Visualization of Interface Metaphor for Software:
An Engineering Approach

Dinesh S. Katre
By adopting and sharing multi-disciplinary approach, 
knowledge is transformed into wisdom.

How much can one imagine by simply employing one's own logic?

Bhartruhari, Vākyapadiya, 5th Century AD
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Dinesh S. Katre
# Table of Contents

LIST OF TABLES & FIGURES ............................................................................. VI  
ABBREVIATIONS ............................................................................................ IX  

ABSTRACT ............................................................................................................. 1  

CHAPTER 1. INTRODUCTION ............................................................................. 2  

CHAPTER 2. PROBLEM IDENTIFICATION .......................................................... 9  
2.1 Literature Survey ......................................................................................... 9  
2.2 State-of-the-art .......................................................................................... 10  
2.3 Gap Analysis .............................................................................................. 12  
  2.3.1. Linguistic Metaphor and Interface Metaphor .................................... 12  
  2.3.2. Multi-sensory Experience ................................................................. 13  
  2.3.3. Pre-facto Analysis and Evaluation .................................................... 13  
  2.3.4. Design Process .................................................................................. 14  
  2.3.5. Testing the Usability ......................................................................... 15  
  2.3.6. Scope and Objectives of Research ................................................... 15  
2.4 Choice of Terminology ............................................................................... 17  
2.5 Methodology ............................................................................................... 18  

CHAPTER 3. SELECTION OF INTERFACE METAPHOR .................................. 19  
3.1 Identification Based on Common Knowledge .......................................... 19  
  3.1.1. Dependence on Existing Knowledge ................................................. 19  
  3.1.2. Trilogy of Knowledge Dimensions .................................................. 20  
  3.1.3. Stratification of Users ....................................................................... 21  
  3.1.4. Broad Definition of Knowledge Dimensions .................................... 21  
  3.1.5. Comprehension Based on Knowledge Availability ....................... 23  
  3.1.6. Professional and Educational Dimensions ....................................... 23  
  3.1.7. Day-to-day Dimension .................................................................... 24  

---

I
Table of Contents

3.1.8. Cultural Dimension 25
3.1.9. Miscellaneous Dimension 26
3.1.10. Reach of Interface Metaphor 26
3.1.11. Identification of Candidate Interface Metaphors 27

3.2 Braiding of User’s and Design Models ________________________ 28
3.2.1. States of Interface Metaphor 28
3.2.2. Technique for Identification of Candidate Interface Metaphors 29
3.2.3. Comparison with Cognitive Walkthrough 31

3.3 Classification Based on Interrelationships_________________________36
3.3.1. Coherent Interface Metaphors 37
3.3.2. Diverse Interface Metaphors 37

3.4 Assessment Based on Conceptual Structure___________________________39
3.4.1. Animate and Inanimate Metaphors 40
3.4.2. Levels of Conceptual Structure 41
3.4.3. Assessment Based on Conceptual Structure 43

CHAPTER 4. TUNING THE INTERFACE METAPHOR______________________46
4.1 Aspects and Determinants for Tuning the User Experience__________47
4.1.1. Perspective and Focus 47
4.1.2. Field of View 49
4.1.3. Affordances 49
4.1.4. Flavor and Tone 50
4.1.5. Fusion 51
4.1.6. Multimedia Representations 52

CHAPTER 5. ANALYSIS OF INTERFACE METAPHOR ___________________54
5.1 Dissection of Interface Metaphor______________________________54
5.1.1. Objectives of Metaphor Dissection 54
5.1.2. Preparation 54
5.1.3. Format for Metaphor Dissection 55
5.1.4. Precautions For Metaphor Dissection 58

5.2 Dissection of Coherent Interface Metaphor ______________________60

5.3 Dissection of Animate Metaphor_______________________________64
5.3.1. Traits 64
5.3.2. Actions 64
Table of Contents

5.4 Dissection of Diverse Interface Metaphors _____________________________ 66
   5.4.1. Integration of Diverse Interface Metaphors 66
   5.4.2. Cooperative Integration of Diverse Interface Metaphors 66

CHAPTER 6. QUANTITATIVE EVALUATION OF INTERFACE METAPHOR __ 71
6.1 Elements of Quantification ______________________________________ 71
   6.1.1. Conceptual Bandwidth 72
   6.1.2. Usable Conceptual Bandwidth 73
   6.1.3. Coverage of Interface Metaphor 73

