects of RTSG are located on a plane, the objects

themselves are 3D isometric projection. And the operator needs to move in a large scale. In the disordered game space, the player still could easily realize the accurate selection.

4.2.2 Navigation and Order Region

The navigation and order region is on the bottom of screen, it include 3 parts:

①A small overview map, is what we usually called navigation map. A white rectangle shows what portion of the total map is displayed in the detailed view. Clicking in this overview changes the position of the white rectangle accordingly and updates the detailed overview. All buildings and troops are displayed as small dots, a different color for each player. In case troops outside the detailed view are attacked, an animated red cross and some audio feedback indicate where to look. A green cross that works similarly is used to indicate that a process (e.g. building of a new unit) is finished.



Figure 31. Overview Map

A simplified dynamic overview of the process could inform the operator about that part of the process that is not visible in the detailed overview. By simply clicking in the overview the operator can navigate to a desired part of the process. The color coding within the map could be useful to indicate the state of a component ('failure' or 'no failure'). Since at a certain time many processes can be disturbed, it will probably be a cacophony of sounds and visuals if each disturbance is animated with audio feedback, although it might be interesting to prioritize these disturbances and only animate the most important ones.

②The properties frame in the middle of the bottom part on screen. It displays the current selected object in wire frame with damage indication. Object dependent data is displayed. A small video-screen displays the commander of the object. In case troops are being built within the selected object or a new technology is investigated, a progress bar appears. This progress bar is qualitative.

A properties view could be used to show the parameters that are important for each component. Here also time related information can be displayed (e.g. time passed in shutdown sequence). If necessary a visual could indicate exactly where a failure occurred within the component (to support the service staff). The video screen could display an image of a camera stationed at the component or perhaps even a direct video- and communication link with the service staff at the site. Service staff can also be integrated into the system as objects. A local or global positioning system could update their position in the factory. Simply clicking on them could establish a communication link. In this way, the staff that is nearest to the component that needs service, can be selected by the operator.



Figure 32. Properties Frame

③The action frame, it displays icons that represent the possible actions that can be done with the current object. The icons have a tooltip-text that appears when the cursor is moved over it, and all actions have shortcut keys. Some actions have one sentence of extra information. In case of place-depended actions (e.g. walk to ...) the detailed overview is used to specify them.



Figure 33. Action Frame

This frame could display the actions that are available for each component (e.g. start-up, toggle on or off, shut-down). Icon representation can be used along with tooltip-text to indicate the possible actions at a time; the set of possible actions can be updated dynamically. In case service staff is also supported by the system as objects, the staff could be directed to a particular place. The instructions could for example be sending to a pager.

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In these 34 chapters, we survey the broad disciplines that loosely inhabit the study and practice of human-computer interaction. Our authors are passionate advocates of innovative applications, novel approaches, and modern advances in this exciting and developing field. It is our wish that the reader consider not only what our authors have written and the experimentation they have described, but also the examples they have set.

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