

3D SPACE

*Special Project in Advanced Computer
Environments*

by Dale Andrew Keith Patterson BCompSci (Hons)

*PhD thesis submitted for the degree of Doctor of Philosophy, in the School
of Information Technology, Bond University, December 2003.*

Abstract

The primary objective of this research is to use the benefits offered by computerized **three dimensional graphics** and apply those to the field of **human computer interaction**. Focussing primarily on the interactive content of the 3D world, this research describes a range of innovative new interface elements demonstrating specific new 3D interfaces/components designed to provide a new **interactive 3D** method for handling a range of particular common real-world tasks (ranging from simple value setting tasks up to larger scale systems for browsing structured sets of hierarchical data). These systems incorporate new design concepts such as **active 3D interfaces** that present their data to the user rather than statically waiting for the user to interact with them (these systems prove particularly useful in the presentation of large sets of data). Overall this set of components introduces a range of new interface styles that prove very effective in many mainstream real world tasks.

In addition to the development of these systems, this project demonstrates a new high level 3D interface development tool designed to simplify the challenge of constructing interactive 3D user interfaces and in doing so make **3D interface development** available to a wider developer base. By constructing the components mentioned above in a structured generic form, this combination of a new development tool and a range of re-usable components provides a **strong development platform**, from which more complex **interactive 3D interfaces** can be constructed.

In essence the core idea that underlies this research is making the construction of interactive and functional 3D interfaces simpler to undertake (by developing effective re-usable components to handle mainstream tasks) while at the same time generating resulting 3D interfaces that are more effective and more capable of providing users with an enjoyable and functional 3D working environment.

Acknowledgements

The author would like to acknowledge the contributions of many people to this research including the project supervisors at Bond University, Dr Zheng da Wu and Dr Michael Rees. The support and flexibility they provided throughout the research enabled the project to reach its full potential.

Personal thanks particularly go to Dr. Rees for his inputs in the areas of user testing and interface research and to Dr. Wu for introducing the author to 3D graphics many years ago and providing support in this area throughout the research project.

The author would also like to thank Bond University for its continual support of this research and provision of scholarships, without which this project could not have been completed. Many thanks are also passed on to all of the test users, all of whom freely contributed their time and without whom this research would not exist. Last but not least the author would like to thank his family whose support throughout this project, particularly at the hardest points, helped carry it through to the completion.

Contents

Chapter 1: Introduction	1
1.1 Motivation	1
1.2 The Idea	1
1.3 The Contributions	2
1.4 Evaluation	3
1.5 Discussion	3
1.6 Organization	4
Chapter 2: Background	6
2.1 3D Interfaces - The Elements Involved	6
2.2 3D Interface Principles	8
2.2.1 Presentation Principles	9
2.2.2 Presence Principles	9
2.2.3 Navigation Principles	10
2.2.4 Interaction Principles	13
2.2.5 Multi-User Principles	16
2.2.6 General Principles	17
2.3 3D Interface Development Tools	19
2.3.1 Three Dimensional Graphics Libraries	19
2.3.2 VRML a 3D Interface Platform	19
2.3.3 3D User Interface Libraries	21
2.3.4 Games and Game Engines	25
2.3.5 3D Authoring Tools	25
2.4 3D Interface Applications	27
2.4.1 Cone Trees	27
2.4.2 Perspective Wall	28
2.4.3 Information Visualizer	29
2.4.4 Racks (Transformation Tools)	29
2.4.5 3D-Menu, M-Cube and SuperCube	30
2.4.6 HoloSketch	31
2.4.7 Visualization Techniques	32
2.4.8 Data Mountain	33
2.4.9 The 3D Workspaces	33
2.5 Summary	34
Chapter 3: Challenges for 3D Interfaces	36