6.2 Quantitative Evaluation of Coherent Interface Metaphor _________ 75
   6.2.1. Quantitative Evaluation of ‘Classroom’ Metaphor 75
   6.2.2. Proportion of A and B 76
   6.2.3. Proportion of Coverage Versus Usage 77
   6.2.4. Proportions of Structural Categories 78
   6.2.5. Quantifying the Types of Multimedia Representation 78

6.3 Quantitative Evaluation of Animate Metaphor _________________ 80
   6.3.1. Quantifying the Coverage of Traits 80
   6.3.2. Quantifying the Depth of Traits 80

6.4 Quantitative Evaluation of Diverse Metaphors _________________ 83
   6.4.1. Quantitative Evaluation for QuickMM Album Author 83
   6.4.2. Proportions of Core and Supporting Metaphors 84

6.5 Trade-offs ________________________________________________ 86
   6.5.1. Re-sequencing 86
   6.5.2. Restructuring 87
   6.5.3. Insight of New Requirements 88

6.6 Comparison Between Candidate Interface Metaphors ____________ 90

CHAPTER 7. USER AND APPLICATION DOMAIN LEXICONS _____________ 92
7.1 User Domain Lexicon (UDL) _________________________________ 92
   7.1.1. Mental Models Associated with UDL 93
   7.1.2. Discovering the Mental Model 93
   7.1.3. Format for Documentation of UDL 94

7.2 Application Domain Lexicon (ADL) ____________________________ 95
### Table of Contents

7.3 Fusion of UDL and ADL .................................................. 96  
   7.3.1. Traceability of Lexical Tradeoffs 96  
   7.3.2. Conceptual Parallels Between ADL and UDL 96

CHAPTER 8. USABILITY HEURISTICS OF INTERFACE METAPHOR ...... 99  
8.1 Usability Heuristics .................................................... 100  
   8.1.1. Familiarity 101  
   8.1.2. Similarity 102  
   8.1.3. Extensibility 103  
   8.1.4. Compatibility 104  
   8.1.5. Co-operability 105  
   8.1.6. Representability 106  
   8.1.7. Cognitive Ergonomics 107  
   8.1.8. Feasibility 109

8.2 Quantifying the Heuristic Evaluation .................................... 111  
   8.2.1. Converting the Grades into Points 111  
   8.2.2. Assigning Different Weightages to Heuristic Criteria 113  
   8.2.3. Pre and Post Rendering Heuristic Evaluation 113  
   8.2.4. Post Development Heuristic Evaluation 113  
   8.2.5. Comparison of Usability Evaluation Methods (UEMs) 113

CHAPTER 9. MULTIMEDIA RENDERING AND USABILITY TESTING ...... 115  
9.1 Application of Interactive Multimedia .................................... 115  
   9.1.1. Giving Tangible Form to Visualization 116  
   9.1.2. What Impedes User Interface Designers 116  
   9.1.3. Availability of Technology and Technical Skills 116  
   9.1.4. Objectives of Multimedia Rendering 117

9.2 Multimedia Rendering .................................................. 118  
   9.2.1. Delineation of User Interface 119  
   9.2.2. Diffusion of Interface Metaphor 119  
   9.2.3. Interaction Design 123  
   9.2.4. Usability Testing in Lab 123  
   9.2.5. Remote Usability Testing 123

CHAPTER 10. INTEGRATION WITH SDLC .................................... 125  
10.1 Integration of Visualization Process with SDLC ....................... 125  
   10.1.1. Selection Process 125  
   10.1.2. Tuning Process 127

IV
# Table of Contents

10.1.3. Entire Visualization Process 128  
10.1.4. Applications 129  

CONCLUSION, MAJOR CONTRIBUTIONS AND FUTURE SCOPE 130  
Conclusion 130  
Major Contributions 133  
Future Scope 134  

