Navigation and Selection in 3D

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Overview

- Cognitive Issues
  - Wayfinding and cognitive maps
  - Limitations of human spatial ability
  - Effective affordances
  - Depth Cue Theory
- Interface Design
  - Navigation Metaphors
  - Cost of Knowledge
  - Focus+Context
  - Manipulation and Selection
  - 3D vs. 2D

Introduction

- As hardware and software improvements are made more computer interfaces are being developed using 3D graphics
- It is inherently difficult to depict objects in 3D space on the 2D medium of a computer screen
- Designers of 3D interfaces must consider the cognitive aspects of human perception within 3D environments and the effect of the additional dimension on user interaction

Cognitive Issues

Navigation

- Planning and execution of travel through space
- The human perceptual system has evolved various means to facilitate navigation through *wayfinding*
  - A process of building up an understanding of one's environment through the formation of mental models (cognitive maps) and through the use of physical maps

Cognitive Issues

Cognitive Maps

- Formed from
  - basic components that correspond to objects within the environment
    - paths
    - edges
    - landmarks
  - logical groupings of these components
    - nodes
    - districts
- Developed most efficiently from an overview of an environment

Cognitive Issues

Physical Maps

- Support wayfinding
  - Allow a user to develop a cognitive map more quickly
  - User establishes a relationship between the environment that a physical map represents and their cognitive map
  - Can be very effective in user interfaces when they provide both an overview and a detailed view

Cognitive Issues

Spatial Ability

- Design of a 3D interface must consider the limitations of a user's spatial ability
  - Spatial orientation
    - The ability to retain relationships between objects and use oneself as a reference while manipulating them.
  - Spatial visualization
    - The ability to manipulate the relationships within an object
  - spatial relations
    - The ability to create a mental image of an object from different imagined view points

Cognitive Issues

Affordances

- The ways that interface components communicate how they may be used to allow a user to accomplish a task.
- Affordances for 3D interface components are often borrowed from 2D interface design
- Should ideally reflect the dimensionality of the 3D environment
- 3D metaphors should be intuitive as we are very accustomed to manipulation and navigation in three dimensions in the real world.

Cognitive Issues

Depth Cue Theory

- The study of how information about the 3D world is provided via various depth cues
- Depth cues are translated by the human perceptual system to obtain an understanding of physical space
- Essential to the realistic portrayal of 3D graphics
  - depth information must be provided visually so that the illusion of three dimensions is maintained

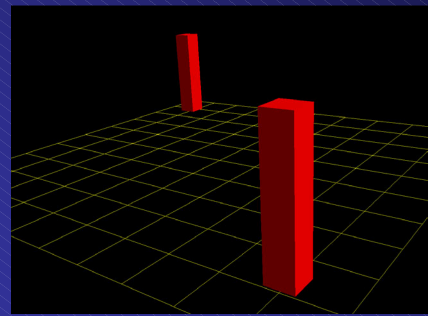
Cognitive Issues
Depth Cue Theory

Perspective

- The extension of rays from a viewpoint to features in the environment
  - Convergence of parallel lines to a single point
  - Relative difference in size of distant objects compared to those that are close to the viewer
  - Perception of scale afforded by the proximity of objects to other objects whose size is known
  - elements of uniformly textured surfaces can also provide effective depth cues as they will become smaller as they become more distant from a viewpoint

Cognitive Issues
Depth Cue Theory

Perspective



Perspective distortion and depth cues from parallel lines and surface texture

Cognitive Issues
Depth Cue Theory

Occlusion

- Very strong depth cue provided where one object overlaps another
- Viewer perceives one object to be closer to them in relation to the other
- Does not provide information about distance between objects or relative size but can help to establish structure in visually complex objects

Cognitive Issues
Depth Cue Theory

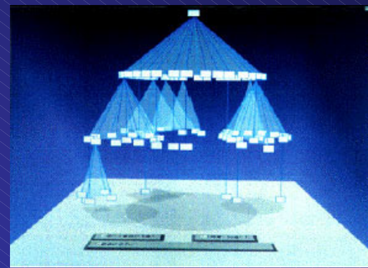
Occlusion

- Transparency is a means of partial occlusion that can be used to provide a depth cue while allowing information about the occluded object to be revealed

Transparency as a form of partial occlusion in Rekimoto and Green's Information Cube