3.1	Tools for 3D Interface Development	36
3.1.1	How are 3D Interfaces built today?	36
3.1.2	Steps to further 3D Interface Development	38
3.2	Principles for 3D Interface Design	39
3.2.1	Design Principles in Use Today	39
3.3	Applying 3D Interfaces to Real World Tasks	40
3.3.1	Which 3D Components are Effective?	40
Chapter 4:	Overview of the 3D SPACE Project	42
4.1	The Goals	42
4.2	The Approach / Methodology	43
4.3	The Broad Conceptual Ideas	44
4.4	Overview Summary	45
Chapter 5:	The 3D Interface Construction Tool	46
5.1	Why Build a Tool?	46
5.2	The Features of a 3D Interface Builder Tool	47
5.2.1	Shaping the 3D Space	48
5.2.2	Adding The Interactivity	51
5.2.3	Development Platform - Bringing the Features Together	54
5.3	Implementing the Builder Tool	55
5.3.1	The Builder Application Itself	55
5.3.2	The Basic Development Environment	61
5.4	How it Works: Using the Construction Tool	63
5.4.1	Example Application of the 3D Interface Builder	64
5.5	Discussion	72
5.5.1	Choosing the Outputs	73
5.5.2	Options for Interface Development	73
5.6	Summary	74
Chapter 6:	The Set of 3D Interface Components	76
6.1	Designing the Set of Components	76
6.1.1	The Key Design Concepts for the Components	76
6.2	Tasks to be Handled	78
6.3	Designing, Building and Testing the Components	79
6.3.1	Building the Components	80
6.4	The 3D Components	80
6.4.1	The Flow Component	81
6.4.2	The Tunnel Component	94
6.4.3	The Orientation Aid Component	97

6.4.4	The 3D Slider Component	106
6.4.5	The Drum Selector Component	111
6.4.6	The Simpler Components	117
6.4.7	The Circulatory System Interface	130
6.4.8	The Full Environment Interface.....	144
6.4.9	Component Set Summary	155
Chapter 7: Evaluating 3D SPACE - Testing On Users		157
7.1	Experiment Design	157
7.2	Experimental Results.....	158
7.2.1	The 3D Components	162
7.2.2	The 3D Interface Builder	215
7.3	General Observations & Discussion	223
Chapter 8: Conclusions		225
8.1	Contributions.....	227
8.2	Future Potential	228
8.3	Final Remarks	229
References		I
Appendix A: User Testing Configuration		VII
The Hardware		VII
Why a Laptop?		VIII
Impact of a Mouse / Trackpad?		VIII
The Software		VIII
The Testing Process		IX
Data Recording		X
Recording the Quantitative Data		X
Recording the Qualitative Data		XII
Appendix B: User Testing Documents		XIV
Explanatory Statement for Research Participants.....		XIV
Participant Informed Consent		XVI
3D Interface Development Information		XVII
The Task:		XVII
Information on using the Builder Tool:.....		XVII
Appendix C: Ideas for Designing Components		XIX

Figures

Figure 5.1: 3D Development tool options.....	47
Figure 5.2: Actual Tool (left) vs. Concept of Tool (right).....	48
Figure 5.3: The Eyeball (Camera).....	49
Figure 5.4: Lights in the Tool.....	49
Figure 5.5: Example Objects.....	49
Figure 5.7a: Example of an object and its attributes	51
Figure 5.7b: World made up of tree of items	51
Figure 5.8: Setting Interaction Attributes	52
Figure 5.9: Programmed action settings (i.e. Set Sensitivity, Write Action).....	53
Figure 5.10: Non programmed action settings (i.e. Set Sensitivity, Choose Action, Set Arguments)	53
Figure 5.11: World building features & Interaction control	54
Figure 5.12: Tree of Items	56
Figure 5.13: Basic inheritance of item attributes.....	56
Figure 5.14: Basic Items and their stored attributes.....	57
Figure 5.15: Underlying Systems of the Builder Application	59
Figure 5.16: The Builder Application (Java and C++/OpenGL elements).....	60
Figure 5.18: The basic 3D interface development cycle.....	61
Figure 5.19: Generic Development cycle	62
Figure 5.20: Components and their relationship to the builder.....	63
Figure 5.21: Insert Items into Space, Add interactivity to items, Preview Final Interface.....	63
Figure 5.22: Single cylindrical item.....	64
Figure 5.23: Concept of spinning cylinder of items	65
Figure 5.24: Empty World (Builder tool screenshot).....	65
Figure 5.25: The Add Object Dialog.....	66
Figure 5.26: The basic DrumItem	66
Figure 5.28: Attribute Setting Dialog (left) with Touch Event Handler dialog (right).....	67
Figure 5.30: Four view window.....	68
Figure 5.31: DrumItem cylinders arranged in a cylindrical pattern.....	69
Figure 5.32: Spin Control Device	70
Figure 5.33: Screenshot of the Completed Interactive Drum Component.....	71
Figure 6.1: Two Dimensional Scrolling vs. The Three Dimensional Flow	81
Figure 6.2: Pod Racer Game (screenshot)	82
Figure 6.3: The set of results, displayed in 3D flow form.....	83
Figure 6.4: Motion of the set over time relative to the users view.....	83
Figure 6.5: The Value of Depth (Cube vs. Rectangle).....	84