APPENDICES  
A. Study of Knowledge Dimensions 136  
A1. Stratification of Users 136  
A2. Professional / Educational Dimensions 136  
A3. Day-to-day Dimension 137  
A4. Cultural Dimension 138  
B. Example of CTP and IPS 140  
B1. Visualizing the Traversal of Record 140  
C. Variant Aspects and Determinants of Variance 141  
C1. Comparison of Variance in Interface Metaphor 142  
D. Preparing to Dissect the Interface Metaphor 150  
D1. Selection and Tuning of "Classroom" Metaphor 150  
D2. Selection and Tuning of Diverse Metaphors 152  
E. Dissection of Office Cabin Metaphor 154  
F. Examples of UDL and ADL 156  
G. Examples of Heuristic Criteria 159  
G1. Familiarity 159  
G2. Similarity 161  
G3. Extensibility 164  
G4. Compatibility 164  
G5. Representability 165  
G6. Cognitively Ergonomics 168  
G7. Feasibility 171  
H. Multimedia Rendering of Interface Metaphor 173  
I. Sample of Captured Mental Models 174  
J. Remote Usability Testing 177  
K. Viability of the Process 191  
L. Background Information 200  
M. Glossary of New Terminologies 202  
References 207
List of Tables & Figures

Table 2.1  Comparison of Linguistic Metaphor and Interface Metaphor
Table 3.1  Identification of Common Knowledge Dimensions & Domains
Table 3.2  Reach of Metaphor based on Knowledge Dimensions
Table 3.3  Software Projects and Interface Metaphors
Table 3.4  Comparison of IPS and CTP with Cognitive Walkthrough
Table 3.5  Juxtaposing CTP and IPS
Table 3.6  Template for Selection Process
Table 3.7  Dissection of ‘Classroom’ as Interface Metaphor
Table 3.8  Unmapped Requirements (URs) of ‘Classroom’ Metaphor
Table 3.9  Unmapped Concepts (UCs) of ‘Classroom’ Metaphor
Table 3.10  Second Level Dissection of CDM 1
Table 3.11  Second Level Dissection of CDM 5
Table 3.12  Dissection of Animate Singleton Metaphor
Table 3.13  Dissection of Album Metaphor (Inanimate Singleton)
Table 3.14  Dissection of Exhibition Metaphor (Multitudinous)
Table 3.15  Dissection of Greeting Card Metaphor (Inanimate Singleton)
Table 3.16  Dissection of Calendar Metaphor (Inanimate Singleton)
Table 3.17  Unmapped Requirements (URs) of QuickMM Album Author
Table 6.1  Rating the Coverage
Table 6.2  Quantification of First Level Dissection
Table 6.3  Quantification of Second Level Dissection (CDM1+5)
Table 6.4  Aggregate Projections
Table 6.5  Proportion of Structural Categories
Table 6.6  Counting the Types of Multimedia Representation
Table 6.7  Calculation of Coverage and Depth of Traits in Application Software
Table 6.8  Coverage and Depth of Traits
Table 6.9  Aggregate Projections of Diverse Metaphor
Table 6.10  Proportion of Metaphoric Coverage Versus Usage
Table 6.11  Proportion of Structural Categories
Table 6.12  Re-sequencing of Software Requirements
Table 6.13  Comparison between the candidate interface metaphors
Table 8.1  Aggregate Score of Heuristic Evaluation
Table 8.2  Quantification Metrics for Heuristic Evaluation
Table 8.3  Quantified results of ‘classroom’ metaphor (pre-rendering)
Table 9.1  Linking the Documents and Artifacts of Visualization Process
Table 9.2  Standard UCD Documents
Table A1.  Stratification of subjects for 3D Watershed Game Project
Table A1.  Applications of ‘Book’ Metaphor
Table D1.  Selection of Interface Metaphor for Inscript Typing Tutor
Table D2.  Tuning of Interface Metaphor for Inscript Typing Tutor
Table D3.  Selection of Interface Metaphor for Quick MM Album Author
Table D4.  Tuning of Interface Metaphor for Quick MM Album Author
Table E1.  Dissection of ‘Office Cabin’ as Interface Metaphor
Table E2.  Unmapped Concepts (UCs) of ‘Office Cabin’ as Interface Metaphor
List of Tables & Figures

Table F1. Sample of User Domain Lexicon (UDL)
Table F2. Sample of Application Domain Lexicon (ADL)
Table K1. Resource Allocation (A)
Table K1. Resource Allocation (B)