Cognitive Issues
Depth Cue Theory

Cast Shadows



Cast shadows in Robertson et al.'s Cone Tree

Cognitive Issues
Depth Cue Theory

Cast Shadows

- Caused by the absence of light created by an occluding object between a light source and a surface
- Help to establish the height of an object above a plane and locate objects in relation to a surface
- Affect the perceived size, elevation and relative depth of an object and can provide additional information about shape, layout and depth
- Most effective when shadows are cast on a surface that is relatively close to the user as a user is more likely to be able to connect an object with its shadow

Cognitive Issues
Depth Cue Theory

Shape from Shading

- Originate from the interaction of light with surfaces
- Provides structural information that reveals shape
  - *Lambertian shading*:
    - Light reflected from an object equally in all directions based on surface geometry
    - Brightest surfaces are those that face the light source
  - *Specular shading:*
    - Highlights reflected from a glossy surface
    - Depends on the shininess of the surface
    - The closer that the view point is to the point of reflection the brighter the reflection will appear
  - *Ambient shading*:
    - Light that arrives equally from all directions
    - No specific light source

Cognitive Issues

Depth Cue Theory

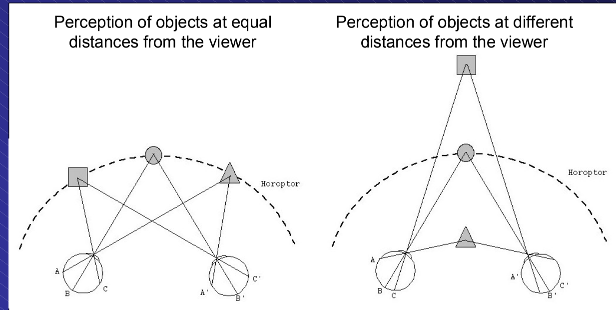
Structure from Motion

- As objects move through space they provide varied feedback to a viewer that is perceived as patterns of light.
  - Motion parallax
    - Occurs when a viewer travels past objects at varying distances, akin to looking sideways out of a moving vehicle
    - Distant objects appear to move more slowly than those that are closer to the viewer
  - Velocity Field
    - Expanding pattern of movement perceived when a viewer moves forward through a cluttered environment
  - Kinetic Depth Effects
    - Kinetic depth effects occur when objects move through 3D space and are thereby viewed from various angles
    - Example…

Cognitive Issues

Depth Cue Theory

Stereoscopic Depth



Source: www.cs.dartmouth.edu/~wittie/reu/stereo.html

Cognitive Issues

Depth Cue Theory

Stereoscopic Depth

- Originate from the difference in viewpoint relative to the distance between the eyes
- The brain interprets differences in the placement of objects viewed by each eye by assuming that they are at different depths
- Stereoscopic displays
  - Divide the display into sections to present slightly offset views of an image to each eye
  - Create a more realistic illusion of depth that can greatly enhance a user's sense of *presence* within a 3D environment

Interface Design

Navigation Metaphors

- *World in Hand*
  - The user grabs a part of the environment to manipulate it
  - Best for viewing relatively compact environments as there are few cues for navigation over long distances
- *Eyeball in Hand*
  - The user directly manipulates their viewpoint to observe the environment from a different perspective
  - Usually not particularly effective as certain viewpoints may be confusing or impossible to achieve when constrained by the boundaries of the display or by objects that block their path

Interface Design

Navigation Metaphors

- *Walking*
  - User is able to move through the environment constrained only by the effects of virtual gravity
  - Often used in virtual reality applications or in information landscapes
  - The effect of gravity restricts movement but can help to prevent disorientation as the user is always able to determine the up direction – viewpoint restricted to a certain vertical position
- *Flying*
  - Allows a user to move through an environment as if they were in an aircraft but without the restrictions of gravity
  - A very flexible navigation metaphor as there are usually minimal constraints in any direction so that a wide range of movement and perspectives are achievable

Interface Design

Cost of Knowledge

- A calculation of the additional useful information that becomes available as a user navigates an information structure for each unit of time expended
- The more time that a user spends navigating through successive information structures within a system the higher the cost in relation to information discovered
- Can be used as a guideline for improving interface design by developing environments that minimize the amount of time and work a user must invest in performing a task

Interface Design

Focus+Context

- Techniques that provide both overview and detail by integrating both in the same view
- Use distortion or selective reduction techniques that allow a user to focus on specific components in context with the entire display
- Can provide focus within visually complex environments
- Help a user to remain oriented as he has reference to the entire display space and can recognize landmarks for navigation

