CHAPTER 2

3D User Interfaces: History and Roadmap

Three-dimensional UI design is not a traditional field of research with well-defined boundaries. Like human–computer interaction (HCI), it draws from many disciplines and has links to a wide variety of topics. In this chapter, we briefly describe the history of 3D UIs to set the stage for the rest of the book. We also present a 3D UI "roadmap" that positions the topics covered in this book relative to associated areas. After reading this chapter, you should have an understanding of the origins of 3D UIs and its relation to other fields, and you should know what types of information to expect from the remainder of this book.

2.1. History of 3D UIs

The graphical user interfaces (GUIs) used in today's personal computers have an interesting history. Prior to 1980, almost all interaction with computers was based on typing complicated commands using a keyboard. The display was used almost exclusively for text, and when graphics were used, they were typically noninteractive. But around 1980, several technologies, such as the mouse, inexpensive raster graphics displays, and reasonably priced personal computer parts, were all mature enough to enable the first GUIs (such as the Xerox Star). With the advent of GUIs, UI design and HCI in general became a much more important research area, since the research affected everyone using computers. HCI is an interdisciplinary field that draws from existing knowledge in perception, cognition, linguistics, human factors, ethnography, graphic design, and other areas.

In a similar way, the development of the 3D UI area has to a large degree been driven by technologies, including 3D graphics technology, augmented and virtual reality (VR) technology, and flight simulator technology, to name a few. As each of these technologies matured, they enabled new types of applications, leading in turn to previously unexplored user tasks, new challenges in UI design, and unforeseen usability issues. Thus, 3D UI research became necessary. In the rest of this section, we chronicle the development of one of these areas—virtual reality, to be precise—and show how advances in VR produced a need for 3D UI research.

In the late 1960s, Ivan Sutherland developed the first head-tracked, head-mounted display (Sutherland 1968) and a vision for the use of this new technology to enable a whole new type of computing (Sutherland 1965). Sutherland was ahead of his time, but finally in the late 1980s and early 1990s, it became more practical to build VR systems. The technologies that enabled this vision included 3D stereoscopic computer graphics, miniature CRT displays, position-tracking systems, and interaction devices such as the VPL DataGlove. Interestingly, when VR first entered the public consciousness through Jim Foley's article in *Scientific American* (Foley 1987), the cover image showed not a display system or a complex graphical environment, but rather the DataGlove—a "whole-hand" input device allowing users to interact with and manipulate the virtual world.

At first, VR was strictly the domain of computer scientists and engineers (mostly in the graphics community) and was used for relatively simple applications. Visualization of 3D scientific datasets, real-time walkthroughs of architectural structures, and VR games were interesting and useful applications, and provided plenty of research challenges (faster, more realistic graphics; more accurate head-tracking; lower latency; better VR software toolkits; etc.). These applications, however, were relatively impoverished when it came to user interaction. The typical application only allowed the user to interactively navigate the environment, with a few providing more complex interaction such as displaying the name of an object when it was touched. As VR technology continued to improve, however, researchers wanted to develop more complex applications with a much richer set of interactions. For example, besides allowing an architect to experience his building design in a virtual world, we could allow him to record and play audio annotations about the design, to change the type of stone used on the façade, to move a window, or to hide the interior walls so that the pipes and ducts could be seen. At this point, some VR researchers realized that they didn't know enough about interface design to make these complex applications usable. Technology had improved to a point where such applications were possible, but more than technology was needed to make them plausible.

Fortunately, because of the earlier focus on interfaces for personal computers, the field of HCI was already relatively mature when VR experienced its "interface crisis." HCI experts had developed general principles for good interface design (e.g., Nielsen and Molich 1992), product design and development processes aimed at ensuring usability (e.g., Hix and Hartson 1993), and models that explained how humans process information when interacting with systems (e.g., Card et al. 1986).