Figure 1.1 Structure of dissertation
Figure 2.1 Physic of interface metaphor
Figure 3.1 Trilogy of knowledge
Figure 3.2 User profiling for finding the common knowledge dimensions
Figure 3.3 Gradation of knowledge dimensions based on commonality
Figure 3.4 Quick evaluation of candidate interface metaphors
Figure 3.5 The braiding of user’s model with design model
Figure 3.6 The structure of a domain
Figure 3.7 Visual representation of conceptual structure
Figure 3.8 The primary attributes of interface metaphor
Figure 4.1 Aspects of interface metaphor and the determinants for tuning
Figure 4.2 Perspective, Focus and Field of View
Figure 5.1 Insight into the dissection of interface metaphor
Figure 5.2 Metaphors in the wording of requirements
Figure 5.3 Reworking the requirement
Figure 6.1 Aggregate projections of ‘classroom’ interface metaphor
Figure 6.2 Proportion of software requirements covered by metaphor
Figure 6.3 Proportion of usage of metaphoric concepts
Figure 6.4 Proportions of metaphor categories
Figure 6.5 Proposed types of multimedia representation
Figure 6.6 Trait wise coverage and depth of animate metaphor
Figure 6.7 Aggregate projections of diverse metaphors
Figure 6.8 Proportion of core and supporting metaphors
Figure 6.9 Restructured software requirements
Figure 8.1 Interdependence of heuristics of interface metaphor
Figure 9.1 Scope of correction in SDLC
Figure 9.2 Gradual diffusion of interface metaphor
Figure 9.3 Multimedia rendering integrated with documents / artifacts
Figure 9.4 Digitized paper mockup
Figure 9.5 Delineation of initial layout of user interface
Figure 9.6 Most functional layout of user interface
Figure 9.7 Rendering and optimization of interface layout
Figure 9.8 Final multimedia rendering of interface metaphor
Figure 10.1 Selection of candidate interface metaphors
Figure 10.2 Tuning the interface metaphor
Figure 10.3 Visualization of interface metaphor as part of SDLC
Figure A1. Hierarchical structure of a university defined by an architect
Figure A2. Hierarchical structure of a bank prepared by a fine artist
Figure A3. Ganesha metaphor used in Dnyaneshwari CD ROM
Figure B1. Traversal of a record through In and Out Trays
Figure C1. Bookshelf, Book Jackets and Reading Stand
Figure C2. ‘Book’ as an element of ‘classroom’ metaphor
Figure C3. Bookmark representations
Figure C4. Exit button in Dnyaneshwari
### List of Tables & Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
<td>Inscript Typing Tutor for Professionals</td>
</tr>
<tr>
<td>G1</td>
<td>Scheduler Icon</td>
</tr>
<tr>
<td>G2</td>
<td>Pictorial representations of various seasons</td>
</tr>
<tr>
<td>G3</td>
<td>World Start and Stop Icons</td>
</tr>
<tr>
<td>G4</td>
<td>Round buttons</td>
</tr>
<tr>
<td>G5</td>
<td>Shelve metaphor</td>
</tr>
<tr>
<td>G6</td>
<td>Television and VCR metaphor</td>
</tr>
<tr>
<td>G7</td>
<td>Village metaphor used by e-World Online Service</td>
</tr>
<tr>
<td>G8</td>
<td>Temple metaphor in <em>Dnyaneshwari</em></td>
</tr>
<tr>
<td>G9</td>
<td>Mobile phones with icons of 'land-line telephone’</td>
</tr>
<tr>
<td>G10</td>
<td>Eighteen <em>Puranas</em> as beads of necklace and crown with ten flowers as <em>Upanishadas</em></td>
</tr>
<tr>
<td>G11</td>
<td>Light box metaphor of PhotoDisc</td>
</tr>
<tr>
<td>G12</td>
<td>Lightbox in Photo Software</td>
</tr>
<tr>
<td>G13</td>
<td>Gesture Icon, e-mail video and clear video icons</td>
</tr>
<tr>
<td>G14</td>
<td>Oversimplified form of season indicator</td>
</tr>
<tr>
<td>G15</td>
<td>Key-frame icons</td>
</tr>
<tr>
<td>G16</td>
<td>File compression icons</td>
</tr>
<tr>
<td>G17</td>
<td>Syntactic Design of Icons</td>
</tr>
<tr>
<td>G18</td>
<td>Headlight Icon</td>
</tr>
<tr>
<td>G19</td>
<td>Slider visualized (A) and the actual implementation (B) for Typing Tutor software</td>
</tr>
<tr>
<td>G20</td>
<td>Visualization of tabs</td>
</tr>
<tr>
<td>H1</td>
<td>Traversal of a record through In/Out trays rendered using multimedia</td>
</tr>
<tr>
<td>I1</td>
<td>Usability testing</td>
</tr>
<tr>
<td>I2</td>
<td>Season indicator</td>
</tr>
<tr>
<td>I3</td>
<td>Sliding cupboards as user interface</td>
</tr>
</tbody>
</table>
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCI</td>
<td>Human-Computer Interaction</td>
</tr>
<tr>
<td>UXD</td>
<td>User Experience Design</td>
</tr>
<tr>
<td>CIM</td>
<td>Candidate Interface Metaphor</td>
</tr>
<tr>
<td>CDM</td>
<td>Cross-Domain Mappings</td>
</tr>
<tr>
<td>UCs</td>
<td>Unmapped Concepts</td>
</tr>
<tr>
<td>URs</td>
<td>Unmapped Requirements</td>
</tr>
<tr>
<td>CTP</td>
<td>Commentary of Task Performance</td>
</tr>
<tr>
<td>IPS</td>
<td>Interface Play Script</td>
</tr>
<tr>
<td>DT</td>
<td>Dissection Termination</td>
</tr>
<tr>
<td>UDL</td>
<td>User Domain Lexicon</td>
</tr>
<tr>
<td>ADL</td>
<td>Application Domain Lexicon</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
</tr>
<tr>
<td>IPS</td>
<td>Interface Play Script</td>
</tr>
<tr>
<td>SDLC</td>
<td>Software Development Life Cycle</td>
</tr>
<tr>
<td>UCD</td>
<td>User Centered Design</td>
</tr>
<tr>
<td>UEM</td>
<td>Usability Evaluation Method</td>
</tr>
</tbody>
</table>
Abstract