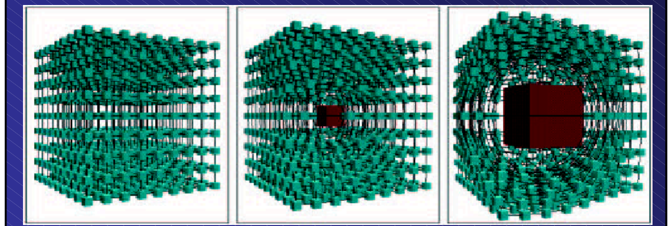
Interface Design

Focus+Context

- Distortion changes the size and location of objects within the display area according to a degree of interest calculation
- This is not as straightforward in 3D interfaces where objects deep within a structure may remain occluded
- A visual access distortion function is required to remove occlusions by clearing a line of sight to a focal point within a 3D structure

Interface Design

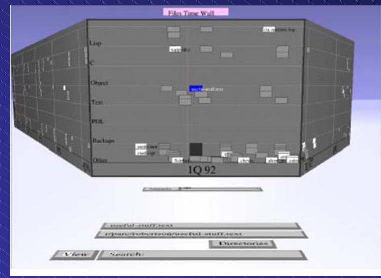
Focus+Context



An illustration of Sheelagh et al.'s visual access distortion function

Interface Design

Focus+Context



Perspective used for focus+context in Card et al.'s Perspective Wall

Interface Design

Focus+Context

- Perspective
  - Can provide a more intuitive view of a virtual environment than other distortion techniques. Card et
  - Converging parallel lines provide depth cues that suppress the perception of distortion by creating the illusion of distance

Interface Design

Focus+Context

- Other Focus+Context Techniques
  - Filtering
    - Removes elements of the display using a degree of interest calculation or dynamic queries
  - SelectiveAggregation
    - Causes similar structures to coalesce when they are distant from the area of focus and to dissolve into their component cases when are closer to it.

Interface Design

Manipulation and Selection

- Can be used to overcome problems of occlusion and the distortion of perspective in 3D environments
- Rotation
  - Allows the user to effectively adjust the viewing angle and discover new information about the content and structure of an object or group of elements
  - Rotation must occur at a speed that allows a user to track the transition
    - Helps to reduce cognitive load by allowing the perceptual system to follow the changes in spatial relationships caused by rotation ensuring that the user remains oriented

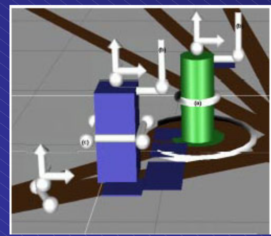
Interface Design

Manipulation and Selection

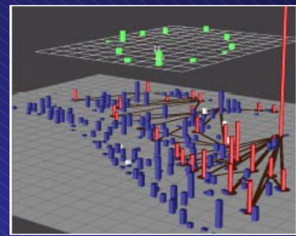
- Selective Dynamic Manipulation (Chuah et al.)
  - User has the ability to move, highlight, resize, recolour or otherwise manipulate objects
  - Ghost images of objects that are moved can be displayed in their original location to preserve spatial relationships and ensure context is maintained
  - Objects can be manipulated individually or as part of a comparison set
  - Addresses the problem of occlusion
  - Objects can be brought together for comparison to overcome the distortion of perspective

Interface Design

Manipulation and Selection



Object handles for manipulation in Chuah et al.'s SDM.



Moving a comparison set in Chuah et al.'s SDM

Interface Design

3D vs 2D

- Advantages
  - More efficient use of space for focus+context
  - allow a user to move to a different view point to gain a better perspective and gain insight into structural relationships and patterns
  - Present a more realistic simulation of space
  - Afford of a sense of presence within the virtual environment

Interface Design

3D vs 2D

- Disadvantages
  - Occlusion
  - Scaling issues related to 3D perspective (distortion)
  - 3D manipulation mechanisms place additional demands on users
  - 3D displays are not truly 3D as they rely on 2D input and output devices
    - Can cause navigational conflicts as a user may perceive conflicting depth cue information

Interface Design

3D vs 2D

- Disadvantages
  - Users are generally much more familiar with 2D interfaces and may require more time to become adept at navigating and manipulating a 3D environment
  - User Disorientation
    - It is much easier to become lost in three dimensions than it is in two
    - This can be alleviated to some extent by using focus+context techniques that allow a user to maintain visual contact with effective landmarks

Conclusion

- No definitive answer to the question of whether 3D interfaces are an improvement over their 2D counterparts
- Most studies have shown that there is no significant difference in the ability of a user to perform a task in either type of interface but users often report a marked preference for 3D displays
- While 3D graphics can be used to develop very effective interfaces the appropriate technique to use will depend on what method is best suited to the task that a user seeks to accomplish