Francis T. Marchese
Ebad Banissi *Editors*

Knowledge Visualization Currents

From Text to Art to Culture

Springer

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Preface

This book is concerned with how visualization is used to represent and interpret complex information, particularly text, at the intersection of knowledge, art, and cultural heritage. It gathers together extended versions of 11 papers that were presented at the 15th International Conference on Information Visualization, held 13–15 July 2011 in London, United Kingdom. They are organized into four sections covering knowledge, text, art, and cultural visualization.

The intended audiences for this collection are researchers from both industry and academia, groups that reflect the backgrounds and activities of this book's contributors. It puts forward unique examples of applied knowledge visualization from disciplines such as the law, business management, the arts, and humanities, exposing the evolution of visualization as a field. By examining the theoretical and practical aspects of visualization from the early Sumerian tablets through the twenty-first century legal contracts, this book underscores the important role that the process of visualization plays in extracting, organizing, and crystallizing the concepts found in complex data.

I. Knowledge Visualization

The term knowledge, derived from (Middle English knoulech: knouen, to know), is defined as "awareness, consciousness, or familiarity gained by experience or learning." It is often cophrased with the theoretical or scientific notion of philosophy or gnoseology (from Greek gnosis: knowledge, and the logos: study) as the science of knowledge and its causal principle. Visualization is defined as the creation of a mental image, a process that is related to visual perception. Knowledge visualization is often used as an extension of, or leading from information visualization, or visual analysis, and certainly uses similar conceptual abstract models and metaphors. But the key to understanding it as a field is recognizing its emphasis on collaboration.

Knowledge visualization is a young discipline that continues to evolve. The first two chapters of this book explore its current state of affairs. In "What is an Effective Knowledge Visualization? Insights from a Review of Seminal Concepts," Martin J.

Eppler compiles an expanded array of seminal concepts for defining the foundations of knowledge visualization by culling material from diverse domains such as art history, psychology, philosophy, education, and management science. He then derives a set of five principles for creating effective knowledge visualizations. The discussion of knowledge visualization's nature is expanded in Chap. 2, where Stefan Bertschi and seven other experts answer the questions: What is knowledge visualization, and what should it be? Each contributor considers a different aspect of knowledge visualization for exposition such as the use of graphics, storytelling, knowledge discovery, and visual thinking. These individual views offer a snapshot of the present and a perspective of the possible future of a discipline that could not be timelier aiming for a common understanding of the visualization of knowledge.

II. Text

The three chapters of Part II are concerned with text as both a visualization modality and the visualization of textual matter itself. Francis T. Marchese begins by taking a historical approach, looking at how tabular structures have been used to organize and visualize knowledge from the ancient through the medieval times in his chapter "Tables and Early Information Visualization". He pinpoints milestones in the history of visualization that include: Sumerian accounting tables, the chronicles and canon tables of Eusebius of Caesarea, medieval calendars, and the use of tabular grids used to communicate conceptual abstractions such as religious dogma and degrees of blood relation.

In "Contract Clarity and Usability through Visualization," Helena Haapio illustrates how visualization may be employed to remove the ambiguities in knowledge transfer that are a natural part of business relationships. In particular, she demonstrates how potential conflicts in understanding among a diverse collection of stakeholders may be avoided in the text-oriented contact creation process by integrating visualization techniques into practice.

Finally, Andreas Kerren et al. use wine reviews as a sample study of how their interactive visualization system is useful for linguistic exploration, and analysis of lexical, grammatical, and discursive patterns in text. Their chapter, entitled "Visualization of Sensory Perception Descriptions," illustrates how the visual, olfactory, gustatory, and textual properties that embody a particular wine's quality may be compared with other wines from a worldwide knowledge base.

III. Art

Part III of this book contains chapters revisualizing that which has already been "visualized." Chapter 6, "Colorscore: Visualization and Condensation of Structure of Classical Music," by Aki Hayashi et al. demonstrates how complex orchestral score structure may be transformed into a visualization displaying in parallel the melodic patterns of each member of the orchestral ensemble. Such visualization provides composers, arrangers, musicians, and listeners with a concise overview of an entire musical work making it easy to see patterns that would otherwise be difficult to perceive from scores alone.

Many examples of art may be viewed as knowledge visualizations. In particular, the Renaissance artworks that transformed the Biblical and related texts into visual form are exemplars. The optical theory behind these works, their evolution, and ultimate integration into contemporary visualization systems is examined by Theodor Wyeld in his chapter “The Implications of David Hockney’s Thesis for 3D Computer Graphics”. By analyzing the artworks of Eyck, Vermeer, Caravaggio, and others throughout the art history he explores the parallel and sometimes intersecting threads of theory and practice in their expression of naturalness, now rendered matter-of-factly in contemporary 3D graphics systems.

In Chap. 8, Yulia Petrova et al. exploit 3D visualization and graphics systems to plan the restoration and reconstruction of both the architecture and the interior decor of a twelfth-century Russian church extensively damaged during the Second World War—the Church of the Transfiguration of Our Saviour on Nereditsa Hill. Faced with the daunting task of reconstructing a building nearly reduced to rubble and assembling interior frescos from more than 300 K surviving fragments, these researchers fashioned a process that integrated archaeological materials, archival and present-day documentation, scientific research, traditional artistic practice, and digital methods to render the church and its interior.

IV. Culture

In a true sense of the word, the structure of knowledge and its application is not dependent upon any particular discipline. Indeed, it is the fact that all patterns of human knowledge, belief structures, and behaviors may be abstracted, integrated, and subsequently transmitted to succeeding generations that gives culture its definition. These cultural attributes are what made possible Petrova et al.’s reconstruction of the twelfth-century Russian church. Some of these attributes are explored in the three chapters that comprise this section.

Deray and Day describe an approach for reframing of the cultural heritage as bodily experience articulated through narrative-based media in Chap. 9—“Mediation of Knowledge Construction of Historic Sites: Embodied Interaction + Space.” Using a building’s architecture to frame a knowledge-embedded space, they construct an experimental environment in which the written correspondence between early owners of an historic house is explored by its visitors. As viewers walk through the space, they sense changes in visual and auditory production that communicate a narrative structure. The result of these authors’ work is a proposed set of design guidelines and mediation strategies for enhancing bodily experience of historic content and context.

Some fundamental structures are system and scale independent. The fractal-branching patterns exhibited in river deltas and the respiratory systems come to mind—both of which having evolved over time. In "Memory, Difference, and Information: Generative Architectures Latent to Material and Perceptual Plasticity," Lucia, Sabin, and Lloyd examine the evolutionary "architecture" arising from analysis of the information content of the spatiotemporal patterns left behind by humans and single-celled life forms as they engage their environment. Such architecture is the antithesis of traditional top-down Euclidean geometric designs deeply rooted within architectural culture. Yet, as the authors propose, their methodology may be utilized to analyze all architectural forms, thus providing a means for creating an enhanced understanding of architectural space, its perception, and use.

The closing chapter by Kenderdine, Shaw, and Gremmler entitled "Cultural Data Sculpting: Omnidirectional Visualization for Cultural Datasets," examines how immersive 360° stereographic visualization systems may be employed to explore massively complex datasets of cultural interest. From the immersive rendering of entire Chinese tombs to visual access of 166 K pages of the Buddhist Cannon, this research demonstrates how embodied interaction and knowledge-based interfaces enhance the collaborative analysis and the understanding of large bodies of information important to cultural heritage.

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We are extremely thankful to all the authors who have contributed to this edited collection. It has been a pleasure to work with them during all stages of the book's preparation. We are grateful to the organizers of the Information Visualization conference for creating the eclectic environment that made such a collection possible. We also offer our appreciation to Simon Rees and Wayne Wheeler, editors at Springer-Verlag, United Kingdom, for their support during the preparation of this work.

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Part I
Knowledge Visualization Background

Chapter 1
What Is an Effective Knowledge Visualization? Insights from a Review of Seminal Concepts

Martin J. Eppler

Abstract The domain of knowledge visualization (KV) focuses on the collaborative use of interactive graphics to create, integrate, and apply knowledge. This emerging approach nevertheless builds on decades of research on using images collaboratively for sense making and knowledge sharing. In this chapter, we review the seminal concepts from different disciplines that help to explain how visualizations can effectively act as collaboration catalysts and knowledge integrators. Our review makes it apparent that many different labels and conceptions exist in very different domains to explain the same phenomenon: the integrative power of visuals for knowledge-intensive collaboration processes. These concepts can be used to compile a list of the requirements of an effective KV. We conclude this chapter by showing the theoretical and practical implications of this review.

1.1 Introduction

The domain of knowledge visualization (KV) is a relatively young discipline that focuses on the collaborative use of interactive graphics to create, integrate and apply knowledge—particularly in the management context. This young field nevertheless builds on decades of research on using images collaboratively for sense making and knowledge sharing.

The objective of the current chapter is to make this rich legacy of the knowledge domain field visible and use it to inform the practice of visualizing knowledge. In this chapter, we will thus review the seminal concepts from different disciplines that help to explain how visualizations can act as collaboration catalysts and support the elicitation, integration, and application of knowledge on a team or group level. This review will make it apparent that many different labels exist in various domains to explain the basically same phenomenon: the integrative power of visuals for knowledge-intensive collaboration. Our review of the key concepts, however, will also reveal that visuals must meet certain criteria to achieve this integration function effectively.

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This chapter is structured in the following manner: First, we provide an example of a KV and discuss the already-identified attributes of such epistemic (knowledge-intensive) images in Sect. 1.2. Then, we describe the rationale behind our review of the key concepts that can inform KV conceptions in Sect. 1.3, where we also discuss seminal, highly cited constructs from disciplines as diverse as sociology, art history, e-learning, psychology, epistemology, or design. We cluster these constructs according to their emphasis on visualization or collaboration respectively. As a main contribution we identify similarities among the concepts and summarize them in five derived KV principles. To illustrate these principles, we focus on a few seminal concepts in more depth in Sect. 1.4. In the subsequent Sect. 1.5, we derive implications from the reviewed constructs for the theory and practice of KV. The final Sect. 1.6 of this chapter consists of a short conclusion and an outlook on future research in this area.

1.2 The Realm of Knowledge Visualization

We define KV (in contrast to the mostly data-driven information visualization field) as follows: KV designates all (interactive) graphic means that can be used to develop or convey insights, experiences, methods, or skills [6, 7]. This definition implies that the realm of KV is not limited to computer-based images and that the main purpose of KV is to support the (inherently social) processes of creating and sharing knowledge with others.

Figure 1.1 provides a simple example of this approach. This figure represents the completed analysis conducted by a management team regarding the service quality problems in their call center. Starting with the empty iceberg metaphor (as a discussion template) and its tip containing the label "service quality low", the team went to probe its root causes and mapped the main issues or problem drivers in a reverse causal chain backwards to the less visible problems (in the lower part of the iceberg). In doing so, the group elicited the team members' different insights regarding the current challenges in the call center. The graphic iceberg template and corresponding facilitation method enabled the team to pool these insights and relate them to each other, as well as devise adequate improvement actions.

The resulting image can then be used in subsequent meetings to explain the problem to other staff members and to help in the implementation of improvement measures. The image contains knowledge on a detail level, such as the impact of budget restrictions on the available infrastructure, as well as one overall insight, namely that the service quality level is just the tip of the iceberg of a much larger problem. The image in Fig. 1.1 is a typical knowledge representation in the sense that it contains various types of images, such as the visual metaphor of an iceberg, sketch marks for highlighting (the blue circle) as well as diagrammatic elements (text elements and arrows). It also indicates a process of how to discuss the problem analysis, namely in an overview to detail, top-to-bottom process.

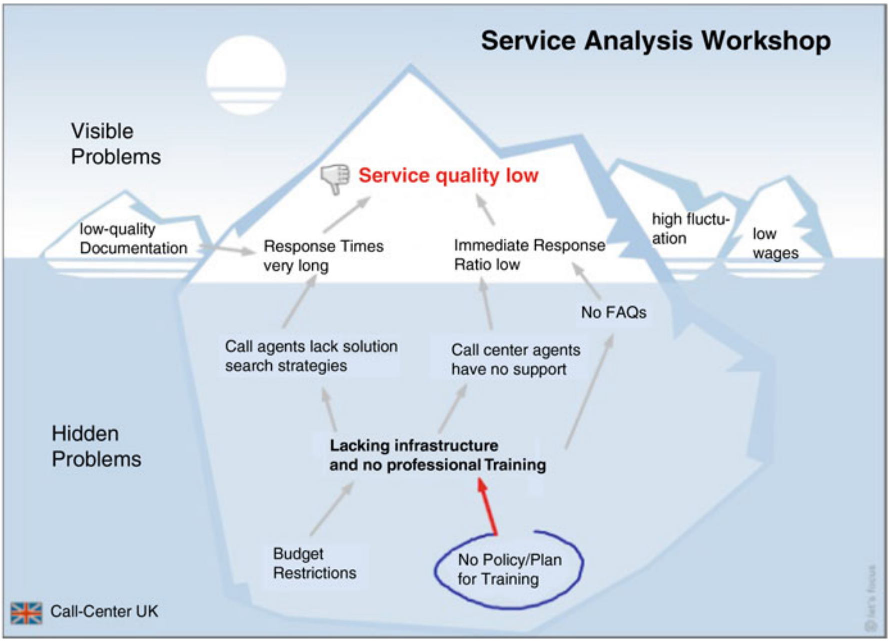

Fig. 1.1 An example of a knowledge visualization

A KV, such as the simple one depicted above, consequently has to fulfill the following criteria to merit the label in our (group-level) application context:

1. It has to be able to *capture* and *depict Knowledge*, that is to say (valid and current) insights, experiences, concepts, perspectives, opinions arguments, etc., of informed participants.
2. Ideally, it contains *insights* from more than one *person* alone and *relates* these ideas to one another.
3. It has to be *visual* in the sense that the knowledge mapped in the image is spatially positioned within a diagram, visual metaphor (as above), sketch, map, or photograph, or combinations thereof.
4. It has to support the (group) *process* of knowledge integration among various people. It should in other words *facilitate (synchronous or asynchronous) conversations*.
5. To achieve this, the visualization has to be *revisable* or flexible, so as to be able to react to changing insights in a group over the course of time.
6. It has to be *communicable* in the sense that the image can be communicated to others (of different professional background) who have not been present during its creation process (this is, for example, a common problem with the use of mind maps).
7. Ideally, its use leads to *new discoveries* or insights that were previously unknown and that are *useful* to viewers of the visualization.

These criteria are derived from the cognitive [9] and collaborative dimensions of visualization research [1] and from the practical use of KVs in management [6, 7]. However, requirements for KV may go beyond this straight forward list of attributes. Are there other key characteristics that KVs should exhibit to support knowledge processes? Are these seven attributes confirmed by approaches in other domains?

To answer these questions, we have reviewed seminal concepts related to 'collaboration through artifacts' (the larger subject domain). These concepts are shortly presented and compared in the next section.

1.3 A Review of Seminal Concepts

Having described the goal and rationale of reviewing concepts related to KV and more broadly working with artifacts to share knowledge, we now proceed to a concise overview of closely related constructs from different domains.

Altogether, we have been able to identify the following concepts that describe the key notion of using visualization as a catalyst for knowledge sharing. Each one contains a profound insight into the nature of images as collaboration platforms. We will briefly discuss these insights in this section.

The selection criteria for these concepts were that (a) they have to be highly cited, i.e., have achieved more than at least 100 citations (in Google Scholar), (b) they have to specifically address (at least partly) images as knowledge exchange mechanisms, and (c) relate them to collaboration contexts (to a lesser or greater extent).

We were also interested in concepts from radically different domains, so that different kinds of insights into collaborative visualization could be fruitfully integrated.

To select highly influential concepts, we have counted the total amount of citations reported on Google Scholar for the first three articles (in terms of citations), employing the concept in the article title or abstract. This has lead to the list of seminal concepts that appears in Table 1.1.

These concepts not only differ with regard to their disciplinary background, but also with regard to their respective focus. As we have shown in Fig. 1.2, the concepts can be distinguished regarding their emphasis on the role of images or on the actual collaboration that (graphic) artifacts can support.

The resulting segmentation shows two main groups of concepts, namely those focusing on visualization (represented by visualization scholars such as Edward Tufte, James Elkins, or Barbara Tversky), and those focusing primarily on collaboration (visualized as empty bubbles in the matrix, such as the ethnographic work of Barbara Knorr-Cetina in the context of scientific discovery, or of Kathryn Henderson in the area of design engineering).

More important than their differences, however, at times, are the astonishing (given their radically different backgrounds) similarities among these concepts. In Table 1.2, we have articulated the key requirements for KV directly deduced from these seminal concepts.