This dissertation presents a comprehensive process for visualization of interface metaphor for software, which is helpful in designing interactive user interfaces with magical super-affordances and definitive user experiences. The steps of this process are integrated with the Waterfall Model of Software Development Life Cycle (SDLC). It mainly focuses on pre-facto analysis, quantitative and qualitative evaluation of interface metaphor to be performed during Requirements Engineering (RE). In this, the candidate interface metaphors are identified within the common knowledge dimensions of specified users. Commentary of Task Performance (CTP) and Interface Play Script (IPS) are written similar to a drama script; and then juxtaposed for capturing the mental model and sensory details of the tasks. The candidate interface metaphors are classified as coherent and diverse based on the interrelationships coded in the cognitive map. The conceptual structures are further categorized at different levels as Domain, Conglomerate, Multitudinous, Singleton (Inanimate, Animate), and Flat Concepts to help in assessing their potential. Various aspects of the selected candidate interface metaphors are identified and tuned based on the determinants of software and user for crafting the desired user experiences. The analysis of interface metaphor is performed through its concept-by-concept dissection. Cross-Domain Mappings (CDMs) are formed between the resonating metaphoric concepts and software requirements. The dissected conceptual structure is quantified to identify the Cross-Domain Mappings (CDMs), Unmapped Concepts (UCs), Unmapped Requirements (URs), Usable Conceptual Bandwidth and Coverage. After this User and Application Domain Lexicons are built to help in designing the linguistic metaphors to be used in the user interface. Interdisciplinary Usability Heuristics and Usability Indicators are identified for the qualitative evaluation of interface metaphor. Quantitative metrics is provided for quantifying the results of heuristic evaluation. Interface metaphor is given a tangible form through multimedia rendering. The documents and artifacts generated through the visualization process are linked with it for corroboration of results. Usability heuristics are applied and tested on the multimedia rendering. A Remote Usability Testing method is developed for evaluating the cross-cultural issues. The interface metaphor is then accepted for incorporation in the design of software after satisfactory clearance through usability evaluations and tests.
Chapter 1. Introduction

This dissertation presents a comprehensive process for visualization of interface metaphor for software applications. The steps of this process are integrated with the Waterfall Model of Software Development Life Cycle (SDLC). This process is designed to help the interface designers and user experience designers in performing pre-facto analysis and usability evaluation of Candidate Interface Metaphors (CIMs) in the formative stages of software development. It also helps the software developers in specifying the software requirements with full awareness of the proposed interface metaphor during the Requirements Engineering (RE) stage itself.

The user interface provides an effective communication medium between a human and a computer [Pressman, 2001]. User interfaces are designed with metaphors as they help you understand one thing in terms of the other [Lakoff et al., 1980]. A metaphor highlights similarities between the known and the unknown (user interface). In the context of this dissertation, the term visualization is to be interpreted as formation of mental visual images. This definition has acquired more meaning in terms of the recall and imagination of all sensory experiences [Owen, 1999].