The application of existing HCI knowledge to VR systems helped to improve their usability. But there were some questions about VR interfaces on which traditional HCI was silent. Consider the architectural design example again. Suppose the architect wants to move a doorway and change the door's paint color. An HCI expert would tell us that the movement task would best be accomplished by direct manipulation (like dragging an icon on your computer desktop), since that would provide direct and continuous feedback to the user. But how should a direct manipulation interface be implemented in VR? How does the architect select the door? Once the door is selected, how does he move it? How do the architect's hand and body motions map to the movement of the door? Again, the HCI expert might suggest that for the painting task, we need a simple menu selection mechanism, perhaps based on a real-world metaphor such as paint sample cards. But what does a menu look like in VR? How does the user activate the menu and select an item within it? Where does the menu appear in the 3D world?

Questions such as these indicated that a new subfield of HCI was needed to address the issues specific to the design of interfaces for 3D VEs. In parallel, other technologies, such as interactive 3D graphics for desktop computers, augmented reality, and wearable computers, were also being developed, and researchers found that developing UIs on these platforms was also problematic. The common theme of all of these interactive technologies is interaction in a 3D context. Thus, the new subarea of HCI is termed *3D interaction, 3D user interface design*, or *3D HCI.*

In the next section, we look at the types of research problems addressed and approaches used in 3D UI work and position them with respect to related work in other fields.

2.2. Roadmap to 3D UIs

To help you understand the material in this book in its proper context, it's important to discuss what types of work are part of the 3D UI area, what disciplines and areas make up the background for 3D UI work, and what impact 3D UIs have on other areas. In this section, therefore, we present brief snapshots of a wide variety of areas with some connection to 3D UIs. Figure 2.1 illustrates our basic organizational structure. In the following lists of topics, we provide at least one important reference for each topic and, if applicable, a pointer to a particular chapter or section of the book where that topic is covered.

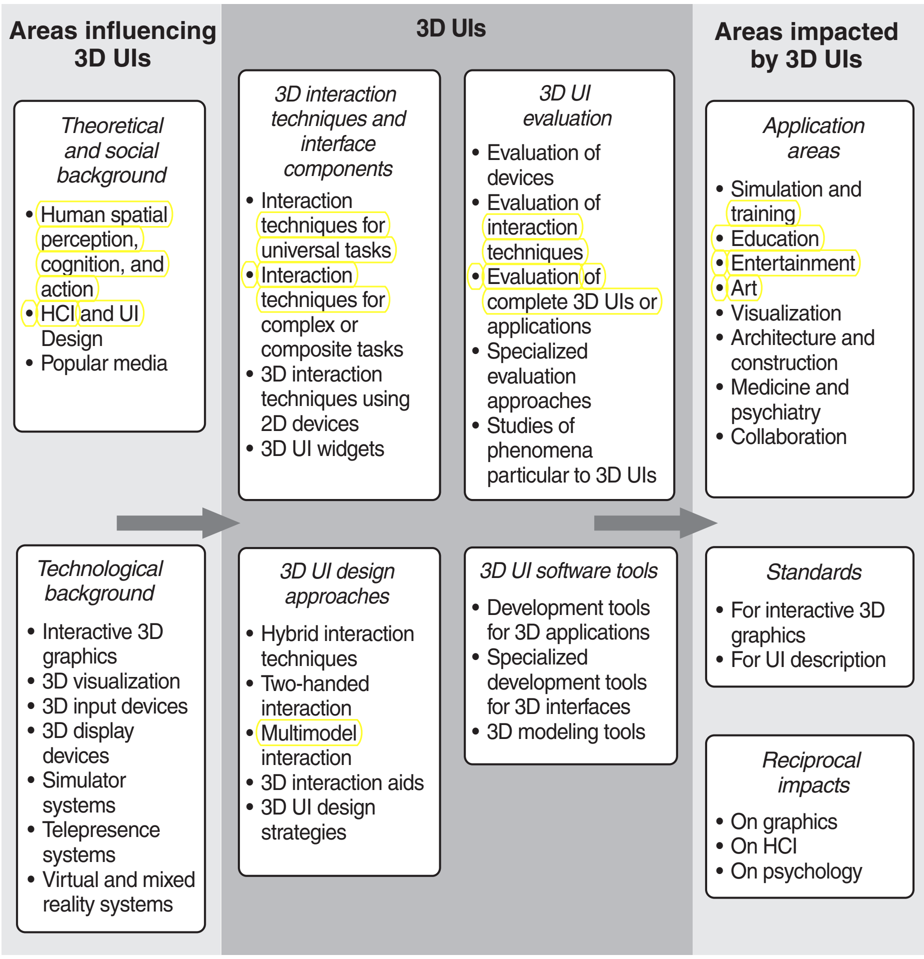

Figure 2.1 *Roadmap to 3D UIs.*

2.2.1. Areas Informing the Design of 3D UIs

We can draw upon many areas of research when considering the design of 3D UIs. The following sections discuss the theoretical and social background as well as the technological background for the topics covered in this book.