Table 1.1 The key concepts related to knowledge visualization from different domains

Concept	Concept domain	Originator	Citations (Σ top 3)
Boundary object	Sociology	Star et al. [18]	2,083
Epistemic object	Epistemology	Knorr-Cetina [14]	1,919
Dynamic affordance	Management	Cook and Brown [2]	1,523
Transitional object	Management	Eden and Ackermann [3, 4]	1,200
Notation criteria	Philosophy (of art)	Goodman [8]	1,120
Cognitive dimensions of notation	Computer science	Green [9]	110
Confection	Information design	Tufte [21]	924
Immutable mobile	Sociology	Latour [15]	860
Visual language	Instruction	Horn [12]	499
Conscription device	Sociology	Henderson [10]	366
Representational guidance	e-Learning	Suthers [20]	324
Diagrammatic reasoning	Logic	Peirce [11]	283
Visual hybrids	Art history	Elkins [5]	113
Visuospatial reasoning	Psychology	Tversky [22]	100
Affiliative object/working artifact	Management, anthropology	Suchman [19]	200
Object oriented/mediated collaborative action	Management	Kaptelinin [13]	600
Scaffold	IT/management	Orlikowski [16, 17]	300

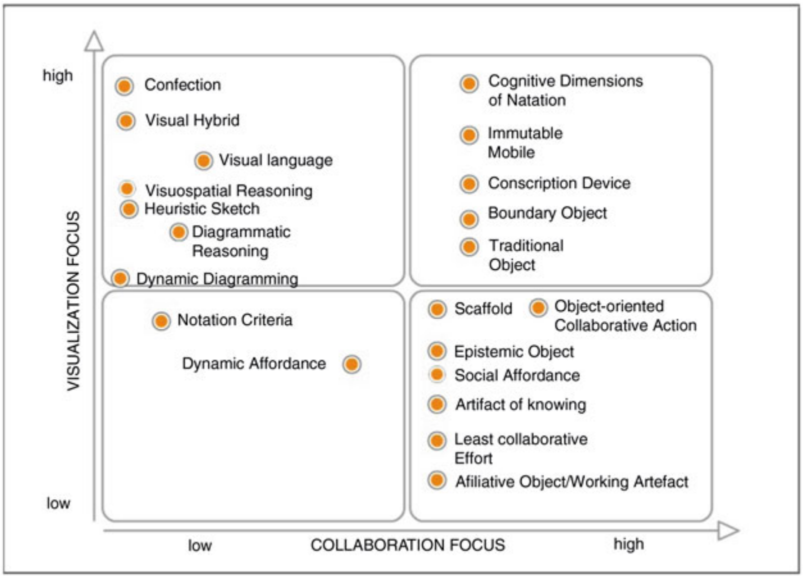

Fig. 1.2 A segmented overview of the key concepts for knowledge visualization

Table 1.2 Requirements derived from the concepts

Derived KV principle	Base concepts	Main insight of the concepts
Visual variety	Confection; visual hybrids; visual language; boundary object; notation criteria; cognitive dimensions of notation	An image that is able to capture and convey the knowledge of different people requires different ways of expression, ranging from simple sketched marks to complex rich visual metaphors contained in a single image
Visual unfreezing	Immutable mobile; boundary object; conscription device; notation criteria; cognitive dimension of notation; transitional object	To be useful for knowledge sharing and collaboration, a visualization must be able to be switched from a fixed mode to a flexible, modifiable mode and back
Visual discovery	Diagrammatic reasoning; visuospatial reasoning; dynamic affordance; representational guidance; conscription device; cognitive dimensions of notation	A visualization for collaboration must provide assistance for reasoning, reflection, and linking items in new ways so as to facilitate new discoveries from the shared insights
Visual playfulness	Representational guidance; diagrammatic reasoning; transitional object; conscription device, scaffold	In order to overcome rigid assumptions or role definitions and narrow perspectives, the visual should provide playful mechanisms to reframe issues and cajole participants into a different mindset and thus generate new insights and intensify collaboration
Visual guidance	Representational guidance; transitional object; boundary object; diagrammatic reasoning; dynamic affordance, affiliative object, scaffold, mediated collaborative action	The visual has to fulfill a dual role of not only capturing and structuring contributions, but also of providing a process of doing so in a useful sequence of actions

Compared with the original list of KV attributes presented earlier, we notice that visual playfulness is a new item, while visual variety, visual unfreezing, and visual discovery, as well as visual guidance are existing ones that are confirmed. Based on these attributes we can now provide a normative definition of what a KV should amount to, namely a communicable image, consisting of various visual notations, that is interactively annotated in a playful yet systematic manner and leads to new discoveries while remaining flexible to incorporate future revisions and insights.

In the next section, we present a few of the above-listed seminal concepts in more detail to show how they contribute to the emerging principles of KV.

1.4 Select Seminal Concepts in Detail

To illustrate the principle of *Visual Variety*, we can use Elkin's idea of *Visual Hybrids*, Tufte's concept of *Confection*, and Latour's notion of *Immutable Mobile*:

A *visual hybrid*, according to Elkins [5] is a graphic notation system that not only relies on one image genre, but combines two or more visualization formats (such as graphs, charts, tables, diagrams, genealogical trees, etc.). According to Elkin: "Especially given the hurtling development of new image technologies, mixed images can be said to be the norm rather than the marginal exception" [5, p. 91].

Very close to this notion is the idea of a visual confection. A *confection* according to Tufte "is an assembly of *many visual events*, selected from various streams of a story, then brought together [. . . .] Confections illustrate an argument, present and enforce visual comparisons, combine the real and the imagined, and tell us yet another story" [21, p. 121]. "Confections are not direct representations of pre-existing scenes, nor are they the result of placing data into conventional formats such as statistical charts, tables, or maps" [21, p. 122]. Tufte himself thus envisions that there are other visualizations than simple data or information representations.

Also, Latour's concept of immutable mobiles emphasizes the need for visual variety defining such artifacts as consisting of "*figures, diagrams, plates, texts, silhouettes*." [15, p. 37].

Latour's concept can also be used to explain the concept of *Visual Unfreezing*. Inscriptions are mobile as their elements can easily move, but these inscriptions become immutable and fixed on paper, once they have been confirmed by all participants.

Star and Griesemer's concept of a *Boundary Object* also emphasizes this dual nature of collaborative artifacts. Boundary objects, according to Star and Griesemer [18], are "both *plastic* enough to adapt to local needs and constraints of the several parties employing them, yet *robust* enough to maintain a common identity across sites." Boundary objects are weakly structured in common use, and become strongly structured in personal use. They may be abstract and conceptual or concrete and specific. They have different meanings in different social or professional contexts, but their structure is common enough to more than one professional community to make them recognizable means of translation.

The principle of *Visual Discovery* is not unique to the domain of KV, as detecting new patterns is also the main aim of the field of information visualization. In the KV context, the pursue of novel insights takes on a different form, as they are generated not out of the analysis and mapping of mass data, but rather visualized individual and collective views, opinions, assessments, and analyses.

This notion of insight through a process of interacting with a visual is probably best captured in the concept of *Diagrammatic Reasoning* that was first introduced by Charles Peirce [11]. The visualization becomes a think tool with which an individual or a group tackles a difficult problem. A simple example of diagrammatic reasoning is the positioning of elements according to their similarities in overlapping or containment circles, as in a Euler or Venn diagram. From this positioning, new insights can emerge, for example, groups with many versus groups with few members.

The principle of *Visual Guidance* is a particularly important concept for KV, as images in this context are not only used as representations of data but as catalysts for a collaboration process. Images act as signposts to what should be discussed and in what order. We find this attribute in Suthers' [20] concept of *Representational Guidance* in the context of e-learning and in Cook and Brown's [2] concept of

Dynamic Affordance in the management context. An image used in collaboration can act as a representational guidance, according to Suthers, by providing certain constraints to a discussion, by stimulating certain actions in a group, and by drawing attention to certain discussion topics (that are made salient graphically). Dynamic affordance, according to Cook and Brown's perspective, is what becomes possible when knowledge is used as a tool in the context of situated activity [2, p. 392]. These situated activities can be influenced through artifacts that invite participants to do one thing rather than another. Visuals thus provide affordances to steer the discussion in a particular direction.

Regarding the new principle of *Visual Playfulness*, we can—for instance—use Eden and Ackermann's notion of *Transitional Objects*. In their book on strategic management, Eden and Ackermann [3, p. 71] state that to do something enjoyable together can make collaboration easier; for example, tinkering with a strategy visualization used as a transitional object. Used in this provisional, exploratory or playful way, the visualization encourages an open dialogue and is capable of change by the group in real-time [3]. According to Eden and Ackermann, the participants who interact in this way waste less energy in impression management and are more immersed in their knowledge exchange than they would otherwise be. In this way, playfulness can be conducive to productive collaboration.

1.5 Implications

In terms of *practical implications*, the principles derived from the review of seminal concepts can be used as a checklist for group facilitators in the preparation stage of their work. They can use the identified attributes to evaluate or improve their discussion templates and thus make them more conducive to knowledge elicitation, integration, and application. More specifically, the five principles derived above can be used to check questions before knowledge creation, sharing, or application session, as exemplified below:

- *Visual variety*: Have you provided a sufficiently rich visual vocabulary that enables participants to express their ideas through various ways, such as through diagrams, sketches, metaphors, or simple text additions?
- *Visual unfreezing*: Have you incorporated ways in which certain states of a collaboratively drawn visualization can be captured and 'frozen' for later reference? Are there clear criteria when a frozen visual can be reelaborated and changed again?
- *Visual discovery*: Does the visual template provide affordances to connect elements in a new way or look at the big picture and detect new patterns?
- *Visual playfulness*: Does the visual invite participants to change perspectives, assume new roles, immerse in the collaborative effort, let go of assumptions or otherwise reframe issues creatively?
- *Visual guidance*: Does the visual offer a clear 'roadmap' of how it should be iteratively populated or completed? Is it clear where to start in the visualization and how to proceed?

In terms of *theoretical implications*, we have seen that in spite of their great differences in background, the examined concepts have an astonishing congruence with regard to the underlying mechanisms that they discuss. Anyone working on a future theory of collaborative KV is thus well advised to venture outside the realm of his or her own discipline and make use of the insights generated in such diverse disciplines as design, instruction, sociology, psychology, or art history. In this way, the domain of KV could also make this often dispersed knowledge accessible to scholars and practitioners alike.

1.6 Conclusion

In this chapter we have made an attempt to define the requirements of a KV that deserves the label. We have done so based on our practical experience [6, 7], the cognitive and collaborative dimensions framework [1, 9], and based on seminal concepts in the literature on collaborating with artifacts [2–5, 8–12, 14, 15, 18, 20, 21]. This has resulted in an extended list of requirements for KVs that we captured in five KV principles. These principles can be used to assess or improve KV templates used in knowledge-sharing tasks of teams.

In future research, we would like to see which of these requirements are in a trade-off relationship with one another and how they can be achieved through the help of interactive visualization software and adequate facilitation interventions.

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Chapter 2
What Is Knowledge Visualization? Eight Reflections on an Evolving Discipline

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Abstract Almost a book within the book this chapter collates eight expert reflections on Knowledge Visualization; what it is and what it could or should be. An average of 825 words long, topics span from representation, storytelling, and criticizing the lack of theory, to communication, analytics for the masses and reasoning, to trendy Visual Thinking and creativity beyond PowerPoint. These individual views provide a picture of the present and the future of a discipline that comes at precisely the right time. Despite the diverse character of its parts, written by academics and practitioners alike, this unique compilation constitutes a whole, a facetted answer to the question in its title, thus aiming to convey a common understanding of visualizing the true resource of our time, knowledge.

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2.1 Introduction

The International Symposium on Knowledge Visualization and Visual Thinking held annually at the International Conference Information Visualization is now in its eighth year, and it is about time to assemble a selection of expert opinions on where we are today and where this evolving discipline is heading.

In order to achieve this, members of the Symposium's Advisory Committee were invited to participate in a joint paper, and seven coauthors have accepted the invitation. The requirements were: to contribute a personal view of no more than 625 words, with no illustrations allowed, using a few references if needed. The topical requirement stated that these personal opinions had to reflect on the current and/or future state of what the authors consider to be Knowledge Visualization.

The result is a set of individual vistas on a multifaceted discipline. Each individual contribution has been revised and extended for this book chapter (resulting in an average length of 825 words). Each view sheds a different perspective on the notion of Knowledge Visualization and highlights specific theoretical or practical aspects. While these reflections highlight the different associations with the term, they also show emerging commonalities, such as a process view on visualization. Nonetheless, it is the diversity of visualization that comes to the fore in this international collaboration, spanning across professional cultures and mind-sets, with contributions written by academics and practitioners alike, extending from what Knowledge Visualization is perceived to be, to what it does and could or should be doing and representing.

These eight reflections have been restructured and ordered in such a way that they follow this vision from fact to fiction. Even though the chapter ends in a conclusion, it was never the intention to provide a final answer. It is rather to convey understanding and to introduce this multifaceted discipline to a wider audience, but also to inspire further thinking about knowledge, a resource second to none, and how to make use of all visual means to bring this resource alive.

2.2 Beyond Text: The Graphical Structuring of Knowledge

Sabrina Bresciani Visualizing knowledge refers to mapping concepts graphically by structuring text and visuals in a meaningful way. Visual representations are used to organize and structure information and ideas in order to convey knowledge to amplify cognition and to enhance communication. Examples of Knowledge Visualization include conceptual diagrams, knowledge maps, and visual metaphors.

In recent years, we have witnessed a growing interest in Knowledge Visualization from the business community. Yet, visualizing ideas is not a novelty for humanity. The cave men visualized their hunting strategy for teaching best practice and discussing improvements some 15,000 years ago (i.e., in the caves of Lascaux, France). Today, modern business men visualize their organizational strategy to discuss ideas, make decisions, and communicate the strategic plan to employees [41]. With verbal and textual communication we are constrained to express ideas in a linear and sequential format. Our thoughts, however, are not linear: we think and make sense of reality through associations, relationships, and comparisons. The brain is wired for interpreting visual information, which is perceived faster and better than verbal or textual information. Dual coding theory states that we process information through the verbal/textual channel *and* the visual channel: only when both channels are used, performance in terms of understanding, recall and engagement is enhanced [31].

Having such insight, why are we utilizing only one part of our brain? Through the use of spatial distribution of text, Knowledge Visualization leverages on both the textual and the visual abilities of the brain to express meaning. Knowledge Visualization can overcome the limitations of textual/verbal communication and of visual representations alone. Adequate use of visualization empowers people to become better communicators, expressing complex ideas more clearly, showing overview and relationships. Knowledge Visualization structures conceptual knowledge [24, p. 7] and provides salience, thereby facilitating the focus on certain information at the expense of other. Images have an impact also on the emotional attitude of the viewer, by providing engagement and motivation. Visualizing knowledge is useful for collaborative work: mapping the group dialogue can facilitate the integration of knowledge and it can surface misunderstandings more prominently than text.

To understand the meaning of Knowledge Visualization, the difference to Information Visualization should be addressed. The two concepts overlap in their common aim to offer insights to the viewer: "Knowledge visualization [...] designates all graphic means that can be used to construct and convey complex insights" [8, 14, p. 551]. However, the unique nature of Knowledge Visualization lies in the content that is being mapped, posing a stronger emphasis on knowledge and experiences rather than on numerical information. Adopting the definition given by Chen [8, p. 387], "[t]he term *information visualization* refers to computer generated interactive graphical representations of information." By contrast, Knowledge Visualization is not necessarily computer generated and its visualized content generally consists of refined and aggregated information. The ancient cave paintings and a business mind map drawn with pen and paper are common examples of Knowledge Visualization which are not computer mediated at all.

Recent developments in Information and Communication Technology (ICT) enable a widespread use of Knowledge Visualization by empowering any user with limited drawing skills to easily create conceptual visualizations. In recent years, reflecting a trend in society, we observe the emergence of Knowledge Visualization as a new discipline, based on a growing number of case studies and theoretical conceptualizations [12, 15]. Yet, the lack of a solid theoretical background poses a significant limitation for the development of this particular field.

Future directions of development for Knowledge Visualization are seen along the following three main paths. Firstly, if the discipline were to find stronger legitimization in the academic domain, rigorous research evidence of the advantages of Knowledge Visualization over plain text is needed. Current theoretical perspectives could be substantiated by experimental studies measuring the impact of visualization, especially in emerging forms of collaborative interactions, including visual groupware and social media. After all, visualizing knowledge is not without risks [3]. For a deeper understanding of its effects, typical challenges and mistakes committed while creating or using Knowledge Visualization (i.e., oversimplification and ambiguity of meaning) should be investigated. Secondly, the diffusion of innovative input devices such as (multi-)touch screens is enabling new ways of interaction with software and particularly in groups. This particular disciplinary field would benefit from understanding the implications of these fluid forms of interaction. Thirdly, still as an emerging discipline, it could expand its horizon of applications by introducing and testing knowledge visualizations in new domains, intercultural communication among others, a context where visual representations can be particularly useful to overcome linguistic and cultural barriers.

The graphical mapping of concepts—made easier by modern communication technologies—promises to enhance human abilities for reasoning and communicating beyond text. Considering this, one can see why visual structuring and representation of knowledge is so powerful. Regardless, whether they are cave paintings from some 15,000 years ago, sketches and visual concepts supporting contemporary decision making in organizations or detailed work breakdown structures in IT project management, we could not do without them. Despite the challenges mentioned, it is the way we as human beings process information that eventually highlights the potential, importance, and promising outlook of Knowledge Visualization.

2.3 Conveying Knowledge Through Storytelling

Andrew Vande Moere *Knowledge* is information that has been made part of a specific context, the collection of influences that impact the way we understand its expression. In order for information to transform into knowledge, the information must share some context with a preexisting experience, in order to become meaningfully connected and fully understood. In that sense, Knowledge Visualization can be considered as "data visualization in context". While Knowledge Visualization facilitates people to investigate trends, patterns, and outliers in data, it does not necessarily aim to explore or discover them, but rather attempts to unravel the driving or causal principles that control these data phenomena. Using the knowledge gathered from the context, such data trends can be explained, rather than simply observed and discerned. Knowledge, therefore, is not about knowing the facts, but knowing the contributing factors and the underlying context in which the facts have come about.