Chapter 2 presents the arguments in different categories for defining the problem statement of this dissertation. The present understanding of the software community about application of interface metaphor is mostly based on post-facto analysis of successful software products. The researchers have stated that there isn’t adequate guidance available for finding suitable interface metaphors [Vaantinen, 1994] [Smilowitz, 1996] and for carrying out its pre-facto analysis [Madsen, 1994]. There are several other related issues that remain to be addressed such as the theoretical basis for selection of interface metaphor [Madsen, 1994] [Smilowitz, 1996], the method for its optimization, evaluation and its qualitative study [Marcus, 1994, 1998] [Vaantinen, 1994]. Also, there is a
need to measure the applicability and potential of a metaphor [Palmquist, 1996] from the perspective of software design. The method for observing the trade-offs between the design of software and interface metaphor [Yousef, 2001] is needed so that the trade-offs could be regulated. Finally, the seamless fusion (the integration) of form (the interface metaphor) and function (the software) is extremely important [Gaver, 1995]. Poovaiah [1994] has highlighted the need of conceiving the design process of interface as a temporal process in terms of an interaction across time; as an organization of its various elements. All these issues together indicate that the process for visualization of interface metaphor needs to be defined. This chapter sets the objectives, defines the scope of work and the limitations of this research. The dissertation presents a structured process for visualization of interface metaphor. It also shows how the steps of this process are integrated with Software Development Life Cycle (SDLC).

The important steps of the proposed process are discussed from chapter 3 onwards. Chapter 3 focuses on how to identify, classify, categorize, assess and then select the candidate interface metaphors. The first section of this chapter brings out how the candidate interface metaphors can be identified based on the common knowledge dimensions of specified users. It explains the trilogy of knowledge dimensions between the user, the interface metaphor and the software. This section outlines the dimensions of knowledge in terms of professional, educational, day-to-day, cultural and miscellaneous; which help in selecting the candidate interface metaphors. If the required knowledge dimension of a candidate interface metaphor is not matching with the knowledge available with users then it is rejected.

The second section of chapter 3 provides a technique for identification of candidate interface metaphors. It begins by explaining unmanifested and manifested states of interface metaphor. In this, Commentary of Task Performance (CTP) and Interface Play Script (IPS) are written similar to a drama script. These are juxtaposed and compared to reveal the candidate interface metaphors. This technique captures the mental model of users associated with the tasks taken up for computerization. It mainly captures the sensory details of the task, which are most essential while visualizing the interface metaphor. These
include visual, spatial, verbal, auditory and tactile details familiar to the user. Commentary of Task Performance (CTP) and Interface Play Script (IPS) also provide the justification for selecting a particular candidate interface metaphor. This technique is more useful for software projects that focus on computerization of existing processes. It helps in seamless braiding of user’s model, user requirements / user experience requirements and design model.

The third section of chapter 3 shows how the candidate interface metaphors can be categorized in terms of animate and inanimate entities. The candidate interface metaphors are classified as coherent and diverse based on the interrelationships coded in their cognitive maps.

The fourth section of chapter 3 shows how the potential of an interface metaphor can be assessed based on its conceptual structure. It helps the user interface designer in estimating its coverage as against the requirements of software. The candidate interface metaphors are further categorized at different levels in the conceptual structure. These are termed as Domain, Conglomerate, Multitudinous, Singleton (Animate, Inanimate) conceptual structures and Flat concepts.

Identification, classification, categorization and assessment constitute the sequential steps of the selection process of candidate interface metaphors. These are to be performed during the Requirements Elicitation stage of software.

Chapter 4 presents various qualitative aspects of interface metaphor and the determinants for tuning and crafting the desired user experiences. The aspects of interface metaphor such as perspective, focus, field of view, flavor, tone, affordances, fusion and multimedia representations can be tuned to synchronize with the respective determinants. The tuning of interface metaphor helps in choosing the right approach for satisfying the usability objectives and user experience requirements of software. We have termed the sensation of similarities between the reference and application domains as conceptual resonance.
Chapter 1
Introduction