Theoretical and Social Background

Human spatial perception, cognition, and action The defining feature of 3D UIs is that users are viewing and acting in a real or virtual 3D space. Thus, psychology and human factors knowledge about spatial perception; spatial cognition; and human navigation, movement, and manipulation in 3D space contains critical background information for 3D UI design. Examples of such knowledge and theories include

- Visual perception and 3D depth cues (e.g., Bruce and Green 1990; Kosslyn 1993; see Chapter 3, section 3.2.2)
- Human spatial abilities and individual differences in abilities (e.g., Shephard and Metzler 1971)
- Building spatial knowledge about 3D environments (e.g., Thorndyke and Hayes-Roth 1982; see Chapter 7, section 7.2)
- Spatial sound perception (e.g., Durlach 1991; see Chapter 3, section 3.3.1)
- Properties of manual reaching and grabbing (e.g., MacKenzie and Iberall 1994; see Chapter 5, section 5.1)
- Cognitive planning of actions (e.g., Card et al. 1983)
- Presence (e.g., Slater et al. 1994)

Basic principles of HCI and UI design A great deal of knowledge, theory, and practical advice has been generated by researchers in HCI. Although some is particularly focused on traditional desktop UIs, much can be generalized to apply to 3D UIs as well. Examples include

- Generic heuristics or guidelines for UI design, such as visibility, affordances, and constraints (e.g., Nielsen and Molich 1992; Norman 1990)
- Models and theories of HCI, such as activity theory, GOMS (Goals, Operators, Methods, and Selection Rules), and scenario-based design (e.g., Bødker 1991; Card et al. 1980; Rosson and Carroll 2001)

- UI design and evaluation techniques such as hierarchical task analysis, ethnographic analysis, heuristic evaluation, cognitive walkthrough, and usability studies (as found in HCI textbooks such as Shneiderman 1998; see Chapter 11)

Popular media A very different source of inspiration and vision for 3D UI work has been popular books (especially science fiction), films, and other media. Much of this vision has involved fully "natural" interaction with intelligent interfaces in perfectly realistic environments. Some specific examples are

- Books such as *Snow Crash* (Stephenson 1992), which describes the "Metaverse," a futuristic, realistic version of the Internet; *Neuromancer,* which coined the term "cyberspace"; and *Disclosure* (Crichton 1994), which features a VE with natural physical movement and natural language interaction.
- Television shows such as *Star Trek: The Next Generation*, which features the "Holodeck."
- Films such as *The Matrix,* which envisions an entire race of people living unsuspectingly in a thoroughly realistic virtual world.

Technological Background

Interactive 3D graphics Producing realistic but synthetic 3D images on a computer screen has been a focus of computer science research for almost 50 years. One particular line of research has focused on interactive 3D graphics—images that are rendered in real time so that users can interact with the images directly. This technology provides the environment in which 3D UI designers do their work. Some representative advances in interactive 3D graphics are

- Fast line and polygon rendering algorithms (e.g, Bresenham 1965)
- Texture-mapping procedures (e.g., Watt and Watt 1992)
- Real-time lighting methods (e.g., Bishop and Weimer 1986)
- Dedicated graphics processors for fast hardware-based rendering (e.g., Olano and Lastra 1998)
- Algorithms for drawing stereoscopic images (e.g., Davis and Hodges 1995)

30706 02 pp011-026 r1jm.ps 5/6/04 3:49 PM Page 17

3D visualization An important application area for 3D computer graphics has been visualization—changing abstract data into a perceptual form so that humans can use their well-developed visual sense to find patterns, detect anomalies, and understand complex situations. Research in visualization includes