Stories are a powerful means of providing context. Not surprisingly, knowledge has been often shared and communicated through the process of storytelling [38]. Storytelling tends to place information (e.g., activities, events, facts) within a commonly accepted contextual framework, often by exploiting the qualities of internalization and socialization. While a story aims to convey a series of specific truths, it is the narrative that provides a context in interpreting the overarching meaning, which potentially transforms it into knowledge that is actionable.

While Knowledge Visualization has been recognized as an independent scientific discipline [6], the relevance of storytelling toward its scientific goals is still relatively unexplored. However, storytelling is important in visualizing knowledge, as the way data is framed or presented significantly affects how it is interpreted. Early research proposed some simple "actions" such as animation, mood, and place as particularly effective storytelling techniques in data visualization [42]. A more recent study has investigated more qualitative design dimensions such as genre and visual or narrative structure to categorize the existing methods of visual storytelling in the domains of online journalism, graphic design, comics, business, art, and visualization research [37]. In comparison to most other storytelling methods, computer games provide a nonlinear way to structure a narrative, such as by using rules, goals, or mechanics of play. Accordingly, recent research has shown that "game-y" information graphics have the ability to motivate users to experience and bias both the exploration of data parameters and the nature of insights in new ways [10]. Similarly, rhetoric strategies such as omission, classification, or contrast can be exploited to directly or indirectly prioritize certain interpretations of the data [20]. With this theoretical background in mind, the emerging popularity of online visual storytelling [35] presents at least two new challenges for the field of Knowledge Visualization.

First, the use of storytelling in visualization has been primarily considered on a phenomenological level, as a set of design techniques that enable the visualization designer to direct a viewer's attention through a sequential narrative, or a series of visual transitions. This experiential viewpoint might miss the role of context in the visualization practice, and how the explicit or implicit presentation of the surrounding influences has the potential to augment the visual sense-making process from observing eventual data patterns and trends into reasoning about the underlying meaning of their occurrence. If context propels data-driven knowledge acquisition, then how is it best represented? Second, it might be equally revealing to analyze visual storytelling techniques in the context of Knowledge Visualization, or vice versa, investigate Knowledge Visualization design methods in their ability to convey knowledge through storytelling. Such wide analysis should at least provide a better understanding of the effectiveness of specific visualization strategies in conveying knowledge. Alternatively, one might discover promising, but potentially under-explored, storytelling approaches to applications of Knowledge Visualization.

While Knowledge Visualization might be less entertaining or eye-catching than most popular forms of "visual storytelling " such as in journalism, design, or art, both approaches essentially focus on conveying some form of context, and therefore also knowledge, to an increasingly information-hungry audience. What might make Knowledge Visualization inherently different from other types of visual storytelling is the complexity and scale of the content that needs to be communicated [42]—any visualization is inherently connected to some form of hard data, which often requires a graphical representation because of its complexity in terms of size, dimensionality or time-dependency. Therefore, with the emerging popularity of data-driven insights in different media, expectations will inevitably shift from simply delivering simple facts and information to conveying its meaning, emotions, interpretations, or consequences, the very knowledge that influence the events in our world today.

2.4 What Is Cooking? Visualization as a Recipe for Success

Tom Crawford While classically, the word communication implies that it is from one person to at least one other, it can also be communicating to yourself as a way of understanding and remembering what you have learned.

The process of Knowledge Visualization contains steps such as gathering, interpreting, developing an understanding, organizing, designing, and communicating the information. While the previous sentence implies a linear flow, it is hardly a linear process. In fact, any step can link to any other step in any number of iterations until a "final" representation is created. Of course, it never is quite final. Even if we were able to come up with the perfect visualization, our knowledge changes and with it changes the visual. In fact, the visual often provides so much insight that our knowledge changes and thus the visual needs to change creating a fascinating recursive loop.

Strangely, while we have learned much about Knowledge Visualization over the last 100 years, we still have yet to rethink and redesign some of the most common forms of communication. For example, the lowly recipe, which has been around and largely unchanged for more than 3,600 years, is a form of communication from one person to another. The original assumption of the recipe designer was that anyone who needed to read it shared a specialized language and process, which often now is learned either as an apprentice or in culinary school. However, that language breaks down when the same information design goes from chef to home cook. The assumptions of terminology and process break down when the home cook has not had the same education or experience as the professional chef.

So, what would happen if we were to rethink the design of the recipe and apply Knowledge Visualization techniques to the problem?

During the early stages of Knowledge Visualization, we would conclude that the recipe contains four basic types of information: ingredients, process, and equipment which are combined in particular ways via a series of techniques. In analyzing the current recipes, we would find that the design mixes the four types of information somewhat randomly which leads to the possibility of mistakes.

For example, the list of ingredients also contains process steps (e.g., 200 g onion, diced). These are two different pieces of information. An ingredient list is essential to make sure that what is needed to make the recipe is present. However, what you do with those ingredients should all be handled in one place. It becomes even more complex when understanding that "dicing" an onion is not one but actually five steps (cut in half, top, peel, plus at least two cuts).

Knowledge Visualization would not only make it clear what kind of onion, but also what then needs to be done with it. No longer would cloves be confused with garlic cloves because they look nothing alike. Photos could be used to show what a ripe banana looks like in comparison to one that is past its prime to help the home cook choose not only the right ingredient, but the freshest and best ingredients. The same idea could be applied to the equipment which is rarely, if ever, shown in a recipe. Food mills, reamers, mandolines, and many other infrequent but valuable tools could not only be shown, but demonstrated directly in the context of the recipe.

Maybe most importantly, certain types of information are best received, processed, and understood when delivered as needed rather than all at once. The traditional recipe is guilty of not understanding this. All of the information is presented at once. That can be helpful when trying to get an idea of what the recipe entails. However, when actually cooking, having all of the information at once can cause errors. If the cook is on step 3, steps 1 and 2 are likely no longer relevant which may cause the cook to return to the wrong place in a recipe. In addition, the information needed to complete the step (ingredient quantities, for example) is not included with the step. Instead, it is in a completely different place causing potential lookup errors. Finally, most recipes are written with only three to seven steps, when in reality most recipes have 20–30 steps. Compound steps cause cooks to miss vital information and skip steps. One solution would be to present a series of visualizations showing each step accompanied by a text description.

The recipe is only one of the common forms of communication that could use a much closer look. By using the tools and process of Knowledge Visualization, we can begin looking deeply at the recipe's components, who it is used by, and what they are using it for, and therefore create more effective tools that reduce errors and increase satisfaction. That is the power of Knowledge Visualization.

2.5 The Missing Step in Discovering New Knowledge from Data

Vedran Sabol To talk about Knowledge Visualization and its potential role in the discovery of knowledge, it is important to agree on a definition of knowledge and understand how knowledge differs from pure data. We define knowledge as an established set of facts, which are recognized to be valid and valuable within a specific application domain. There are many ways in which knowledge can be represented. In computer science, it is often represented through formal models consisting of concepts, relationships between them, and logical conditions—the so-called ontologies—which facilitate processing of knowledge by machines.

Knowledge Visualization is a discipline which focuses on representing knowledge differently, and it does so by expressing facts using a form most natural and intuitive to humans—graphical representation. Knowledge Visualization deals with creating and applying visual representations with the main purpose of constructing and communicating useful knowledge [13]. Visual representation of knowledge can either be static such as sketches and diagrams shown in presentations or on posters or it can be interactive using computer displays and offering possibilities for navigation, exploration, and manipulation of knowledge reaching from small sets of knowledge to large knowledge bases.

The advantages of presenting knowledge in visual form are manifold: visualization not only facilitates understanding, remembering, and transfer of facts, but also provides the fuel for reasoning processes, where new knowledge is derived and created from previously acquired knowledge. As such, Knowledge Visualization targets application domains such as Knowledge Management and Strategic Management in general. In the following, a potential application outside of these traditional domains is explored.

Knowledge Visualization is contrasted by the fields of Information Visualization and Visual Analytics. These two closely related disciplines focus on interactive visualization of data and information, hence, they are operating at a lower level of abstraction than Knowledge Visualization. In this context, data is understood as a collection of raw numbers and characters describing some qualitative or quantitative attributes, for example, persons' names and ages. To obtain information, data is transformed, transferred, and made available for interpretation by users within a specific context where it gains a specific meaning and becomes understandable to these users, for example, retrieval of information on the Internet. However, knowledge which may be present in large amounts of data and information is often hidden (i.e., not explicitly available) and must be "unveiled" to become useful.

Information Visualization tackles this challenge by making use of human visual capabilities to recognize patterns in data sets and to extract new knowledge from abstract information. Visual Analytics takes this idea further by focusing on analytical reasoning and providing tight integration of machine processing and interactive visualization [23, 39]. Typical users of visual analysis tools are data analysts in application domains such as Business Intelligence or Public Security. Although Visual Analytics differs substantially from Knowledge Visualization in its conception and areas of application, both fields share common properties as both breed new knowledge.

Certainly, the process of discovering new knowledge from data does not only involve visualization. Knowledge Discovery is a process consisting of a chain of automated data-processing steps (i.e., selection, transformation, mining, and presentation), where at the end of the process new knowledge is derived from massive amounts of data [16]. Visual Analytics has been successfully applied in the context of Knowledge Discovery, where it serves as the final stage of the processing chain, providing visual means for discovering new knowledge in addition to automated methods.

What is currently lacking in the Knowledge Discovery process is the possibility to capture discovered knowledge and make it explicitly available in a visual form suitable for transfer and communication. It therefore appears as a compelling idea to integrate Knowledge Visualization into the Knowledge Discovery process to fill this gap. The extended Knowledge Discovery process would not only provide means to unveil hidden facts, but would also offer an intuitive visual platform: delivering knowledge as the final product, including all its accompanying facets such as experiences, attitudes, and opinions. Moreover, Knowledge Visualization could be combined and integrated with Visual Analytics, creating a unified visual platform integrating pattern recognition with expressing and communicating recognized knowledge. In such a setting, management support or organizational support in a wider context, provided by Knowledge Visualization, would be closely integrated with analysts' output, which is supported by Visual Analytics. Additional synergies could be generated where properties and functionalities of both visual approaches overlap, for example, in providing support for decision making and offering a common platform for collaboration.

Allowedly, the envisioned application of Knowledge Visualization leaves many conceptual and technical challenges untouched, such as designing workflows integrating Knowledge Visualization with Visual Analytics, or associating models backing Knowledge Discovery methods with Knowledge Visualization representations. If successful, such an application would not only advance the Knowledge Discovery process, but would also trigger exciting new developments in all involved areas of research.

2.6 Connecting Foundations of Knowledge Visualization from Science to Art to Culture

Randy Goebel The current state of the art in the *science* of Knowledge Visualization is pretty well represented by the distribution of papers [1], which I claim shows a healthy diversity of ideas on how to transform data into pictures. There is a balance between the development of new ideas for rendering objects in a visual space, and on the application of existing methods to a variety of application specific data, including health, bioinformatics, geography, and a broad spectrum of web data. In this paradigm, which seeks to articulate rigorous methods of visualization, there remains opportunity to develop insight into visualization semantics and the role of cognitive science in drawing inferences from pictures; I suggest these aspects should be stronger, because, after all, visualization is about how the human visual system can be inferentially amplified by rendering foundation data in appropriate visual spaces.

In this regard, one can note that work on *methods* for visualization are not so distinct from the technical skills and innovation that have emerged in a wide variety of visual artistic media, in everything from ancient art form to modern digital media regardless of the artistic motivation, rendering in visual media requires technical skill and innovation. In fact, one might posit that a distinction between the science and art of visualization lies in that which is to be expressed: An abstract idea infused with culture and identity of an artist, compared with the transformation of concrete data, to be "explained" in a visual manner with the intention of evoking identical perspective in all viewers.

So, this distinction between visual art and Knowledge Visualization is really about whether foundation data is open and shareable. When it is, the transformation to visual media can be assessed with respect to how well it conveys the foundation data.

In the case of the scientific foundation for visualization, progress can be gauged by, for example, the 7 years of the Science Visualization Challenge [18, 30], which has brought the role of visualization into the scientific mainstream. The continued problem here, however, is that while the Science challenge raises awareness and interest in visualization, it still has the flavor of a kind of "beauty contest," instead of a disciplined assessment of the quality of visualization techniques. As opposed to conventional visual *art*, the question should always be about *how well* a particular visualization technique supports visual inference about the foundation data.

With respect to the future of visualization, I think an appropriate approach is captured by Kay's [22] assertion that "The best way to predict the future is to invent it." One strong personal motivation for inventing the future of visualization arises from an assertion I recently read in a paper I was refereeing, which wrote "... as the theory of visualization tells us...." I balked, as there is no theory of visualization. But there should be.

To invent the future of visualization is not to abandon the current state in pursuit of some fundamentally different paradigm, but just to bring a little more scientific thinking to what a theory of visualization should be? If the simply stated goal of visualization is to amplify the human visual system's ability to draw inference from complex data, then we need much more work on *what kinds* of inferences can be made, and *how well* they can be made.

Again from my own viewpoint, not uniformly shared, I believe that it is scientifically useful to view pictures as inductive inferences about the data and data relationships from which they arose. Within that framework, we can not only design experiments that evaluate the quality of inference that a visualization method provides, but can also reflect on how easy it is for humans to reach conclusions intended by visualization methods application.

So, take Alan Kay's generic advice to heart, and invent the future of visualization. This requires a stronger role for good scientific reasoning to guide the connection of visualization research components: clever graphics, scientifically justified "art," innovative multidimensional rendering, all *coupled* with evaluation with respect to the efficacy of making insightful inferences.

Perhaps Knowledge Visualization is a kind of maturing teenager, slowly emerging out of the eclectic chaos of graphics cleverness, scientific modeling art, and overly specific multidimensional rendering? In this view, all technical skills and insight of artistic aspects of visualization are relevant, as long as they inform transformations and rendering from foundation data as opposed to the expression of individual artists.

Increasing maturity is evident in the continued diversity of visualization ideas, coupled with an increasing volume of work on visualization *evaluation* [32]. So, while one would not entertain the veracity of a visual artists rendering of their abstract idea, one must question the veracity of a visual rendering of commonly interpreted foundation data. After all, if the goal of visualization is to amplify our visual systems' ability to draw inferences from visual representation of foundation data, then we need to develop scientific discipline about how to assess alternative visualization methods. From that will emerge aspects of a theory of visualization, and the future will be invented.

2.7 Visualization Beyond PowerPoint

Stefan Bertschi The roots of Knowledge Visualization, as it is presented and discussed annually at the International Conference Information Visualization (IV), are in business and management. Hence, we learn from research into visualization that strategic and operational processes rely on communication and interaction. Visualization of any kind significantly improves communication and therefore business processes. Knowledge Visualization caters for refined and aggregated information commonly used in planning and implementation practices as well as projects and change processes [6]. Though not solely confined to business, Knowledge Visualization aims to understand how the sender's intended meaning can be transferred in such a way that it is not distorted in the recipient's perception, allowing effective and efficient communication to take place.

The human mind is a strange thing; however, for most people we may state that complex dependencies and interactions can more easily be understood when illustrated: An intelligent process flow chart makes more sense than a numbered list describing the same process in words, a project (Gantt) chart showing timelines and interdependencies allows for better understanding than a project scope, even if structured. The difficulties are to be found in how to make best use of the understanding of others, their intentions and perceptions, simply because there is no direct way to look inside their heads. Visualization and Visual Thinking subsequently allow us to reveal these "understandings" because they provoke discussion, allowing the alignment of opinions and arguments.

Knowledge Visualization not only has the potential to solve "the predominant problems in organizations", i.e., to communicate complex contents to diverse audiences, but to pose important problems related to this communication. It "aims to improve the transfer and the creation of knowledge" by giving people "richer means to express what they know" [6, pp. 131, 135). However, this particular research area as well as its everyday application would need an improved theoretical foundation of all its leading mechanisms (e.g., metaphor, meaning, and perception; [2]). Based on such missing theory, Knowledge Visualization equates to managing meaning and perception, whereas processes of constructing and reconstructing meaning need to be recognized and understood.

Media, not to be confused with mass media, are needed to align individuals and their personal perception of things; we need to understand the symbols and representations that allow individuals to be linked. This is a two-way process which has to be supported by suitable mediating structures: it is new forms of collaborative media that allow individuals to "collectively highlight issues and obstacles that would have rendered silence in the old world where communication was rare and one-dimensional" [19, p. 23]. Working toward a common goal is effective in mitigating risks; Knowledge Visualization is to allow, build, and strengthen common understanding.

If organizations in need of successful transfer of knowledge are to ensure that they benefit most from current insight, then the single most important advice would be:

"listen", but even more: "listen with your eyes" (!), beyond meaningful sentences alone. In each of us, there is a reader *and* a viewer. Think of illustrations and visualizations beyond Microsoft PowerPoint and Microsoft Project; think why "pencil selling" just using pen and paper is so much more effective than words alone in selling anything, ranging from goods to projects. Do not be afraid to draw and sketch in front of a live audience, or even better, sketch collaboratively and experience how much better ideas are being generated, ideas that stick in all participants' heads.

Speaking and listening with your eyes also means making full use of the available methods (see for example, the Periodic Table of Visualization Methods; [25]). Knowledge that can be seen can be used effectively and efficiently. It is important to keep a critical mind; if used incorrectly visualizations themselves can be risky [3]. Furthermore, the activities of knowledge workers (such as attorneys, marketers, scientists, and senior executives) are "too variable or even idiosyncratic to be modeled or structured with a defined process". Basically, their need for access to knowledge sources, ranging from online databases and social media to spreadsheets, presentation tools and business intelligence analytics "is presumed to be equally eclectic and unpredictable" [9, p. 90f.]. The range of tools used does not necessarily ease the knowledge process.