Chapter 5 presents a technique for analyzing the selected candidate interface metaphors. It provides detailed examples of dissecting the coherent, diverse and animate interface metaphors. It proves the possibility of dissecting the interface metaphor concept-by-concept; and forming the Cross-Domain Mappings (CDMs) between the reference and application domains. Dissection of coherent and diverse interface metaphors reveals their unique characteristics. In case of diverse interface metaphors - the conceptual proximity and alignment between core and supporting metaphors, cooperative and incoherent integration types are explained. Dissection of an animate metaphor shows how the behavior of software can be conceptualized on the basis of traits and actions. This technique is extremely helpful in foreseeing the missed out and hidden software requirements. It also helps in identifying the skills and efforts required for the design and development of interface metaphor. This chapter introduces new terms like Unused Concepts (UCs), Unmapped Requirements (URs), Dissection Termination (DT) and Terminus Concept, which are helpful in interpretation of results. The dissection of interface metaphor provides objective basis for estimating its coverage and optimization.

Chapter 6 shows how the coverage of candidate interface metaphors is quantified. It also helps in measuring the extensibility of candidate interface metaphors for present and future versions of the software. The quantitative evaluation technique provides definite parameters for comparing the two or more candidate interface metaphors. It also identifies the weaker traits of the software from the perspective of animate metaphor for further improvement. The quantitative evaluation also enables the user interface designer in monitoring and regulating the trade-offs between the software and interface metaphor. These are mostly in terms of re-sequencing and re-structuring of software requirements as per the conceptual structure of the interface metaphor. The quantification technique provides several insights into overall conceptual structure of interface metaphor.

Chapter 7 presents a technique for building User and Application Domain Lexicons. Fusion of User Domain Lexicon (UDL) and Application Domain Lexicon (ADL) helps in designing the linguistic metaphors for user interface.
Formats for building UDL and ADL are designed to integrate unique aspects of domain specific terms and phrases. Special attention is given to context of application and mental models associated with the user vocabulary, which helps in revealing the tacit knowledge of users. These lexicons are very helpful in not only reinforcing the main interface metaphor but also in capturing the vocabulary of users. User Domain Lexicon (UDL) can be developed further beyond the scope of a software project.

Chapter 8 provides the Usability Heuristics of interface metaphor. We have identified eight major heuristic criteria namely Familiarity, Representability, Similarity, Extensibility, Compatibility, Co-operability, Cognitive Ergonomics and Feasibility for qualitative evaluation of interface metaphors. Furthermore, there are 23 sub-criteria and 41 Usability Indicators identified for ensuring the usability of interface metaphor. The objective basis for evaluation is also indicated for each criterion. It is proposed that the pre-rendering evaluation of interface metaphor may be performed before taking it up for multimedia rendering. Quantitative metrics is also provided for quantifying the results of qualitative evaluation.

Chapter 9 shows how interactive multimedia can be used for design, rendering and usability testing of interface metaphor. The proposed application of multimedia integrates all the documents and artifacts generated through the visualization process. It allows the interface designer, software developers and users to refer, compare, crosscheck and corroborate the linked information. The multimedia rendering of interface metaphor reveals several hidden software requirements and usability problems related with it. It enables the software designer in foreseeing the implementation issues. It can maintain the record of all evolutionary stages of visualization along with the reasons of modifications. The user interface designer can test the interface metaphor over the specified users and fix the usability problems. Multimedia rendering of interface metaphor can produce several interface components in terms of graphics, layouts, animations, sounds, and the scheme of interaction design. These can be incorporated in the final software. A remote usability testing method is also developed for
testing the **cross-cultural** aspects pertaining to visual representations of interface metaphor. It involves the **users from diverse geographic locations** in the testing process.

Chapter 10 shows how the steps of visualization of interface metaphor can be **integrated and synchronized with SDLC**. It synchronizes the steps of visualization with the steps of **Requirements Engineering (RE)** process; such as **Requirements Elicitation, Analysis** and **Specification**. The visualization process of interface metaphor is to be completed just before the Requirements Specification stage. It helps the software designer in designing the software with adequate understanding of the expected user interface or user experience.

After this the conclusions, the major contributions of this dissertation and future research extensions are documented.