- Principles of visual data representation (e.g., Tufte 1990)
- General information or data visualization techniques (e.g., Ware 2000)
- Scientific visualization techniques (e.g., McCormick et al. 1987)

3D input devices Computer systems have traditionally used text-based input (keyboards), and 1- (dials, sliders) or 2-DOF (mouse, joystick, trackball) input devices. Three-dimensional input devices provide more DOF for the user to control simultaneously. They are important for 3D UIs because users want to specify points, directions, gestures, and other actions in 3D space in order to accomplish complex 3D tasks. Examples of 3D input device types include

- Tracking devices (Welch and Foxlin 2002, Meyer and Applewhite 1992)
- Multiple DOF joysticks (e.g., Zhai et al. 1999)
- Isotonic 3D input devices (e.g., Simon and Fröhlich 2003)

We discuss 3D input devices in Chapter 4.

3D display devices All visual displays used with computers today are capable of displaying 3D graphics. Often, however, 3D UIs make use of more advanced displays that provide stereo viewing (slightly different images for the left and right eyes, producing an enhanced depth effect) or immersion (being surrounded by a graphical environment). In addition, many 3D UIs make use of nonvisual displays—displays that present information to other senses. Here is a short list of such advanced 3D displays:

- Stereoscopic displays for desktop computers (e.g., Schmandt 1983)
- Walkaround 3D displays (e.g., Bimber et al. 2001)
- Head-mounted displays (e.g., Davis 1996)
- Projection-based immersive displays (e.g., Cruz-Neira et al. 1993; et al. 1995)

- 3D spatial sound systems (e.g., Kapralos et al. 2003)
- Force-feedback, tactile, and other haptic displays (e.g., Burdea 1996)

Chapter 3 presents details on a wide range of 3D display devices.

Simulator systems Before VR, simulator systems pioneered the use of large, interactive displays of 3D computer graphics. Simulators have been used for many applications, including flight simulation, tank and military vehicle simulation, space vehicle simulation, and simulators for entertainment .

Telepresence systems Telepresence systems allow a user in one real-world location to feel as if he were in a different real-world location. They combine sensors (cameras, microphones, etc.) on the remote side with displays (visual, auditory, haptic) and interactive controls (e.g., for rotating the camera) on the local side. Telepresence technology is similar to VR (see below) in many ways (e.g., Stassen and Smets 1995).

Virtual reality systems Immersive VR systems combine interactive 3D graphics, 3D visual display devices, and 3D input devices (especially position trackers) to create the illusion that the user is inside a virtual world. In particular, head tracking produces the effect that the world completely surrounds the user—when the user turns her head to the right, new images are rendered showing the part of the world to the user's right. Since the images are always located at the correct position around the user, they appear to form a seamless 3D environment. Some important VR systems have included

- Sutherland's original head-mounted display system (Sutherland 1968)
- VPL's HMD and DataGlove (Zimmerman et al. 1987)
- The Cave Automatic Virtual Environment (CAVE), originally developed at the University of Illinois-Chicago's Electronic Visualization Laboratory (Cruz-Neira et al. 1993)

2.2.2. 3D UI Subareas

In this section, we describe the various subparts of the field of 3D UIs. These subareas, only described briefly here, make up the bulk of the content of this book. We provide references in this section only when a topic is not covered later in the book.

3D Interaction Techniques and Interface Components

Just as 2D UIs are built from components like windows, scrollbars, menus, and drag-and-drop, 3D UIs are built from a large number of techniques and components.

Interaction techniques for universal tasks (Chapters 5-9): Selection, manipulation, travel, wayfinding, system control, and symbolic input are common, low-level user tasks in 3D interfaces. For each of these tasks, there is a large number of possible interaction techniques (combinations of input device and UI software).

Interaction techniques for complex or composite tasks: More complex tasks in 3D UIs are composed of the universal tasks described above. For example, the task of changing an object's color might involve choosing a "color picker" item from a menu (system control), pointing out an object (selection), and positioning a marker in a 3D color space (manipulation). The low-level interaction techniques for these subtasks can be composed to form a high-level interaction technique for the composite task.