Does this mean the complexity of some of the tools and techniques available is a barrier to creating visuals? I would not necessarily blame the complexity of methodology but the lack of complexity or willingness for creativity in creating these visuals. I have personally had great experiences with visual cocreation both in strategy and in operational processes. Visuals stimulate discussion, and discussion creates knowledge. Arguing this way, full use of methods does not mean to use them all at once, but to use and combine them as necessary. Less is many times more because the average human brain can process far less information than we anticipate: Four complex arguments in one go are too many, rather make your three points, but make them right and sustainably. Transparency and simplicity are the answer—visibly and visualized for business purposes and far beyond.

2.8 Empower Public Discourse on Challenges Involving Complex Data

Wolfgang Kienreich The concept of public discourse refers to the process of collaborative opinion formation and decision making which enables consensual problem solving on a societal level. Participants of public discourse have traditionally utilized news media as a primary communication channel for the distribution of information and the exchange of views and opinions. With the advent of globally available consumer-generated media, an increasing amount of public discourse is taking place on the World Wide Web. However, discourse modalities such as text and images have largely been retained despite the advanced visualization and interaction capabilities provided by this new communication channel.

In many contemporary challenges, as for example climate change and financial crisis, understanding large and complex data sets is a prerequisite for forming an informed opinion. This observation is reflected in the rise of data-driven journalism, a journalistic process which creates news stories based on the analysis of large data sets relevant to the general public. Similar to expert analysts in many domains, in their investigations data journalists utilize approaches which are founded in Visual Analytics. This underlying paradigm contains a "closed loop" integration of automated analysis, visual representation and user interaction, and the aim to use such an integrated approach as method to provide users with new insights [40]. Successful applications have been demonstrated in domains such as Business Intelligence, Environmental Monitoring, and Genetic Research. However, such an approach emphasizes the use of visual abstractions and advanced interaction patterns. Elaborated Visual Analytics have been tailored toward expert users and are not suitable for a general audience.

It is a central characteristic of a postmodern, pluralistic society that a broad majority of individuals should be involved in public discourse. In the face of challenges which involve large and complex data sets, this aspiration necessitates means which empower a general audience to explore, analyze, and comprehend complex data. The required technology is already available in the form of the World Wide Web. The ability of Rich Internet Applications to replace complex proprietary systems has been amply demonstrated in Corporate Intranet environments. The required data is also becoming increasingly available. Many governmental institutions have exposed relevant data to citizens under Open Data policies, and Linked Open Data initiatives interlink data sources to ensure accessibility on a technical level. From a participatory point of view, the primary hindrance barring public discourse from considering complex data sets has been the lack of a suitable visualization and interaction paradigm. Knowledge Visualization is a promising candidate for filling this gap.

Knowledge Visualization postulates the use of visual representations to foster the communication of knowledge between two or more people. It integrates findings and approaches from Information Visualization research, Human–Computer Interaction studies and Information Design theory. Approaches based in Knowledge Visualization also consider cultural and aesthetical aspects of application scenarios. Clear benefits have been demonstrated for common situations such as presentations, discussions and, in general, support in decision making [4]. Knowledge Visualization emphasizes the use of visual metaphors to represent relevant information and facilitates collaborative dissemination and decision making. Systems designed according to this paradigm tend to be accessible to novice users and to produce results comprehensible to a broader audience.

The ongoing debate on climate change is an example of the envisioned role of Knowledge Visualization in empowering public discourse. Numerous public and individual sources report on related phenomena and base arguments on observational indicators. However, the reproduction of scenarios and the validation of facts are hindered by the amount and complexity of the underlying data. Domain experts find it hard to present results in an easily understandable manner and despite the general availability of data laymen cannot easily judge the plausibility of an argument. In this situation, Knowledge Visualization could provide means for interactive visual exploration and validation which would foster understanding beyond the level of highly simplified infographics.

There are technological and societal indicators which support this vision. The omnipresence of mobile devices featuring multitouch surfaces emphasizes the need for simple yet powerful visual interfaces. The rise of consumer-generated media and social networks is increasingly replacing traditional hierarchical communication channels with omnidirectional means of discourse. Recent applications of Knowledge Visualization acknowledge the benefits of collaborative approaches and utilize multitouch tables to support joint analysis of complex problems by groups of experts [7].

The main challenge for Knowledge Visualization will be the integration of automatically computed yet manually directed data analysis with the already highly developed means of visualization and interaction. A considerable amount of experience in this direction has already been accumulated in research into elaborated Visual Analytics. It is likely that a close cooperation of the two disciplines will deliver systems empowering public discourse on challenges which involve complex data in the near future.

2.9 The Doodle Evolution: Back to the Roots in Visual Thinking

Martin Lindner Visual Thinking is a big trend, particularly in the age of the "micro-web". Its main exponents are people such as Dave Gray (CEO of consulting firm XPLANE and coauthor of "Gamestorming"; [17]), Dan Roam (author of "Back of the Napkin"; [33]), Lee LeFever (creator of the simple explanation videos ". . . in Plain English" that became popular via YouTube), or Sunni Brown who coined the term "Doodle Revolution" (book forthcoming; [5]). "Enterprise 2.0" consultancies such as XPLANE or the more mainstream Root Learning use visualizations collaboratively created by workshop participants to change management processes [11].

The wider context, I think, is a new wave of visualizations and Visual Thinking that was started in the 1990s. Of course, we had revolutions in visual language before: Otto Neurath invented modern "infographics" around 1930, and Quentin Fiore, who collaborated with Marshall McLuhan in the 1960s, may stand for another paradigm change. However, the visualization wave reached new heights in the 1990s: digital data, Apple-driven graphic engines and, finally, the Web 2.0 have changed the game.

We have discovered whole new possibilities to collect, organize, and manipulate digital data. This has opened the view on new abstract facts, new complex realities. Meanwhile, human understanding is still stuck in the primary world of physical objects, face-to-face communication, and people doing things to each other in direct ways. In a world of massively mediated interaction and communication, this cognitive model must fail. As mass "macro-media" become grassroots "micro-media" in the era of the World Wide Web [26], they reach beyond entertainment and pop culture.

What we see emerging is a new mode for new ways of collective thinking, networked conversations, and knowledge creation.

Certainly, there are many trends in visualization that run back to the “Big Bang” caused by personal computing and digital networking. A presentation by designer Morville [29] gives a good and visual overview of Visual Thinking. On the “richer” side, we have Hans Rosling’s famous performances explaining the world through statistical visualizations (see the stunning BBC Four video “200 Countries, 200 Years, 4 Min”). This is in line with Al Gore’s effort to visualize the ungraspable reality of Global Warming in his “illustrated talk” that was finally turned into a feature-length blockbuster documentary.

Back in 2000, Al Gore was basically using PowerPoint as visualization tool, which then was criticized by Edward Tufte in 2003 for its inherent tendency toward “Stalinist” visual New Speak: Corporate salespeople were silencing their audience with a power play of curves, bullets, and pies. But at the same time, artist David Byrne introduced new ways of using PowerPoint. In the last 5 years, this has become the mainstream: A bunch of Web 2.0 pioneers has developed a new style of well-designed Visual Thinking (although most are using Keynote, the presentation software for Macs).

Still, Gore had given a professionally produced “wow!” presentation in high-fi quality. In fact, his PowerPoint slide show was the backbone of the feature-length documentary. But the World Wide Web is about user-generated content. The focus has shifted from professional to amateur. And the web’s built-in tendency for low-fi aesthetics and micro-media is more than just a consequence of cheap tools, poor resolution, and poor skills. Today in 2012, we have available high mobile bandwidth, consumer devices taking videos and photos in stunning quality, and cheap simple tools for postproduction. Low-fi visual languages are more popular than ever, because they are related to new cognitive styles emerging around the user-centered media experience of the web.

In the era following the TV-age, videos and visualizations have changed from being a lean-back medium to being a lean-forward medium. They have become tools to think as they emerge as new formats particular to the World Wide Web: simple visual objects that can be produced with little effort by almost anyone, such as a doodle or a napkin sketch. These formats are part of what Manovich [27] called “micro-media ” in opposition to broadband. Because they only require a small attention span to get their ideas and messages, these simple user-generated objects can be easily shared and circulated in the cloud, such as coins: in blogs, via flickr, SlideShare, or YouTube. Their function is being an anchor for individual and collective memories in the midst of a permanent information tsunami. To work as building blocks for collective thought processes, it is essential that these visualizations are somehow “raw” and “unperfected”. They should give me the feeling “I could have done that myself”. They are directed at viewers and users, not consumers.

These new visual styles are part of a paradigm shift from “published ideas” to “circulating ideas”. What people formerly did on their desks is now part of collaborative thinking processes enabled by the Web 2.0 ecosystem. It was web intellectual

Johnson [21] who described this ecosystem in some detail. He even produced a fascinating animated "graphic recording"-video to promote his book quite successfully. It is 4.07 minutes, the length of a pop song. Possibly, this is not mere coincidence; it just may be the natural format for today's hive mind.

2.10 What Is Knowledge Visualization?

By reading merely eight reflections on Knowledge Visualization, it seems difficult to find a unifying definition that says it all about this evolving discipline. First and foremost, the aim of this joint chapter is to span the discipline by provoking a range of individual vistas and opinions. Therefore, let us revisit what we can learn through the eyes of others.

The first four reflections loosely illustrate what Knowledge Visualization is perceived to be; they report on the fact of visualizing knowledge and its role in a wider context.

Sabrina Bresciani organizes her reflection around the need to amplify cognition and to enhance communication; visuals should also consider emotions and experiences. Knowledge Visualization has to question the actual impact of visualizations. This is the somewhat classical description of a discipline which is inherently self-critical, highlighting the risks of visualization, and the lack of a solid theoretical foundation as a significant limitation for further development. It is a call for visual structuring and representation of knowledge building on the heritage of Knowledge Visualization with its variety of methods.

Andrew Vande Moere identifies the importance of storytelling and meaning. In his opinion, Knowledge Visualization allows to explore patterns by putting them close to their context. The "story" is the perfect visual carrier for knowledge, rendering it communicable and actionable; but it is also an "author" of knowledge. It is complexity and scale that make Knowledge Visualization different from other types of visual storytelling. Ultimately, to convey knowledge, information has to be meaningful and appealing at the same time; and the important role of storytelling is to be recognized.

Tom Crawford further illustrates the communicative function of Knowledge Visualization; in his opinion, the nonlinear process of representing knowledge is a recipe for success, if handled correctly and by using visuals as a supporting tool. It is precisely the question of how to present knowledge best which is applied to the lowly cooking recipe, advertising the instruction of all instructions beyond mere science. This is risky and appealing; risky because the visuals are of real-world artifacts; appealing because it is memorable and fun to read. Knowledge Visualization is about effective tools to communicate without loss.

Vedran Sabol sees Knowledge Visualization as the most important element of knowledge processes. It not only provides fuel for reasoning but operates at the highest level of abstraction, allowing sound perspectives, effective decisions, and valuable synergies. He argues for the role of Knowledge Visualization in discovering new knowledge from data, but argues equally to put it at the final stage of the

Knowledge-discovering process chain. Hence, he places the discipline in the position that is giving it the required importance. This is as fascinating as it is challenging because what should follow afterward is action and thus measurable.

The further four reflections loosely describe what Knowledge Visualization could or should be; they report on the fiction of visualizing knowledge and its influence on other aspects of understanding.

Randy Goebel offers a reflection on the theoretical and methodological foundation of visualization. In his opinion, the strength is in the diversity to achieve insightful inferences. He criticizes the lack of a theory of visualization and argues for inventing the future. As important the focus on inference, as appealing is the observation on beauty contests, for often beauty enhances effectiveness. The description of the current state as a primordial soup may be exaggerated, but it is coherent in its own right. Above assessing alternative visualization methods, this could point toward comparing processes with and without visualization.

Stefan Bertschi agrees that Knowledge Visualization is to allow effective and efficient communication; however, there is still a recognizable lack in understanding the underlying mechanisms. In his opinion, more visual "listening" is needed to align sender, recipient, and methodology. As Knowledge Visualization is taken back to its origins in business, this reflection reads like a marketing brochure for visualization. The conclusion of making no more than three points to argue sustainably moves the discipline close to advertising; it is "advertising" knowledge that should be at its core.

Wolfgang Kienreich promotes an alliance between advanced data analytics and Knowledge Visualization, meant as a way of managing the complex digital universe of today's society. Driven by the closed loop of representation and interaction, he pleads for analytical means for the masses. The search for a comprehensible and accessible way to empower public discourse equally opens the door to asking questions about risks or shortcomings of automated visualization techniques and about the vast potential of a general visual language that could be used by organizations and users with limited visual literacy.

Martin Lindner introduces Visual Thinking as the main trend of Enterprise 2.0. In his opinion, it is the user-generated "micro-web" that is linking back to the past. While visual revolutions are nothing new, we see new efforts to overcome the failing cognitive model of objects and physical interaction, promoting collective thinking in the cloud. Written in the style of a blog post, this inspiring reflection resembles the associative structure/logic that is also inherent to Knowledge Visualization. It contains influential metaphors, such as the pop song, that make this type of visualization so effective.

What can be learned from all contributions is that visualization improves communication, in particular the interaction around cognitive processes. Knowledge Visualization and Visual Thinking fabricate the necessary understanding of these processes because knowledge needs to be "seen". If there is one common truth contained in all eight reflections, then it would be: *without successful and sustainable transfer, knowledge is meaningless*. Another theme that can be found in several of the contributions is a certain lack of theory underlying the practical application of visualization.

Because of the apparent lack of a unifying "theory of visualization", Knowledge Visualization—subconsciously or not—has made use of "theory frames". This approach refers to an assembly of various theoretical perspectives and concepts, and all of these taken together "formulate more precise problems and point to far more specific factors and processes of relevance" [34, p. 13]. All reflections in this chapter are leading in a similar direction; instead of attempting to build a unifying theory, they promote broader theoretical orientation which is rooted in past research and varied perspectives. At the same time, they are building a set of theoretical principles that is much more (careful) definition or guiding principle in its own right.

Ultimately, Knowledge Visualization is more than a "frame"; it carries research-led hypotheses and its own evaluation, measuring the effectiveness of visualizations. However, specific explanatory hypotheses are needed to crystallize a theory of visualization. This is where theory frames come in handy as they are often a substitute and at the same time "a major form of knowledge cumulation." [34, p. 15] Parts of the frame, as they are presented in this chapter, help to formulate focused research problems and lead to relevant factors in understanding human meaning and perception. Certainly, a next step would be to bring these parts closer together; the present chapter and volume attempt to do so. Additionally, theory frames are open for revision and this is important to a discipline that is so dependent on interaction, the *act* of visualizing knowledge.

Beyond the diversity of these eight reflections, it becomes apparent how they all (at least implicitly) emphasize a process-driven concept of visualization. The act of visualizing is more important than the image itself: the method is "larger than" the message. Hence, it is "understanding understanding" (cf. [28, 36] that has to be at the core of the Knowledge Visualization theory frame—in producing, deciphering, and evaluating the process of visualizing knowledge and thinking. We might as well conclude that this is as much an art form as it is a science and the reflections throughout this chapter would support that. Another commonality between the parts is the more diligent differentiation between Information Visualization and Knowledge Visualization that is expressed throughout this chapter. It is about understanding Knowledge Visualization, and if this chapter would not already have a title with its leading question included, it would need to be: *Understanding Knowledge Visualization*. The search for an answer does not end here.

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Part II
Text

Chapter 3
Tables and Early Information Visualization

Francis T. Marchese

Abstract This chapter considers the deep history of tables as visualization modalities. It covers a variety of tables that have appeared between 1900 BCE and 1400 CE that include: Sumerian accounting tables; chronicles; canon tables; medieval calendars; gridded tables such as urine and eclipse; and tables that communicate conceptual abstractions, such as religious dogma and degrees of blood relation. These tables represent some of the earliest and most significant milestones in information visualization. Analysis of these tables demonstrates that as early as 1300 BCE the need to visualize information had driven the invention of representations that transformed the way information has been communicated and used.

3.1 Introduction

This chapter explores the early history of tables for information visualization. The organizational constructs of the tabular format are ubiquitous, as may be seen in contemporary artifacts such as calendars, agendas, and time tables; as the foundation for spreadsheets; and for their subsequent support of other information visualization methods [1–10]. It is well understood that tables are important data visualization tools, and the first stage in the information visualization pipeline to organize raw data into a form that may be translated into graphics. The table's strength as a visualization medium derives from its compactly organized, gridded structure; a format that promotes associations among diverse data elements, and facilitates exploration of relationships among them.

I have explored the history of the design of chemical tables [11], particularly the periodic table, demonstrating how its design has evolved over time to meet the changing needs of chemists and their increased understanding of chemical combination. I proceed similarly here, but focus my attention on the early history of tables and their uses for the organization of information, highlighting some of the kinds of tabular visualizations that have appeared between 1900 BCE and 1400 CE. People throughout time have needed to extract, reorganize, and reconnect information, not

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only for documentation and communication, but also for usability. The problems faced were computational in nature, requiring invention of algorithms and visual representations as interfaces to their information.

This chapter will discuss a number of tables from history : Sumerian accounting tables, chronicles, canon tables, medieval calendars, urine and eclipse tables, towers of wisdom, and consanguinity tables. These tables have been selected because they represent some of the earliest milestones in information visualization and provide a starting point for expanding the historical narrative. With the exception of mathematical tables, historians have paid scant attention to tables in general as a mode of information communication [12], mostly focusing on the history of the periodic table [13]. However, similar to the periodic table, the tables covered herein have been instrumental in the transformation of how information has been communicated and used.