<i>Figure 6.6: The Visible Faces</i>	85
<i>Figure 6.7: Flow observed from above (flowing through and under user)</i>	86
<i>Figure 6.8: Flow with and without Shells</i>	87
<i>Figure 6.9: Screenshot of Flow Control System</i>	88
<i>Figure 6.10a: Get Direction of Flow (offset from line of sight)</i>	89
<i>Figure 6.10b: Position the Set</i>	89
<i>Figure 6.10c: Final Set with flow direction</i>	89
<i>Figure 6.11: The tunnel component</i>	94
<i>Figure 6.12: Relative ring sizes</i>	95
<i>Figure 6.13: A “Real” Artificial Horizon</i>	98
<i>Figure 6.14: Actual state of world</i>	98
<i>Figure 6.14a: Users view without aid</i>	99
<i>Figure 6.14b: Users view with aid</i>	99
<i>Figure 6.15: World & User Coordinate Systems</i>	100
<i>Figure 6.16: User Coordinates Rotate relative to World</i>	100
<i>Figure 6.17: Some examples of orientation representing devices</i>	101
<i>Figure 6.18: Dual System Device (showing both world and user coordinates)</i>	102
<i>Figure 6.19: Example Orientation Aid in use</i>	103
<i>Figure 6.20: The Line Slider</i>	106
<i>Figure 6.21: The Spring-Slider Concept</i>	106
<i>Figure 6.22: The Volume-Slider Concept</i>	107
<i>Figure 6.23: Options for indication “maximum volume”</i>	108
<i>Figure 6.24: Screenshot of Sphere Slider in sizing task</i>	108
<i>Figure 6.25: Screenshots of Spring-Slider (multiple viewing angles)</i>	109
<i>Figure 6.26: Two dimensional menu</i>	111
<i>Figure 6.27: HoloSketch interface</i>	111
<i>Figure 6.28: The concept of the drum component</i>	112
<i>Figure 6.29: Drum’s effectiveness from all angles</i>	113
<i>Figure 6.30: Drums efficient use of screen space</i>	113
<i>Figure 6.31: Sub-drum (yellow) in a drum selector component</i>	114
<i>Figure 6.32: 2D button example</i>	117
<i>Figure 6.33: 3D buttons (highlight on OK)</i>	117
<i>Figure 6.34: The Spinner Device</i>	119
<i>Figure 6.35: Road signs for embedded flow navigation</i>	120
<i>Figure 6.36: The flat menu in a 3D space</i>	121
<i>Figure 6.37: Flat menus (outside) vs. Box menus (inside)</i>	122
<i>Figure 6.38: Flat menu and Box menus from above</i>	122

<i>Figure 6.39: 2D GUI slider</i>	124
<i>Figure 6.40: Screenshot of line slider</i>	124
<i>Figure 6.41: Screenshot of “window box” component</i>	126
<i>Figure 6.42: Tree of “window boxes” and items</i>	127
<i>Figure 6.43: The flow interface for unstructured data</i>	131
<i>Figure 6.44: Human circulatory system [Health 03]</i>	131
<i>Figure 6.45: Example of Celtic knot work</i>	132
<i>Figure 6.46: Screenshot of a Circulatory System Interface</i>	133
<i>Figure 6.47: Basic flow of ring of items</i>	133
<i>Figure 6.48: A Movie Item</i>	135
<i>Figure 6.49: The basic ring concept</i>	135
<i>Figure 6.50: Screenshot of users view from inside a ring component</i>	136
<i>Figure 6.51: Motion of the circulatory system as a whole</i>	137
<i>Figure 6.52: Screenshot of a branch</i>	139
<i>Figure 6.53: The Portal Component</i>	145
<i>Figure 6.54: Screenshot of a toolbelt</i>	147
<i>Figure 6.55: The common (cluttered) GUI desktop</i>	149
<i>Figure 6.56: The Pouch Component</i>	150
<i>Figure 6.57: Cycling of data in a pouch compartment</i>	151
<i>Figure 6.58: The Swiss Army Knife component (left is unselected, right is selected)</i>	153
<i>Figure 6.59: The full component set</i>	155
<i>Figure 7.1: Example Result Chart</i>	160
<i>Figure 7.2 Example Item</i>	162
<i>Figure 7.3: Example of Set (shown with “In to Out” Flow arrangement)</i>	162
<i>Figure 7.4 The target web page</i>	163
<i>Figure 7.5: Top to Base (Sparse) Flow</i>	163
<i>Figure 7.6: Left to Right (Dense) Flow</i>	164
<i>Figure 7.7: In to Out (Flat) Flow</i>	165
<i>Figure 7.8: In to Out - Left (8 High) Flow</i>	165
<i>Figure 7.9: In to Out (Spinning) Flow</i>	166
<i>Figure 7.10: Correct Selections by Flow Type</i>	167
<i>Figure 7.11: Incorrect Selections by Flow type</i>	168
<i>Figure 7.12: Charts - User Assessment of Flow Interfaces</i>	169
<i>Figure 7.13: Charts - User Comfort & Confidence Levels</i>	170
<i>Figure 7.14: Flow Component Wrap-up Questionnaire</i>	172
<i>Figure 7.15: Experienced vs. Inexperienced Users</i>	174
<i>Figure 7.16: Chart - Errors with “No Aid”</i>	178