3D interaction techniques using 2D devices (Chapter 5, section 5.4.7): A special category of 3D interaction techniques are those that operate in a 2D input context (i.e., on the desktop). For example, in 3D modeling programs running on desktop computers, we need a way to map 2D mouse input to the 6 DOF of a 3D object.

3D UI widgets (Chapter 8, section 8.3): Not all 3D interaction is "natural," operating directly on the objects in the world. For many complex tasks, we need specialized objects that are not part of the environment but that help the user to interact with the environment. For example, a virtual knife might help a designer to slice through an automobile model to see a particular cross-section, or a small icon representing a piece of paper could be attached to a building to indicate the presence of textual information about it.

3D UI Design Approaches

Low-level interaction techniques and interface components are the building blocks of complete 3D UIs, but it is not trivial to put these elements together in a usable and understandable way. Thus, we need higher level approaches or strategies for building 3D interfaces.

Hybrid interaction techniques: One way to improve on the usability of individual interaction techniques is to combine the best parts of existing techniques. For example, the HOMER manipulation technique (Bowman and Hodges 1997) is a hybrid of two other types of techniques: ray-casting and arm-extension.

Two-handed interaction (Chapter 10, section 10.2.3): 3D UIs can take advantage of a much richer set of inputs than can 2D interfaces. One powerful approach is to develop interactions that allow the user to use both hands in a complementary way. Taking this approach even farther, 3D UIs can be designed around "whole-body" interaction.

Multimodal interaction (Chapter 8, section 8.7): Another design strategy that makes sense for 3D UIs is to use many different input and output "modalities"—so-called *multimodal interaction.* For example, combining hand-based gestures with speech input provides a powerful and concise way to specify complex actions.

3D interaction aids (Chapter 10, section 10.2.1): Purely virtual 3D interaction can be very powerful and flexible, but it can also be frustrating and imprecise. Including physical objects ("props") in a 3D UI helps ground the user and constrains the interaction. For example, placing a 2D menu on a physical 2D surface helps the user find the menu and make a precise selection. Including physics (forces, collisions, etc.) or constraints (snapping, grouping, etc.) in a 3D world can also make interaction easier.

3D UI design strategies (Chapter 10): Overall strategies for designing 3D UIs include

- Using real-world metaphors that help guide the user to the correct actions
- Applying principles of aesthetics and visual design
- Basing UI design on formal taxonomies of devices or interaction techniques
- Basing UI design on guidelines developed by researchers
- Using "magic" to allow the user to go beyond the perceptual, cognitive, or physical limitations of the real world
- Intentionally violating assumptions about the real world in the virtual world

3D UI Software Tools

Tools are needed to turn conceptual UI designs into concrete prototypes and implementations. This subarea has not received as much attention as design, but there are a few important categories of tools.

Development tools for 3D applications: A wide variety of software libraries, toolkits, application programming interfaces (APIs), and integrated development environments (IDEs) exist that allow programmers to develop 3D applications. Typically, these applications are written in a standard programming language such as C++ and make use of special APIs for 3D graphics, 3D device drivers, and so on.

Specialized development tools for 3D interfaces: Very few tools are designed specifically to aid the implementation of 3D UIs. Some 3D toolkits include a few default interaction techniques or interface widgets. Also, some work has been done on 3D UI description languages. Standards such as Virtual Reality Modeling Language (VRML) and Extensible 3D (X3D) include some interaction functionality, although the implementation of this functionality is left up to the browser or viewer developers.

3D modeling tools: All 3D UIs include 3D geometric objects and/or scenes. We are not aware of any 3D modeling tools aimed specifically at 3D UI visual design, but modeling tools used in other domains, such as animation, architecture, and engineering, can also be used to develop the objects and elements in a 3D UI. Common tools today include AutoCAD, 3D Studio Max, and Maya.

3D UI Evaluation

Just as in traditional HCI, usability evaluation is a critical part of 3D UI design. Evaluation helps designers pursue good ideas and reject poor ones, compare two or more alternatives for a particular UI component, validate the usability of a complete application, and more. We cover 3D UI evaluation in detail in Chapter 11.