The following section presents a brief introduction to the gridding of data and the origins of written language. Subsequent sections cover the nature and importance of Sumerian accounting tables, chronicles, canon tables, and medieval tables as information visualization modalities. Finally, these tables are considered from within Wainer's [14, 15] analysis framework for table design and use.

3.2 Background

The history of graphical representation and analysis of information begins with the grid. The grid is a metric by which we establish distance and direction of any position relative to a reference point, line, or plane. It is latitude and longitude, or the perpendicular x and y axes. It is the American football gridiron, and Manhattan's east–west streets and north–south avenues. Twenty-five thousand year old representations of the grid are found on the walls of Lascaux cave in southern France. There is a hieroglyphic symbol resembling an orthogonal grid, which was used to designate districts of towns. Ancient Egyptian surveyors used the grid to lay out land. About 140 BCE Hipparchus employed latitude and longitude to locate celestial and terrestrial positions. Ptolemy, an astronomer and geographer, utilized these methods to map the known world in a standardized and consistent way. By the second century CE Ptolemy published his *Geographia*, a collection of 25 geographical maps, along with methods for constructing and using grids [16]. First century CE Chinese cartographers used grids to map the country. The Romans employed a grid system called the centuriation, which, according to David Turnbull, turned "all Europe into one vast sheet of graph paper" [17]. The ancients created charts and maps to organize their geographical knowledge. Today, maps and charts have evolved into general graphic representations designed to facilitate a spatial understanding of objects, concepts, processes, and events. Their purpose of ordering knowledge remains central to their utility.

Gridding space creates containers—locations that may hold a variety of information. The contents of elemental positions within the periodic table and spreadsheet

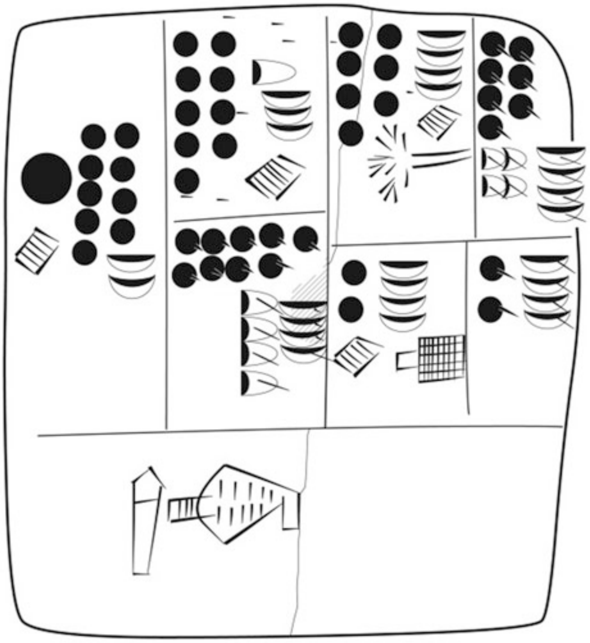

Fig. 3.1 Uruk III tablet (MSVO 3, 51, Louvre Museum, Paris, France). (Drawing courtesy of Englund [18])

cells are just two examples. It appears as well that the creation of containers through gridding was important to the Mesopotamian origins of written language. With the agricultural revolution approximately 10,000 years ago, need arose to document and manage economic transactions related to farming, livestock, fisheries, and the division of labor of a complex society. This was particularly the case for the powerful fourth millennium BCE Mesopotamian cities which traded agricultural and animal products for metals and luxury goods with geographically distant kingdoms. Documentary evidence for these accounting practices is found in more than 5,000 clay tablets recovered from the ancient Sumerian city of Uruk and its surroundings dating to the mid-fourth millennium BCE [18]. The inscribed grid on these clay tablets created boxes, each of which represented one accounting unit. Contained within a box was an ideogram, a symbol that represented a word or idea, and a numerical value representing a quantity.

Figure 3.1 shows a drawing of a tablet from the Uruk III period (ca. 3300–3000 BCE) containing an accounting of deliveries of barley and malt from two individuals for the production of beer [19]. The bottom row bears the name of the official in charge. The tablet is read from right-to-left and top-down. Each row corresponds to an individual, with the first two columns containing entries for malt, followed by a column for barley. Subtotals are given in the third column (barley groats (top) and malt (bottom)). The left-most box displays the grand total. No formal language was used to express the relationship between the signs and symbols in the tablet. Instead, the grid structure provided that syntax [20].

3.3 Early Tabular Correlations

The use of a grid as an organizational construct for Mesopotamian pictographic "texts" was ultimately abandoned, evolving into cuneiform, a symbolic language that supported linear writing and the phonetics of spoken Sumerian. By the latter third of the third millennium BCE, written concepts were collected and organized in simple tables or lists used to organize a wide variety of information that was administrative, lexical, and chronological in nature.[1] Administrative lists began as simple legers, binding together nouns (what) with numbers (how many). Lexical lists began as collections of words for study or practice. By 2500 BCE, "textbooks" appeared that systematized and formalized knowledge, employed in part for scribal training. Such lists included observations of natural phenomena—astronomical events, weather, river heights, etc. Event lists began as organized sequences of kings' reigns. Soon daily events were recorded, encompassing among other things wars, plagues, battles, festivals, etc. Correlated lists such as dictionaries, tables of mathematical-metrological notations, translations (e.g., Sumerian—Akkadian), or phonetic readings appeared. In this latter instance, lists were organized according to an acrographic principle, in which all the words in the list were selected because they had their first sign or symbol in common; any other correlations among words beyond this may be considered incidental. Hence, this was a graphical organization as opposed to a conceptual one.

The first systematically structured tables (see e.g., Fig. 3.2) originated in Mesopotamia about 1850 BCE [22]. The evolution of cuneiform from a pictographic into a symbolic language that supported the phonetics of spoken Sumerian created a compact language that facilitated accounting practice as well. In an analysis of Mesopotamian tables from this period, Robson [22] has found striking similarities with contemporary counterparts. These similarities may be seen in Fig. 3.2, which shows both the obverse and reverse sides of a cuneiform tablet from the temple of Enlil at Nippur. It is a record of sources of revenue and monthly disbursements to 46 temple personnel by its bursar Ḫunabi for the year 1295 BCE [23]. There are column headings and row titles. Column headings at the top of the table specify month names. Names and professions are shown in the right-hand column (e.g., seeress, weaver, overseer, temple servant). Eighteen of the individuals listed receive no payment for all or half the year (Notice the blank "smooth" cells along rows). These individuals are classified as either dead or fugitive. Grid locations within the table contain numerical information that are part of calculations, flowing first down a column, and then across a row. Subtotals for each individual are given every six months, culminating with a yearly total adjacent to row labels. The table is annotated with explanatory interpolations under columns containing totals, and a summary column at the table's end.

The utility of this tabular format was cemented with the invention of the sexagesimal (base 60) place value system of arithmetic that provided a means for each

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[1] See Chap. 5 of Goody [21] for a complete discussion.

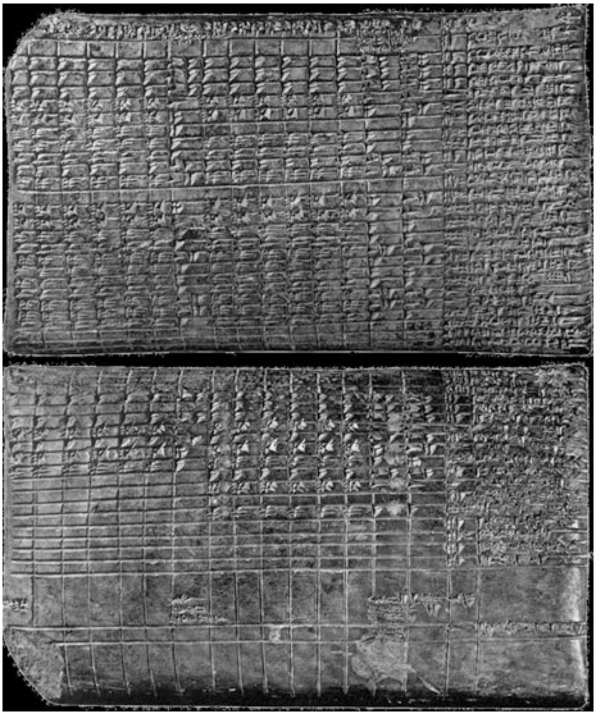


Fig. 3.2 Cuneiform tablet, temple of Enlil at Nippur (CBS 3323, University of Pennsylvania). (Reproduced from [23])

table cell to be quantitatively linked in a formal mathematical way. As Robson has observed, "the new format enabled numerical data and relationships to be seen and explored in ways hitherto unimaginable," creating "conceptual advances in quantitative thinking" [22].

3.4 Chronologies

A chronology is a record of events in the order of occurrence. One of the earliest extant historical records is the *Parian Marble*, a Greek chronological table covering the years from 1581 BCE to 264 BCE, inscribed on a stela (now at Oxford's Ashmolean Museum) [24]. A later example decorated the Emperor Augustus's arch in the Roman Forum. Known today as the *Fasti Capitolini Consulares*, it is a collection of marble plaques listing in tabular format all the chief magistrates of Rome since the Republic's foundation and the victorious leaders from Romulus onward [25]. Although the ancient world had many chroniclers such as Herodotus, Pliny the Elder, and Josephus, only fragmentary records exist of attempts to create a synchronous chronology encompassing all cultures of the known Western world [26]. This was to change with Eusebius of Caesarea.

Eusebius of Caesarea (c. 263–339/340 CE), also known as Eusebius Pamphili, was Bishop of Caesarea in Palestine, scholar, friend, and biographer of the Emperor Constantine I; and historian who wrote *Historia Ecclesiastica*, an early history of the Church [27]. But before he wrote his Church history Eusebius wrote his *Chronicles* (ca. 311 CE), a universal history of the nations from Abraham through Constantine I [27]. The *Chronicles* are divided into two parts. The first part, the *Annals*, summarizes the history of each nation individually. The second, the *Chronological Canons*, synchronized the historical records of all the nations.

The challenge Eusebius faced in creating the *Chronological Canons* was not only how to link together chorographical information from Hebrew, Greek, Persian, and other sources, but also how to translate the relative chronology of each kingdom or empire into a universal time line to produce a synchronized succession of events. Universal dating did not exist during Eusebius's time. The Anno Domini (AD/BC) system of dating used today was not created until 525 CE, and not widely used until 800 CE [28]. Exacerbating Eusebius's problem was that different cultures based their chronologies on different reckoning schemes. Ancient Greeks dated years according to Olympiads, which were on four year cycles. The Hebrew calendar follows a solar schedule segmented by lunar cycles. The Macedonian calendar followed a lunar cycle—a year has only 354 days. And the information reported by early historians and commentators could be just plain inaccurate!

Eusebius's eventual solution to his problem began with the codex, the forerunner of the contemporary book. Invented by the Romans, the codex was originally constructed by binding together waxed wooden writing tablets, and eventually papyrus and parchment sheets [29]. The codex is more practical than a scroll, given that it allows random information access, as opposed to a scroll's sequential access; and unlike the scroll, both sides of a sheet may be used for writing.

Eusebius began his process of correlation by drawing a multicolumn table on a codex page. Each column corresponded to a kingdom and each row to a year in a king's reign [30]. The leftmost column represented the dominant empire during a historical time period. It began with the Assyrians. The Persians took their place, and eventually the Romans occupied this column. The total number of columns varied as kingdoms came and went. There were as many as nine columns, for which Eusebius used a double-page spread. Eusebius left a space in the middle of each page to allow for commentary. Finally, Eusebius decided to set the starting date for his universal history with the earliest date he felt he could reasonably compute, that being the birth of Abraham. He marked off every tenth row with the number of years since Abraham's birth.

He filled his table by finding correlations between loosely connected regional years linking them together by placing them on the same row of the table. For example, he determined that Darius of Persia and Alexander the Great of Macedonia lived at the same time, since the latter overthrew the former. This linked the Greek and Persian lists. He linked Jewish with Persian events by noting that the Bible recorded the second temple in Jerusalem was built in the second year of the Persian king Darius' reign.

Clearly this was an arduous task, something that could be easily handled today with computer intervention. But as Eusebius must have realized, one strength of tables is that all data are visible, thus making the viewing of inconsistencies or inaccuracies easily apparent. And there were many errors! Eusebius dealt with this problem by drawing a line under the periods of confusion to highlight these errors for future resolution.

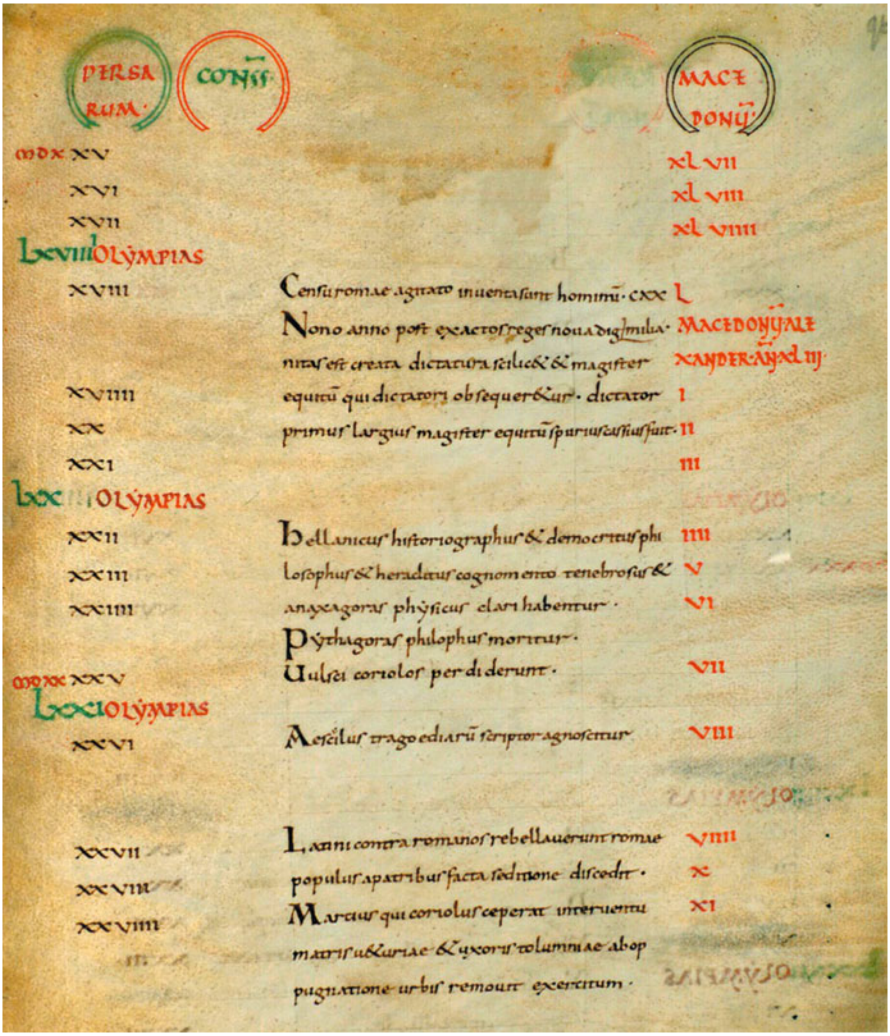
Eusebius's own *Chronicles* in the original Greek no longer exists, but a Latin translation by St. Jerome does. This bishop and Church scholar translated Eusebius's tables, adding dates from 325 to 379 CE; publishing his *Chronicon* in 380 CE [31]. Figure 3.3 shows a page from Jerome's *Chronicon*, taken from a ninth century CE copy of the manuscript (MS. 315, fol. 96r, Merton College, Oxford University). The page is arranged in four columns—Persia, Rome, and Macedonia, with a column of commentary. Three ink colors (black, red, and green) were used as a means to distinguish dynasty lists. Eusebius specified the use of color to enhance legibility, and Jerome carried this through with his own version. In the far right column (in red), the rise of Alexander as King of the Macedonians is noted. To its left, Eusebius/Jerome recorded that Pythagoras died in the sixth year of Alexander's rule. On the table's far left column are two small red roman numerals (MDX and MDXX) designating the time lapsed in years since the birth of Abraham. Olympiads are shown in red, preceded by green roman numerals specifying the 69th, 70th, etc., in the sequence. Finally, at the top of the Persian column, the roman numerals mark the 15th and subsequent years of Darius's 36 year reign.

Eusebius recorded all aspects of culture in his Chronicle, including the real and fictitious: inventions, wars, lives of poets and scholars, lifespans of gods and politicians, to name but a few. As such, it became a comprehensive cultural compendium that inspired the creation of future chronicles and itself lasting until the Protestant Reformation.

3.5 Canon Tables

A gospel is a New Testament book that describes the life and works of Jesus. There are four Canonical Gospels that were written by the evangelists Matthew, Mark, Luke, and John sometime between the years 60 and 80 CE. During the early Middle Ages, these four gospels were often assembled into their own volume, a gospel book, and used as a teaching or evangelical tool. The most famous book of this kind is the *Book of Kells* created by Celtic monks around the year 800 CE.