**Figure 1.1 on next page presents the structural diagram of the dissertation.**
Figure 1.1 Structure of dissertation
Chapter 2. Problem Identification

2.1 Literature Survey

The topic of this dissertation is highly interdisciplinary and it touches upon diverse domains such as Software Engineering, Cognitive Science, Semiotics, Linguistics, Visual Communication and Multimedia Visualization. This topic of research belongs to the new emerging discipline called Human-Computer Interaction (HCI). It is based on the study of research publications mostly from diverse technical journals and magazines like ACM Interactions and Communications of the ACM, Human Factors in Computing, Man Machine Studies, IEEE Software and SIGGCHI Bulletin. These have regularly covered interdisciplinary articles and papers related to the topic of dissertation. Large number of research papers from the proceedings of international conferences such as Computer Human Interaction (CHI) and HCI International are studied. Most of the journals and conference proceedings were accessed from ACM and IEEE Digital Libraries. The study also includes research papers from a variety of other sources such as Journal of Educational Multimedia and Hypermedia, Journal of Computer Documentation, Journal of Human Computer Studies, etc. There are several other sources like ISO standard for usability and electronic proceedings of a variety of conferences. These are appropriately cited during the deliberations and enlisted in the list of references.

The research papers, articles and books authored / edited by the most notable researchers in the domain of HCI are studied. These include HCI experts like Aaron Marcus, Brenda Laurel, Jakob Nielsen, Thomas Erickson, John Carroll and Keran Holtzblatt. We have also studied the works of George Lakoff (Cognitive Linguist) and Donald Norman (Cognitive Psychologist and Usability Expert). These are appropriately cited while positioning the problem statement of the dissertation.
2.2 State-of-the-art

The research on interface metaphor during 1981–1990 broadly covered its emergence, benefits, understanding of how it works and its applications. Whereas, the later part of research during 1991–2005 raises the problems, issues and gaps in the process of development of interface metaphor. This is a very broad categorization based on prominent trends of the research publications on interface metaphor.

The first Graphical User Interface (GUI) that used menus, buttons, icons and mouse pointer emerged in 1981 from Xerox Palo Alto Research Center (PARC). It was used as part of the 8010 Star Information System designed for business professionals who handled information. Star’s GUI represented the typical office environment in the form of Desktop metaphor. The success of Desktop metaphor captured the interest of user interface researchers [Johnson et al., 1989]. This indeed was the beginning of cautious use of metaphor as an integral part of user interface. It proved that interface metaphor could capture the mental model1 of users [Erickson, 1990]. It inspired further research initiatives on interface metaphor in terms of using the cognitive psychology [Johnson et al., 2000] for improving the effectiveness of user interface.

But the Xerox PARC was not the first to use metaphors. Metaphors have been expressed through language since ages. Metaphors are pervasive in everyday life of humans. We commonly use them for understanding one thing in terms of the other [Lakoff et al., 1980]. If you look at the history, the writings in ancient religious scriptures and iconography are quite metaphorical in nature. Nyāyasiddhānt Muktāvali of Vishwanāthanyāyapanchānan [17th Century A.D.] provides the definition of metaphor in Sanskrit (an ancient Indian language) as below.

\[ \text{तत्त्वज्ञाते सति तद्गतभूयो धर्मवक्त्वम् जागृत्यम्} \]

It can be translated as- being different from each other X and Y share many same properties. Humans have always used metaphors as the tool of innovation, creation.

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1 The gut feeling based on experience used to understand the functionality or behavior of system (Dix et al., 2004).
and communication [Richard, 1941][Gasset, 1925] [Mountford, 2000]. However, the success of Desktop metaphor resulted in several articles and research publications that attempted to define the role, the cognitive model and advantages of using the interface metaphor.

The present understanding of interface metaphor broadly covers following points-

- It provides a conceptual model to users for predicting the functionality of a system [Norman, 1988].
- It can incorporate the features of real world into the computer application [Nielsen, 1994].
- It can help in determining the presentation and behavior of software [Brad, 1990].
- It also enables the users to start learning from what is already known and familiar to them [Erickson, 1990].
- It superimposes essential similarity (between the software and real world) through visuals (words and images) or through acoustic or tactile means. It also represents the mental models through navigation, tasks and roles [Marcus, 1998].

With the faster insertion of information technology across the world, usability of user interface became the focal area of research. The trends of research in Human Computer Interaction (HCI) accelerated in the year 1990 [Carroll, 2002]. User interface became a basis for the product’s usability and commercial success [Marcus, 1995]. Naturally, the use of interface metaphor is now considered most inevitable [Chen. 2002] aspect of user experience design. **In summary, the interface metaphor continues to be an important area of research in the 21st century [Hamilton, 2000][Marcus, 2002].**

The next section of this chapter identifies the requirements, gaps and problems pertaining to application of interface metaphor in software products.