Evaluation of devices: In 3D UIs, evaluation must start at the lowest level, since all the UI components are novel and unfamiliar. Thus, comparisons of the usability of various input and output devices are necessary. For example, one might compare the performance of different device types for a simple 3D rotation task (Hinckley, Tullio et al. 1997).

Evaluation of interaction techniques: As new 3D interaction techniques are developed for universal or composite tasks, formative usability studies can help to guide the design of these techniques. When there are many possible techniques for a particular task, a comparative evaluation can reveal the tradeoffs in usability and performance between the techniques.

Evaluation of complete UIs or applications: At a higher level, usability evaluation can be used within the design process (formative evaluation) or at its end (summative evaluation) to examine the quality of a fully integrated UI or complete 3D application.

Specialized evaluation approaches: Some researchers have investigated generic methodologies for evaluating the usability of 3D interfaces. For example, in testbed evaluation (Bowman, Johnson et al. 2001), interaction techniques are compared by having subjects use them in a wide variety of different tasks and situations so that a complete picture of the technique's quality is obtained.

Studies of phenomena particular to 3D UIs: Most usability evaluations measure things like time to complete a task, perceived ease of use, or error rates. There are some metrics, however, that are unique to 3D UIs. One of these is *presence*—the feeling of "being there" that you get when immersed in a virtual 3D world (Slater et al. 1994). Because presence is not a concept that applies to most UIs, researchers have only recently begun to define it precisely and devise methods for measuring it. Another unique phenomenon is *cybersickness*—feelings of physical discomfort brought on by the use of immersive systems (Kennedy et al. 2000). Again, precise definitions and metrics for cybersickness are just beginning to emerge.

2.2.3. Areas Impacted by 3D UIs

This section addresses the impact of 3D UIs on other domains. This impact is mainly felt in the applications that are enabled by 3D UIs.

Application Areas

Simulation and training Three-dimensional environments based on virtual or augmented reality can be used for simulations of military operations, robotic agent actions, or the spread of a disease within the body, just to name a few. Training in a 3D environment for tasks such as surgery, spacewalks, or aircraft piloting is also a very popular application area.

Education Students can learn topics from Newton's laws to environmental design in 3D worlds. If the worlds are highly interactive, students can experiment with a range of situations to help them construct their own mental models of how something works.

Entertainment Three-dimensional environments already provide the context for the most popular video games on desktop computers. When 3D interaction is added, allowing more direct involvement in the world, and when many players can all be immersed in the same environment, the possibilities are endless. A famous example of the potential of this application area is the DisneyQuest attraction at Disneyworld in Florida.

Art Three-dimensional worlds provide artists a new canvas for new types of expression. Although some of today's 3D art is passive, most of it is interactive, responding to viewers' positions, gestures, touch, speech, and so on.

Visualization Scientists, engineers, business analysts, and others all work with large, complex, 3D (or higher dimensional) datasets. Exploring these datasets visually, querying them to extract information, and navigating to find patterns in them is another powerful application of 3D interaction.

Architecture and construction Architectural design and construction projects are organized around large 3D environments, but most tools currently used in these domains are 2D (drawings or text). With 3D interfaces, Architects can visualize and modify their designs directly, contractors can address the coordination of construction equipment on a worksite, or interior designers can try hundreds of combinations of wall colors, furniture, and lighting and see the results immediately.

Medicine and psychiatry Three-dimensional applications are being used in the medical domain for telemedicine (remote diagnosis and treatment), 3D visualization of medical images such as MRIs, and psychotherapy for anxiety disorders such as phobias, just to name a few examples. All of these applications require a usable 3D interface.

Collaboration Today's workgroups are often scattered around the globe. Technologies such as augmented reality, with an appropriate 3D UI, can allow such groups to work together as if they were located in the same place. For example, a group of stakeholders could discuss the design of a proposed new feature at a park, as we suggested in the preface.

Standards

There are no "standard" 3D UIs today in the sense of de facto standards (such as the desktop metaphor) or in the sense of documented standards (such as ISO standards). However, 3D UI work has had a small impact (that will continue to grow) on certain areas of standardization.

For interactive 3D graphics: The World Wide Web Consortium (W3C) defines international standards for many aspects of the Internet, including interactive 3D graphics. This work has led to the VRML specification, and its successor, X3D. These standards provide a well-defined method for describing interactive 3D environments and indicate the features and functionality that 3D Web browsers need to implement. Although they focus on geometry, appearance, and organization, these standards do include some interactive components, and more are being added all the time.