Christian Bibles and gospel books had already taken the form of the codex by the second half of the first century CE [29]. The codex's design strength of random access facilitated preaching by providing unfettered access to all evangelical content. But one significant problem remained. All four gospels possess many passages in common. Analysis of the four gospels from nearly all Greek and Latin manuscripts reveals about 1,165 self-contained passages distributed across Matthew (355), Mark (235), Luke (343), and John (232) [32]. The challenge faced by a student of the



PERSA RUM · CONSS · MACE DONŪ

MDX XV XL VII
XVI XL VIII
XVII XL VIIII
LXVIII OLYMPIAS
XVIII Cenſu romae agitato inuenta ſunt hominū · CXX L
Nono anno poſt exactos reges noua dig milia · MACEDONŪ ALE
nitas eſt creata dictatura ſcilic& & magiſter XANDER · AN XL III ·
XVIIII equitū qui dictatori obſequer&ur · dictator I
XX primus largius magiſter equitū ſpurius caſſius fuit · II
XXI III
LXX OLYMPIAS
XXII hellanicus hiſtoriographus & democritus phi IIII
XXIII loſophus & heraclitus cognomento tenebroſus & V
XXIIII anaxagoras phyſicus clari habentur · VI
Pythagoras philophus moritur ·
MDXX XXV Uulſci corioloſ perdiderunt · VII
LXXI OLYMPIAS
XXVI Aeſcilus tragoediarū ſcriptor agnoſcitur VIII
XXVII Latini contra romanos rebellauerunt romae VIIII
XXVIII populus a patribus facta ſeditione diſcedit · X
XXVIIII Marcius qui coriolos ceperat interuentu XI
matris ueturiae & uxoris uolumniae ab op
pugnatione urbis remouit exercitum ·

Fig. 3.3 Jerome's *Chronicon* (Merton MS. 315, fol. 96r). (Reproduced by permission of the Warden and Fellows of Merton College, Oxford)

gospels is not only how to find those passages that are in common among the gospels, but also those passages that are attributable to a subset of the authors or just an individual author.

Ammonius of Alexandria, an early Church Father, attempted a correlation around the year 220 CE as part of his Harmony of the Gospels (now lost) [33]. Taking Matthew's gospel as a referent, because it was the most comprehensive, Ammonius placed the corresponding passages of the remaining gospels adjacent to Matthew's text. This arrangement allowed the verbatim gospel commentaries to be compared in parallel. It was the method's strength. Its weakness was that it completely destroyed the narrative structure of the other three gospels.

The first successful attempt at creating a tool that crosscorrelated gospel passages was made by Eusebius of Caesarea. He saw the power of Ammonius's method, but wanted to preserve the whole of all the texts, not just the Gospel of St. Matthew. His solution was to create a kind of tabular index called a canon table, containing information about where to locate gospel passages that shared content. Eusebius began his process by numbering all gospel passages, writing a reference number at the beginning of each. For example, there are 355 passages in the Gospel of St. Mathew, so passages were numbered in black ink from 1 to 355 in the gospel margins. Tables were then constructed that correlated these passages. Four column tables related those passages shared by all four authors. Three column tables contained pointers to passages that were shared by only three evangelists; tables with two-column tabular correlations followed. Finally, a single column table was created that contained references to passages unique to each gospel. There were ten tables in all. And they were placed at the beginning of the gospel book with a description of how they were to be used.

A representative example of a Eusebian canon table drawn from the Gospels of St. Ursanne (MS. 34, f. 21, Porrentruy, Jura Canton Library) is exhibited in Fig. 3.4. It is a gospel book on parchment produced during the latter part of the ninth century. This figure shows Canon Table IIII, a three column table enclosed within an architectural arcade. Each column is labeled in Latin with the abbreviated name of an author (MAT (Matthew), MAR (Mark), and JOH (John)). Each table row contains the numbers of three correlated gospel passages. For example, the first row of the canon table in Fig. 3.4 records passage numbers XVIII, VIII, and XXVI. A reader would interpret this line as meaning that the passages numbered XVIII in Matthew, VIII in Mark, and XXVI in John all share commentary about a particular event in Jesus' life. The reader would then look up those numbered passages in each of the gospels to study the commentary.

Now suppose that someone upon reading a passage in one of the four gospels, say John CXXI, wished to discover whether other gospels contained similar presentations. The reader would find a number written in red ink below the passage number of this text placed there by Eusebius to indicate in which canon table a correlation could be found. The reader would then proceed to the designated canon table, here table IIII, read down John's column until arriving at the row containing John's passage number, and then read along that row to find the numbers of the correlated passages.

In the year 331, by the order of the Emperor Constantine, Eusebius sent 50 copies of the gospels to Constantinople, the new capital of the Roman Empire, for use in its churches. By the fifth century they were in common use. In all probability, Eusebius's seeding of the Roman Empire with his canon tables ensured their success as a visualization tool. Indeed, they may be found in nearly all surviving copies of the gospels up to c. 1200, including gospel books written in Greek, Latin, Syriac, Gothic, Armenian, Georgian, and Ethiopian [34].

There are a number of observations to be made about the Eusebian canon tables. First, combinatorially, there should be 12 tables, not ten. However, as Nordenfalk

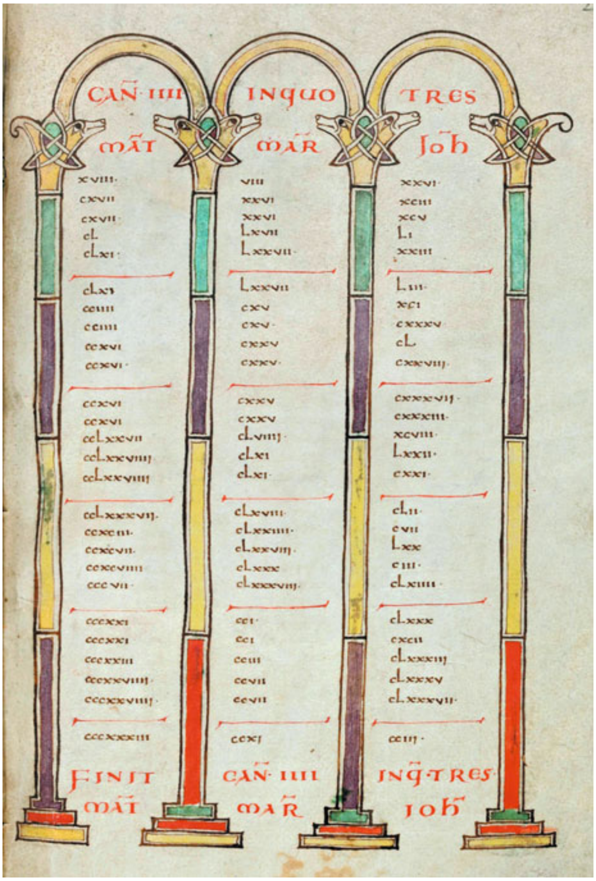


Fig. 3.4 Eusebian canon table from the *Gospels of St. Ursanne* (MS. 34, f. 21, Porrentruy, Jura Canton Library)

[34] has pointed out, Pythagorean "numerical mysticism" may have played a role in their design. To the Pythagoreans, the number 10 (the tetractys) was the holiest and most perfect number—the number used to symbolize the Universe. It also represented the sum of the first four cardinal numbers, which they themselves were geometrically grounded. The number 1 represents a point, the generator of dimension; 2 represents a line of dimension one; 3 represents the plane (triangle); and 4 represents the geometric solid (tetrahedron); 4 was a perfect number as well. It is the first square. It corresponded to the four points of the universe (N, S, E, W) and the four ancient chemical elements (earth, air, fire, water). As such, its perfection was invoked to justify a standardized use of only four Gospels, and in attempts to eradicate the many other, perhaps heretical, versions which coexisted. Thus, to Eusebius it must have made perfect sense to have four kinds of tables consisting of one, two, three, and four columns, which summed to ten, tetractys. Perhaps most importantly, the Pythagorean mathematical laws gave canon tables a firm theoretical grounding. Instead of being

Fig. 3.5 Indices for Canon Table IIII

ad hoc constructions, they endowed canon tables with a physicality joined to the universal order that was an expression of God's physical creation.

It should be noted that Eusebius' prescription for indexing passages only calls for the placement of Canon Table numbers below the passage numbers within the Gospel's margins, but cross references to the comparable passages from other Gospels have been included as well. These cross references were taken from the Canon Tables and placed back within the text so as to add a degree of redundancy, giving the reader direct access to the corresponding passages. This is seen in Fig. 3.5, where links to the passages of Mark VIII and John XXVI have been written below the red IIII. The result is that no longer does a reader need to return to the Canon Table to find which Gospel passage(s) were correlated with Matthew XVIII. Because links to Mark and John were now specified within Matthew's text, the table could be bypassed completely. The effect of these cross linkages was to transform a simple linear connection between the indices contained in a canon table and Gospel passages into a nonlinearly interconnected hypertext system, providing the reader with a means to follow links through the document passage-by-passage. Finally, it is unclear who introduced this revision to Eusebius' prescription, or when, or why it was done. Current scholarship has not yet addressed these questions.

3.6 Medieval Calendars

Keeping track of time was important for medieval agriculture, and even more so for the Christian clergy [35]. The Church's liturgical practices involved a complex cycle of rituals and feasts that were celebrated in varying ways depending on the calendar day of the event. Since prayer was an intrinsic part of these celebrations, calendars were integrated into religious manuscripts such as psalters, breviaries, books of hours, missals, and almanacs.

Figure 3.6 shows a typical medieval calendar for the month of November, taken from an English psalter produced during the first quarter of the thirteenth century (MS. Royal 1DX, fol. 14, British Library). There are two roundels: a lower roundel indicating November's zodiac sign—Sagittarius; and an upper roundel designating the "Labour of the Month"—here, a man slaughtering a pig. The term "Labours of the Months" refers to yearly cycles in Medieval art depicting common rural activities. The contents of cycles varied with date, location, and the kinds of work. For example,

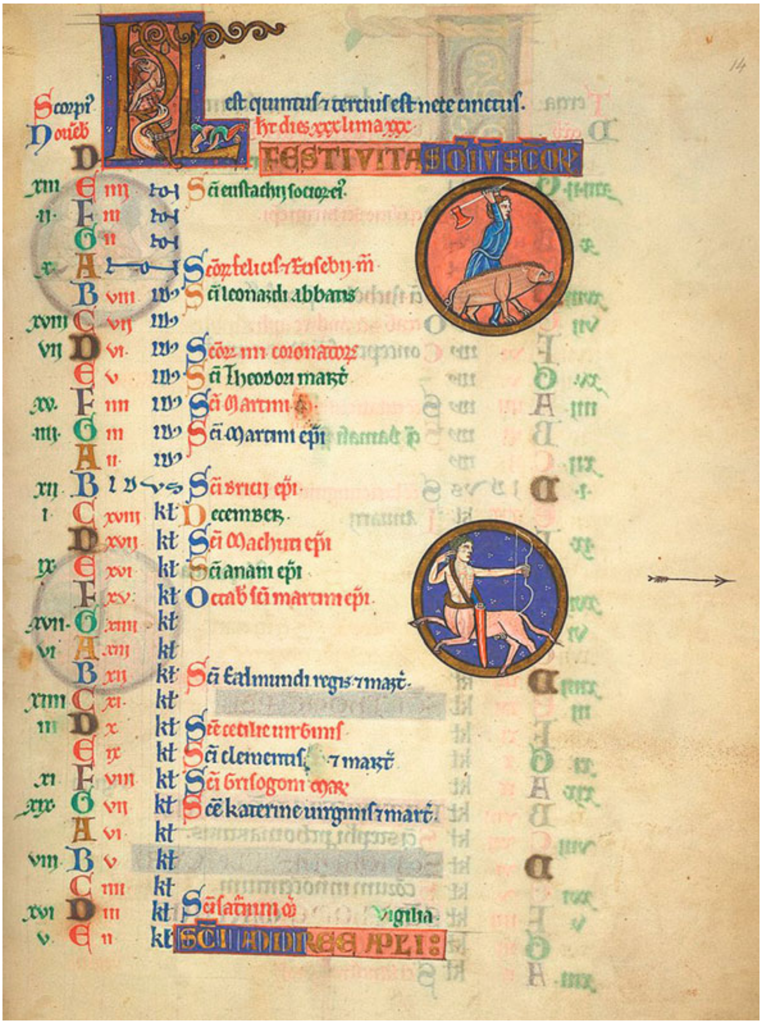


Fig. 3.6 Calendar, November, English psalter (MS. Royal 1DX, f. 14, British Library). (©British Library Board)

April was a time of sowing and July was a month for reaping, so images would reflect these labors.

The column to the left of the roundels lists the feast days, with major feasts written in red. The illuminated "KL" initials at the table's top stand for the Latin word kalends, which marks the first day of the month in the Roman calendar. Below it in blue letters are initials marking in Latin the nones (5th day), ides (13th day), and remaining days until the next month's kalends. This column is augmented by a column of Roman numerals to its left containing a countdown from November's kalends, to nones, ides, and finally December's kalends. The calendar's format carries forth the structure of ancient Roman calendars (e.g., *Fasti Antiates Maiores*), including its use of red to highlight important events (red letter days) [25].

The calendar's first two columns contain roman numerals and letters respectively. These are related to the computus, a collection of algorithms for determining the date of Easter in the Christian calendar that were developed during the early Middle Ages [36, 37]. Easter is the holiest feast day in Christendom, making the correct computation of its date one of the most important computations of the early Middle Ages. The Christian calendar contains two kinds of feast days—immovable, feast days that remain unchanged from year to year; and movable, feasts, such as Easter, that are linked to lunar and solar cycles.

Setting a yearly date for Easter was a source of controversy in the Church as early as the third century. Although originally linked to the Jewish calendar through its relation to the Paschal (or Passover) celebration, various schools of thought within the Church, particularly Rome and Alexandria, had already developed their own methods of reckoning. They argued for Easter to be liberated from the Jewish calendar because in some years the Jewish calendar placed Easter's date either before the vernal equinox or not on Sunday. The First Council of Nicaea in 325 CE decreed that Christians should use a common method to establish the date of Easter independent of the Jewish method, but did not suggest a mode of computation. It would take several centuries before a common method was accepted throughout Christianity.

The problem that Church computists needed to solve was to find the date of Easter, given the requirement that it is to be celebrated on the first Sunday after the 14th day of the lunar month that falls on or after the day of the vernal equinox. Their solutions to this problem were table based, incorporating calculations of the cycles of the sun and moon. Figure 3.7 displays a sample computistical table known as the table of Dionysius Exiguus (MS. 17, fol. 30r, St. John's College, Oxford University) from the Thorney Computus, a manuscript produced in the first decade of the twelfth century at Thorney Abbey in Cambridgeshire, England. It is a perpetual table of the great Paschal cycle of 532 years constructed from a Paschal lunar cycle of 19 years for the repeat of a full moon (columns) and a 28-year solar cycle of recurrent weekdays (rows). When the lunar and solar cycles are combined (19 × 28), a perpetual Great Paschal Cycle of 532 years results. With this table it is possible to predict the date of Easter up to 532 years in the future.

The Paschal table is set between the two inner margins (dark borders) of Fig. 3.7. Color flags designate cells marking the beginning of solar cycles (yellow), and cells which signal the beginning of indictions (green) [38]. Indictions are a Roman bureaucratic cycle of 15 years, established for taxation purposes during the reigns of Diocletian and Constantine that began on September 1st, the start of the fiscal year. Justinian made indictions part of the official dating style for government documents. They were included in the Alexandrian Paschal tables, migrating via Dionysius Exiguus into the standard Paschal tables used in the medieval west [38].

Numerous symbols and encodings frame this table. They were intended to be used in concert with mnemonics, either memory or rhyming schemes, that described how the table was to be utilized; and with computation employing a variation of medieval

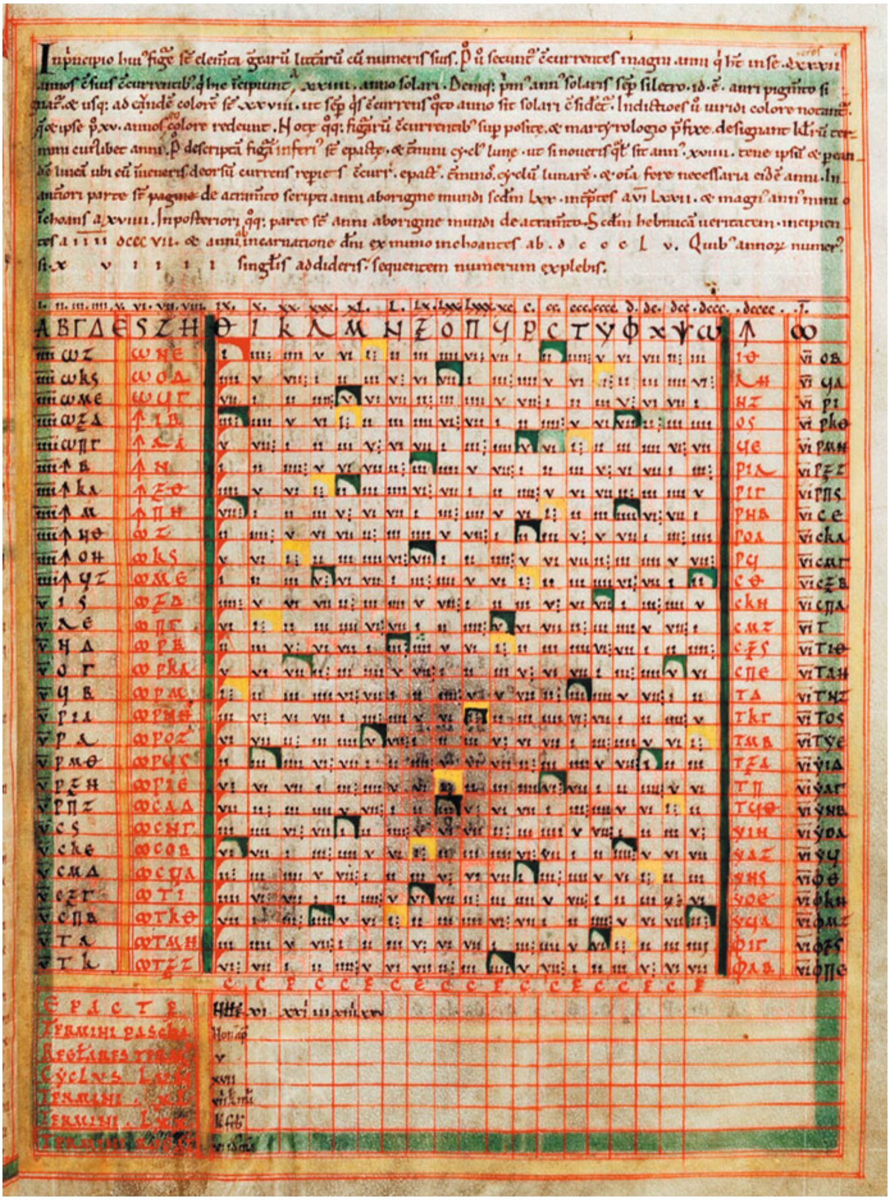


Fig. 3.7 Computus table, Dionysius Exiguus (MS. 17, f.30r, St. John's College, Oxford University). Reproduced by permission of the President and Fellows of St John's College, Oxford

finger reckoning [39]. The complexity of medieval computus meant that calendar reckoning could only be performed by individuals with appropriate training, such as that received in a medieval monastery. Indeed, many calendars were expanded to include additional columns for predicting phases and eclipses of the moon, and for supporting astrological prognostications. But even medieval monks found many of these computations too complex. As a result, simplified versions were designed to make calendars easier to use (see again Fig. 3.6). By employing only the first two columns of the table in Fig. 3.6, it became possible for an average monk to calculate the date of Easter for a given year. This simplification also made it possible for educated laity to own calendars. Such examples have been found in books of hours of rich individuals. One of the most famous is the *Très Riches Heures du Duc de Berry* (c. 1410 CE) by the Limbourg Brothers.