<i>Figure 7.17: Chart - Time with “No Aid”</i>	178
<i>Figure 7.18: Chart - Comparative Orientation Aids</i>	179
<i>Figure 7.20: Chart - Orientation Confidence</i>	179
<i>Figure 7.19: Chart - Disorientation Level</i>	179
<i>Figure 7.21: Chart - How Suitable were Orientation Aids</i>	180
<i>Figure 7.22: Screenshot of the sizing task (Line-Slider)</i>	182
<i>Figure 7.23: Line Sliders (Front & Top)</i>	183
<i>Figure 7.24: Sphere Slider</i>	183
<i>Figure 7.25 Spring-Sliders (Front & Top)</i>	184
<i>Figure 7.26: Charts - Effectiveness of 3D slider components</i>	185
<i>Figure 7.27: Charts - The users opinions of the sliders</i>	186
<i>Figure 7.28: Chart - Summary of 3D sliders</i>	186
<i>Figure 7.29: Screenshot of the small selection set trials</i>	188
<i>Figure 7.30: The Flat-Menu (Rectangle)</i>	189
<i>Figure 7.31: The Box-Menu (Box)</i>	190
<i>Figure 7.32: The Drum</i>	190
<i>Figure 7.33: Chart - Error rates for small set selectors</i>	191
<i>Figure 7.34: Chart - Time taken for small set selectors</i>	191
<i>Figure 7.35: Chart- Suitability to task for small set selectors</i>	192
<i>Figure 7.36: Chart - How enjoyable are small set selectors</i>	193
<i>Figure 7.37: Chart - Wrapup Questionnaire</i>	193
<i>Figure 7.38: Screenshot of the tool-belt used in all trials</i>	197
<i>Figure 7.39: The empty moving world</i>	197
<i>Figure 7.40: The rich world</i>	198
<i>Figure 7.41: Chart - The Tool-belt Component</i>	199
<i>Figure 7.42: Chart - The Portal Component</i>	200
<i>Figure 7.43: Chart - The Swiss army knife component</i>	201
<i>Figure 7.45: Chart - The value of the tool-belt</i>	202
<i>Figure 7.46 A movie item</i>	204
<i>Figure 7.47: The movie library layout</i>	204
<i>Figure 7.48: The Window-Boxes interface</i>	205
<i>Figure 7.49: The Circulatory System interface</i>	206
<i>Figure 7.50: Chart - Suitability of Ring Interfaces</i>	208
<i>Figure 7.51: Chart - Ring component wrap-up</i>	209
<i>Figure 7.52: Chart - Effectiveness of structured set systems</i>	210
<i>Figure 7.53: Chart - Control in the structured set systems</i>	210
<i>Figure 7.54: Chart - How enjoyable are structured set systems?</i>	211

<i>Figure 7.55: Chart - Browsing task interface suitability.</i>	211
<i>Figure 7.56: Charts - User control & enjoyment.</i>	212
<i>Figure 7.57: Chart - Wrapup for structured set selectors.</i>	212
<i>Figure 7.58: Chart - Experienced user initial skills.</i>	216
<i>Figure 7.59: The experienced users post development questions.</i>	217
<i>Figure 7.60: Chart - Mid level user skills pre trial.</i>	218
<i>Figure 7.61: Chart - The mid-level user post development.</i>	219
<i>Figure 7.62: Chart - Inexperienced user skills pre-trial</i>	220
<i>Figure 7.63: Chart - Inexperienced user responses post trial</i>	221
<i>Figure 8.1: Example component use in VR Surgery concept.</i>	229