For UI description: The HCI community has worked to develop methods for the abstract, platform-independent description of UIs, and several have been produced for 2D GUIs (e.g., Hartson and Gray). While these could not yet be called standards, that is their intent. The 3D UI community has also seen the need for such description languages (e.g., Figueroa et al. 2001), and we expect that this will be a focus area in the future.

Reciprocal Impacts

Finally, we note that 3D UI research has influenced some of the areas from which it sprung. These "reciprocal impacts" indicate that 3D UI work has had an effect beyond itself, revealing gaps in our knowledge of other areas.

On graphics: To be usable, 3D UIs often require complex visuals. For example, the principle of feedback indicates that the visual display should show the user information about his actions both during and after the user's input. This means that during 3D object manipulation, we should provide the user with sufficient depth and position cues to understand where the object is in relation to the target location. These cues might include subtle lighting effects, realistic shadows, or various levels of transparency, all of which require complex real-time graphics algorithms. In this and many other ways, the requirements of 3D UIs can drive graphics research.

On HCI: The study of 3D UIs has revealed many areas not addressed by traditional HCI. For example, what metrics should be used to indicate the usability of a system? In 2D UIs, metrics like speed, accuracy, satisfaction, and perceived ease of use are sufficient; in 3D UIs, we also need to assess things like physical comfort and presence. The development of heuristics or guidelines for good UI design is another area that has been studied thoroughly in traditional HCI but that requires further thought and expansion for 3D UIs.

On psychology: As we noted above, the design of 3D UIs is heavily dependent on information from perceptual and cognitive psychology. In an interesting way, even these areas have benefited from 3D UI research. One issue in perceptual psychology, for example, is the design of valid and generalizable experiments studying visual perception, because it's very hard to tightly control what a person sees in a real-world setting and because some visual stimuli are hard to produce in the real world. In a synthetic 3D VE, however, we can remove all the real-world visual stimuli and replace it with anything we like, producing an extremely powerful environment for studying visual perception.

2.3. Scope of This Book

This book is about the design of 3D interfaces, and therefore we focus on the content that is specific to 3D UIs. This roughly corresponds to the topics in section 2.2.2 ("3D UI Subareas"). We also discuss briefly some of the background and application topics from sections 2.2.1 and 2.2.3 when appropriate.

Of course, this book can't cover everything in the roadmap. Some specific items that are not covered include

- An in-depth discussion of presence and cybersickness
- Technical information on the design or workings of various devices
- Graphics algorithms and techniques for rendering 3D environments
- Information on the usage of particular 3D toolkits, APIs, or modeling programs

For information on these topics, refer to the references above and to the recommended reading lists in each chapter.

For a visual representation of the book's coverage, see Figure 2.1. The items shown in black text in the figure are discussed in some detail, while the gray items are not covered or are mentioned only briefly.

We already noted that there are several different platforms for 3D UIs, including VEs, mixed or augmented reality, and traditional desktop computers. In this book, we strive to be as general as possible in our descriptions of interaction techniques and UI components, and the principles and guidelines we provide are usually applicable to any 3D UI. However, we recognize that there are some interaction techniques that are specifically designed for one platform or another. Since we come from a background of research in immersive VEs, many of the examples we use and specific technique descriptions are slanted in that direction. We do cover some desktop-specific techniques in Chapters 5 and 6, and augmented reality techniques in Chapter 12, but not at the same depth as our coverage of VE techniques.

For a more thorough treatment of desktop techniques for 3D interaction, we recommend supplementing this book with *3D User Interfaces with Java3D* (Barrilleaux 2000). This book provides principles, theories, guidelines, and research results applicable to all types of 3D UIs, including desktop 3D UIs, while Barrilleaux's book covers more specific techniques for desktop 3D UIs and provides more implementation details.

2.4. Conclusion

In this chapter, you've taken a tour through the history of 3D interaction and seen glimpses of the many facets of this rich and interesting area. In Part II, we dive into the details of the technological background for 3D UI design.