3.7 Expanding the Grid

The use of bodily wastes, particularly urine, to diagnose disease has been recorded as far back as the early Mesopotamians [40]. Given a sample of an individual's urine, a physician could identify an ailment based on its color, consistency, smell, and even taste. The rise of uroscopy as a broad diagnostic tool began in the early Middle Ages with publication of *De Urinis* by Theophilus Protospatharius, the first treatise exclusively covering the subject of urine, that described a range of possible colors it could exhibit and the diagnostic implications of each [41]. By the early thirteenth century the art of uroscopy had grown in complexity. Gilles de Corbeil (1165–1213), royal physician to King Philippe-Auguste of France, had determined that 20 different types of conditions could be differentiated by recognizing differences in urine sediment and color. He also invented the matula, a bladder-shaped clear glass vessel, in which urine was placed to assess its color, consistency, and clarity.

In order to simplify the increasing complex diagnostic process, tables appeared that depicted urine categories. Figure 3.8 shows a rectilinear version of a urine table (c. 1406; Harley 5311, f. I, i.e., 2, British Library) that also may be found in a circular format known as a urine wheel. Each table row contains drawings of matulas, their contents painted to resemble one of twenty different urine shades, ranging in color from clear to milky, gray, yellow, red, purple, dark green, and black. Color descriptions for each pair of matulas are given in the far left and right-hand columns. Their translations from the Latin are shown in Table 3.1. These descriptions are probably meant to invoke a mental image of an idealized canonical color, but their poetry may seem out of place. For example, the allusion to urine being "bluish-gray as camel skin" would certainly have had an early fifteenth century English physician who owned this book scratching his head, given that camels were not a common sight in the British Isles.

Urine color was assumed to be symptomatic of the quality of digestion of food. Medieval physicians believed that the stomach acted like a simmering pot, cooking food until it was turned into a foundation for blood. There were seven degrees of cooking that ranged from indigestion, to the beginning of digestion, to perfect digestion. They are written vertically in Fig. 3.8. Red lines connect text to matulas, whose contents reveal these characteristics. It was believed that perfectly cooked

Fig. 3.8 Urine flasks (MS. Harley 5311, f. I, i.e., 2, British Library). (©British Library Board)

Table 3.1 English translation from Latin of urine colors given in Fig. 3.8

Top to bottom (left)	Top to bottom (right)
Ruddy as pure gold	Slightly red as occidental saffron
Slightly ruddy as an alloy of gold	Red as oriental saffron
Yellow as of a not-reduced lemon	Slightly red as a lowered flame of fire
Pale yellow as of a reduced lemon	Red as a flame of fire not lowered
Pale as nonreduced juice of meat	Wine-red as of liver color
Slightly pale as a reduced juice of meat	Deep blue as dark wine
Bluish-gray as camel skin	Green as cabbage
Milky as whey of milk	Livid as lead
Light bluish- or greenish-gray as lucid horn	Black as ink
White as well water (i.e., clear)	Black as dark horn

urine exhibited a bright golden hue. If urine was undercooked, pale colors resulted; while overcooking was expressed in darker tones [42].

A urine table was part of a collection of charts that were consulted during a diagnosis that typically included: a calendar; a Zodiac Man, a Vein Man, the Sphere

Fig. 3.9 Eclipses (MS. Arundel 347, f. 34, British Library). (©British Library Board)

of Apuleius;[2] and eclipse tables. Figure 3.9 displays an eclipse table (MS. Arundel 347, f. 34, British Library) identifying the dates and times of lunar eclipses for the

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[2] Zodiac and Vein Man are anatomical diagrams. A Zodiac Man exposes the organs of the human body, linking each to an astrological sign to produce a correspondence between human and universe

years ranging from 1387 to 1414 CE. The circular figure at the center of each table cell illustrates which portion of the moon will be eclipsed on a precise date. Associated text offers data about an eclipse's duration, given in hours and minutes; and its magnitude, specified as the fraction of the Moon's diameter covered by the Earth's umbra.

These tables and charts were often assembled into a portable folding almanac and medical reference guide that was attached most probably to a physician's girdle or belt [44]. Since computistical analysis was essential to diagnosis, folding almanacs could contain, among other things, additional tables for predicting movable feast days; the altitude of the sun at noon in degrees and minutes; the year in the Paschal lunar cycle; the time of lunar conjunction, in hours; and the location of the sun at sunrise in degrees of the relevant zodiacal sign; a liturgical calendar in the format of Fig. 3.6; lunar tables for determining which sign of the zodiac the moon was in for any day of any month, and which planet ruled over the hours; and correlated tables used to find the degree of the moon in the zodiac signs [44]. Used in concert, these tables, charts, and diagrams constituted an early form of visual analytics in which reasoning was facilitated by visual representations of information [45].

3.8 Conceptual Tables

Most early medieval tables were related to physical or natural phenomena that exhibited robust temporal attributes (e.g., astronomical measurements). However, tabular visualizations did exist that were conceptual in nature, helping communicate philosophical or theological theories. The *Tower of Wisdom* is one such example.

The *Tower of Wisdom* (Fig. 3.10; Beinecke MS. 416, Beinecke Rare Book and Manuscript Library, Yale University) is a tabular arrangement of information that appeared in the late thirteenth century as part of a collection of tables and diagrams known as the *Speculum theologiae* (Mirror of Theology). Beinecke 416 does not exhibit a rigidly gridded tabular structure. This tower diverges in arrangement from other "Towers," most notably in its irregularity. "Towers" found in manuscripts from the British Isles contain tabular structures that conform to a strict row/column format[3]; while a French version displays cells in alternating rows shifted by half their lengths, enhancing the architectural stonework motif.[4] Regardless of a tower's precise conformance to tabular structure, its overall design was meant to play an essential role in the medieval art of memory—the utilization of a collection of mnemonic

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known as "microcosm/macrocosm," a Platonic theory positing that the workings of the human body are influenced by the cosmos as expressed through the signs of the zodiac. A Vein Man sketch specifies which veins to be used for bloodletting as part of treatment for a particular illness. A Sphere of Apuleius was a graphical device for computing the outcome of an illness or treatment [43], in essence, predicting whether a patient would live or die.

[3] Two versions of the *Tower of Wisdom* may be viewed at the British Library: Arundel 83 (f.135), known as the *Howard Psalter and Hours* (c. 1310–1320); and Arundel 507 (f.20v), a late fourteenth century theological miscellany.

[4] See Bibliothèque Nationale de France, MS. Français 9220 (f.12), a thirteenth century manuscript.

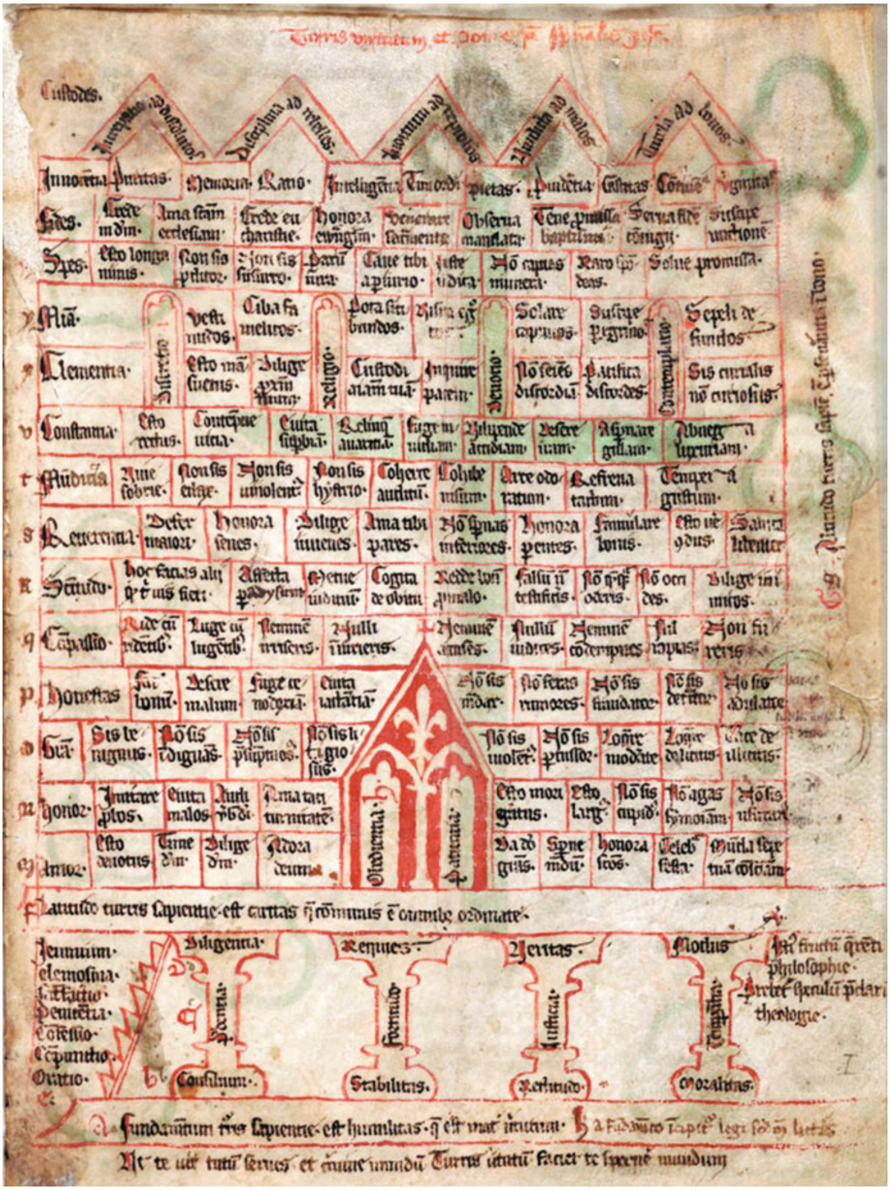

Fig. 3.10 Tower of Wisdom (Beinecke MS. 416, Beinecke Rare Book and Manuscript Library, Yale University)

principles and techniques to organize memory, improve its recall, and to enrich the thinking process as a whole [46].

The original concept and design for the *Tower of Wisdom* came from the Franciscan cleric John of Metz, who created it as a visual aid and object of meditation on moral teaching [47]. Anchored within an architectural frame, the table is meant to be read from bottom-to-top by following an alphabetical sequence of labels. “Humility” is the tower’s foundation. Resting upon it are four pillars representing the cardinal virtues (prudence, justice, fortitude, and temperance) that rise to support the tower. The faithful climb a set of stairs to reach “charity,” the underlying truth to all the moral teachings compiled within the tower, and enter it through one of two doorways labeled “obedience” and “patience.” They then ascend the tower stone-by-stone to ponder the lessons contained within it. The left-most stone in each course renders a guiding principle, such as honesty, compassion, and mercy; each is followed by nine actions related to its guiding principle. One action directs an individual to “be upstanding.” Another declares “flee vainglory.” Yet another, “reject gluttony.”[5]

John of Metz employed the mnemonic “method of loci” as the foundation for his tower. Known sometimes as “memory palace” or “memory walk,” this technique relies on memorization of spatial relationships to absorb, organize, and recall information [47]. The “method of loci ” is a memory technique that originated with the ancient Greeks, was exploited by Roman orators such as Cicero [46], and was later revived and taught to medieval clerics, becoming an important part of medieval monastic education. In it, an individual associates the concepts to be remembered with discrete locations within an architectural plan, such as the rooms in a building, binding them with distinguishing locational features or landmarks. The result is a mental image, by definition a visualization, which may be invoked for information recall by having the individual simply conjure up a walk through the building’s layout; in John of Metz’s case, a walk up the stairs through the doors into the tower.

3.9 Moving Beyond the Grid

During the Middle Ages it was illegal to marry blood relatives as far as the fourth degree. The degree of blood relation or consanguinity is typically shown as a table. Figure 3.11 is a late ninth century example taken from a copy of Isidore of Seville’s (c. 560–636) *Etymologiae*, created in the monastery of St. Gall (Cod. Sang. 231, p. 340, St. Gallen, Stiftsbibliothek). *Etymologiae*[6] is the first encyclopedic work of knowledge in Christendom and its most copied. It was compiled by Isidore of Seville near the end of his life and contains 20 “Books” or chapters that organized and integrated thought from ancient authors spanning, among other things, grammar, mathematics, medicine, astronomy, geography, and the Church. The consanguinity table shown in Fig. 3.11 is from Book IX—*Languages, Peoples, Kingdoms, Cities and Titles*. It is used to graphically communicate the distance between blood relatives. A person, from whom all degrees of relationship are measured, stands at the intersection of mother (mater), father (pater), son (filius), and daughter (filia). Direct

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[5] Smedresman and Warren [48] provide a translation of the tower’s text along with a brief discussion of its meaning.

[6] The critical Latin edition of *Etymologiae* was published by Lindsay [49]. Thayer [50] provides an online version of this Latin text. A contemporary translation is found in Barney et al. [51].

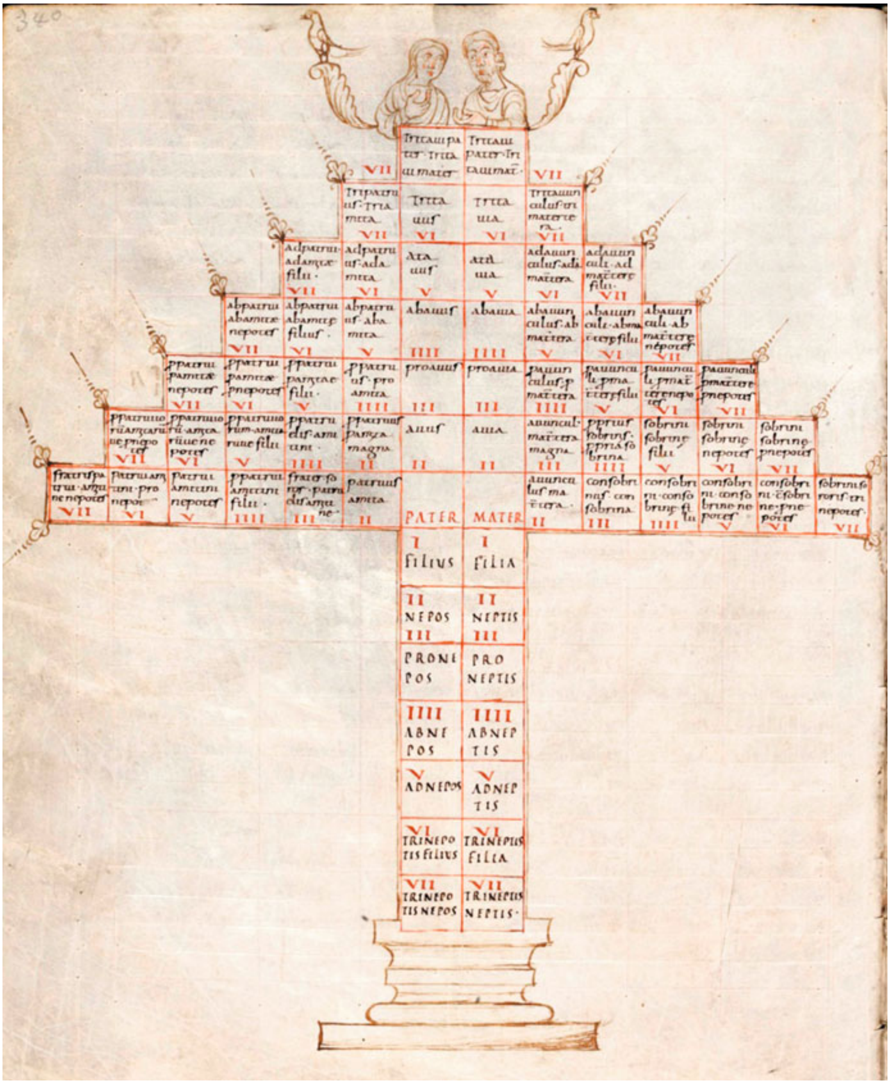


Fig. 3.11 Consanguinity table (Cod. Sang. 231, p. 340, St. Gallen, Stiftsbibliothek)

ancestors and descendants are positioned along the vertical axis; while secondary relationships such as aunts, uncles, and cousins are presented horizontally.

The table's grid is clearly evident in the figure whose empty cells have been pruned away to reveal a tree-like structure. When viewed as a table, the organized collection of cells affords well-defined paths for traversing generations of kinship and quantifying their degree of relatedness. When viewed as a tree, the table binds with the metaphor of the tree of life, which has roots dating as far back in time as the Sumerians.

The tree metaphor was not lost on many consanguinity table designers. Figure 3.12 shows a consanguinity table/tree from an 1134 copy of *Etymologiae,* created at Munsterbilzen Abbey, near Maastricht (Belgium).The tree's trunk is firmly anchored in the earth, with branches extending up and out to engulf a table that exhibits a more greatly disordered columnar arrangement that perhaps is more in keeping with a tree's organic nature. An empty rectangle is found between two rounded cells containing the words "mater" and "pater" that are formed by encircling tree branches. This is where the viewer is to begin. Then he or she moves, as before, through the table.

Another tree variation is found in the *Liber Floridus* (MS. 92, f.102v, Gent University Library), an early twelfth century encyclopedia compiled by Lambert, canon of the Church of Our Lady in St Omer. It contains a tree that maintains a tabular trunk structure similar to that shown in Fig. 3.11. However beginning with one's parents as the origin, each row splits off two branches—one left and one right—that wind through the illustration to create circular nodes similar to those found in Fig. 3.12 that contain the requisite relatives.

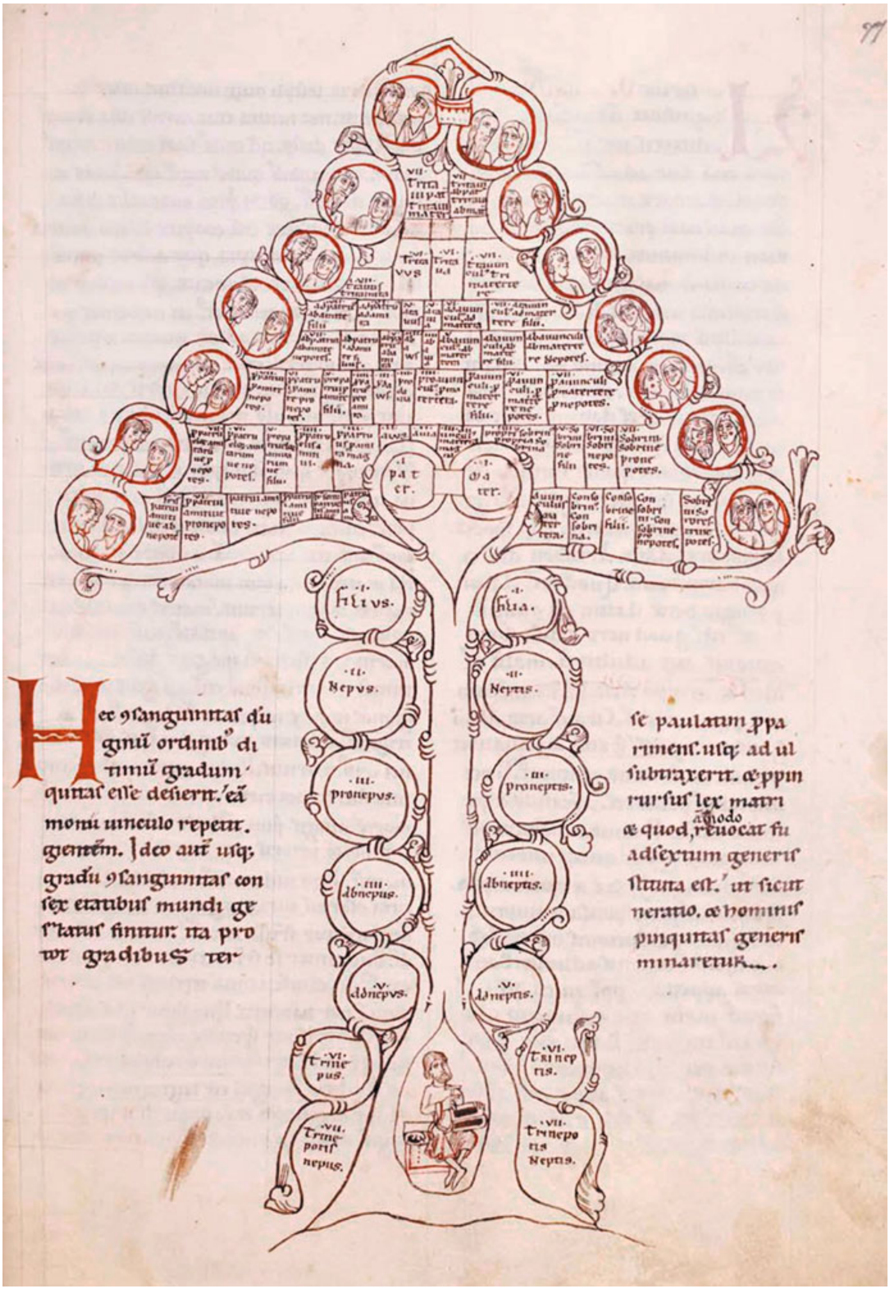
3.10 Analysis

As we have seen, lists and tables possess attributes that make them amenable for use in information visualization. They are discontinuous, bounded, gridded structures that clearly define spaces in which data's relationships and meanings may be extracted from location and relative placement. Unlike narrative text, which supposes a serial reading path, lists and tables may be read in any direction—left-to-right, right-to-left, bottom-up, top-down—or in any arbitrary sequence from edge-to-edge. Such arrangements support open exploration. Also, table boundaries help expose structural relations at both local and global levels.

Wainer [14, 15] has set forth rationales for table usage and design: exploration, communication, storage, and illustration. As part of exploration, tables help answer questions about data. As exemplars of communication, tables provide effective means for presenting data—each table has a story or stories to tell. Storage archives data, supporting a historical context, and aiding in data retrieval. As illustration, tables are used as graphics in support of narrative.

All tables described herein support exploration. The gridded, spreadsheet-like format of the Sumerian table makes it easy to ask questions about individuals and their monthly wages. Eusebius's chronologies and medieval calendars are arranged to make it easy to find important dates and events, while his canon table's structure logically organizes the gospel texts. Even the *Tower of Wisdom*, although designed for systematic exploration from bottom-to-top, may be perused arbitrarily.

If longevity is an effective measure of the communication capability of tables, then both Sumerian and Eusebian tables are highly effective. Sumerian table structure is used in spreadsheets today. The structure of Eusebius's Chronicles remains a standard format for historians. And the medieval calendar's layout is a standard structure for contemporary agendas. And the use of the tabular format to organize images and



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& quod, ãmodo reuocat ſu
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ſtituta eſt. ut ſicut
neratio. & hominiſ
pinquitaſ generiſ
minaretur.

Fig. 3.12 Consanguinity table (MS. Harley 3099, f. 77, British Library) (©British Library Board) link them to text, as is done in the urine and eclipse tables, predates visual-based spreadsheets by 600 years [1]–[10].

The structure of many of these tables supports the creation of narratives paths as well. Eusebius's Chronicles temporal structure and that of medieval calendars sets forth clear narrative paths. The correlated index structure of canon tables provides a means for communicating parallel and intersecting Gospel narrative threads. And the Sumerian table allows the creation of stories about the temple's yearly disbursements to its workers throughout the year.

These tables support ease of information storage and accessibility. The 532-year Easter cycle of the computus table, the myriad feast days of the medieval calendar, and Eusebius's Chronology all imbue these tables with a deep sense of history as well. Indeed, the Roman bureaucratic cycle that became embedded within the computus table (Fig. 3.6) demonstrates the historical evolution of a table from a purely liturgical tool to a secular tool as well.

Finally, in Wainer's rationale of illustration for table usage, tables are viewed as graphical objects in support of narrative. All tables discussed are coherent graphical entities consistent with Bertin's rules for visual encoding [52]. For example, color was an important design component clearly specified by early designers. Eusebius and Jerome dictated the colors to be used, and how to use them. The accompanying text to the computistical table shown in Fig. 3.6 explains a color-coding scheme attributed to Abbo of Fleury (c. 945–1004) [37]. Table cells associated with solar and bureaucratic cycles were highlighted with yellow and green respectively, in order to highlight their temporal patterns for the ease of visualization. Also, the specification of important medieval calendar dates in red, which became known as red letter days, is traceable as far back as the Romans.

3.11 Conclusions

The tables investigated here appeared between 1900 BCE and 1400 CE. Sumerian accounting tables chronicles, canon tables, medieval computus, and calendars, may be considered early milestones in the history of information visualization. Analysis of these tables demonstrates that as early as 1300 BCE the need to visualize information had driven the invention of structured visual representations for information. Ancient Sumerian scribes invented a table structure that anticipated the spreadsheet by nearly 4,000 years. During the late Roman Empire, Eusebius of Caesarea invented respectively, a new representational structure for a chronology, and the concept of the canon table in order to organize and access both historical and liturgical texts. The need to compute a yearly date for the Christian feast of Easter led early medieval scholars to develop computational algorithms for reckoning the date of Easter. Expressed as tables, these algorithms provided a theoretical foundation for the Roman calendar's temporal structure, and eventually furnished a means for the integration of computus with calendral information of a social and religious nature. And the need to communicate complex concepts led to the design of tabular structures that provided a substrate for graphics and iconography. When these tables were used in concert they became an early form of visual analytics that helped both clergy and physicians solve problems related to life and death in the Middle Ages.

Finally, an analysis of these tables employing Wainer's rationales has shown them to be exemplars of table design. Their usability has most assuredly secured each of these table's place in visualization history, ultimately transforming the way information has been used, stored, and communicated.

Acknowledgements I would like to thank Professor Robert K. Englund of the Cuneiform Digital Library Initiative for providing the drawing of the Uruk III tablet. The assistance of the following individuals in securing image permissions is greatly appreciated: Dr. Julia Walworth, Fellow Librarian of Merton College, Oxford; Stewart Tiley, Librarian, St. John's College, Oxford; and Jackie Brown, British Library.

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Chapter 4
Contract Clarity and Usability through Visualization

Helena Haapio

Abstract In the crafting of commercial contracts, many participants are involved, often professionals from different countries and backgrounds. The challenge, then, is to achieve a balance between the business and legal requirements and to facilitate communication and coordination. While some contracts may need to work as evidence in court, most contracts do not. Instead, they need to work as business tools for the parties so they get the results they want to accomplish. Still today, most contracts seem to be written by lawyers for lawyers, the goal being water-tight and legally "perfectï" documents. Such documents are not easy to read, comprehend, or implement. If implementation fails, business and legal problems will follow. To promote business success and prevent unnecessary problems, contracts should be crafted and communicated in more user-friendly ways. This requires overcoming a number of challenges, both perceived and real.

After introducing some of the current challenges in contract design and pre-contract and post-contract communication, this Chapter presents cross-professional work in progress aimed at overcoming the challenges. Drawing from the emerging research and practice of *proactive law, information design*, and *legal visualization*, this Chapter illustrates, with examples, how visualization—adding tables, charts, and images to supplement the text—offers promising new ways to communicate contracts and improve their clarity and usability. For theorists and practical problem-solvers alike, many unexplored opportunities exist for industry-changing innovations in this area.

4.1 Contracts: Challenges in Research and in Practice

When hearing the word "contract," people have a tendency to think of formal, legal documents. Many tend to categorize "contracts" under "law " and think that contracts are best left for lawyers. Traditional management literature seems to have a rather legalistic view of contracts also.

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DOI 10.1007/978-1-4471-4303-1_4,

Contrary to common belief, not the *contracts* but the *contract law* is taught at law school. Contracts do not equal contract law. In the legal field, contracts are often seen as litigators' tools, as evidence in the courtroom. Contract law is mainly about failed contracts. Lawyers tend to look on contracts "primarily as a source of trouble and disputation, rather than a way of getting things done" [1, pp. vii–viii].

In commercial practice, contracts cover both business aspects (such as scope, deliverables, schedule, and pricing) and legal aspects of business deals and relationships. When companies buy, sell, collaborate, network, or outsource, the ability to understand and use contracts is increasingly important. Recent research proves the growing importance of contracts and contracting capabilities for today's interconnected enterprises [2, p. 1061] and competitive advantage [3, pp. 667–668; 4]. Still, in both research and in practice, when contracts are discussed, the legal dominance is striking.

In every collaborative venture where two or more companies work together, a contract is present. It may be written or unwritten, formal or informal. In manufacturing industries, the move from goods to services and solutions makes contracting increasingly complex and time consuming. At the same time, the current business climate requires companies to act quickly. Opportunities are lost if contract creation and negotiation takes too long or if contracts are hard to interpret and to implement.

4.1.1 Perfect (Complex) or Good Enough (Usable) Contracts?

For a young lawyer just out of law school, the goal of contract design may be a legal masterpiece, a contract as close to "perfect" as possible: one that is legally binding, enforceable, unambiguous, and provides solutions for all thinkable contingencies [5, pp. 82–84]. In contrast, the business community in the "real world" requires a different approach. Instead of "contracts in court" or "contract law in the books", the focus must shift to contracting and "contracts in action", as they appear in the commercial world, from both business and legal perspectives.

Voltaire is quoted having stated "The perfect is the enemy of the good" in his book Dictionnaire Philosophique in 1764 [6]. Pursuing the "perfect" solution may end up being less beneficial than accepting a solution that is "good enough" and effective. Rather than perfect contracts, businesses need usable, operationally efficient contracts; these may be more helpful for achieving desired business goals and reasonable risk allocation at an acceptable cost. In fact, for businesses, *the contract* itself is not the goal; *successful implementation* is. Signing a contract is just the beginning of the process of creating value [7, p. 62]. Therefore, the core of contract design should be securing the *performance* the parties expect, not just a contract.

Contracts do not make things happen—*people* do. People need to follow their contracts. Contracts are seldom easy for their users in the field, mostly non-lawyers, to understand and to implement. Their language and complexity may overload readers' cognitive abilities [8, 9]. If this happens and contract implementation fails, it would be wrong to assert that those contracts are "perfect" or even of reasonable quality,

Fig. 4.1 The contract puzzle [12, p. 124]

fit for their purpose. Quite the opposite: even if they are legal masterpieces, they fall short of their ultimate purpose [10, 11].

4.1.2 Contract Puzzle: It Takes A Team

Contract-related issues do not end at the boundaries between academic disciplines or industrial professions. Today's commercial contracts can be viewed through the analogy of a jigsaw puzzle. With a complex project in mind, Fig. 4.1 shows a contract as a puzzle of (1) technical and contextual, (2) performance and delivery, (3) business and financial, and (4) legal and risk management related parts, with (5) project and contract management as the center piece. If correctly assembled—and only if correctly assembled—the pieces of the puzzle form a complete, synchronized picture. Ideally, the supplied solution will meet the customer's requirements, while the project will satisfy the supplier's needs in respect of profitability and risk management [4, pp. 121–123; 12, p. 124].

To be successful, such contracts can seldom be crafted by one person. Rather, they are put together by a team. Research into high-technology firms' contract design capabilities confirms the fact that the input of managers and engineers is needed in key areas, in order to lay the foundation for the deal and construct operationally efficient contracts [2]. Interaction and cross-communication are required, as each stakeholder only has a fragmented understanding of the issues involved [13, p. 6].

After negotiating and signing, the parties must follow their contract. Understandability is a prerequisite in order for users to perform any task. For a vast majority of contracts, the courts, arbitrators, and lawyers are not the primary readers and users—people in the operational and delivery teams implementing the contracts are. These people are seldom lawyers. They need information contained in contracts to coordinate in-house and outsourced functions, manage budget, scope, schedule, resources, and so on.

Even if the contract is as clear as it can be, major issues can arise from a disconnect between the precontract sales or procurement process and postcontract implementation and management. One reason for this is that people are reluctant to read contracts

[14, p. 133]. Few managers have formal training in *how* to read contracts or *why* they should do so [14, 15].

Yet many people are *expected* to read contracts and work with them. The buyer's solicitation team and the supplier's proposal team may consist of people different from those on the contract negotiation team, none of whom may be part of the operational or delivery team. The teams may not meet, they may just "inherit" from their predecessors the contract documents that they are expected to master and work with.

Without guidance, delivering on the promises made in such documents is not easy. On the sell-side, the operational team may not only need to implement the supply contract but also pass on to subcontractors the applicable terms (and risks) of that contract. Things get even more complicated when dealing under global umbrella agreements—framework agreements made between group parent companies designed to be implemented at local level in several countries, all with their own jurisdictional, language and other requirements.

In international business, contracts are frequently written in English. Contract structures, forms, and templates are increasingly based on common law and Anglo-American style drafting, even in civil law countries. Some of the concepts used may not translate well into other languages and cultures, and "legal transplants" can cause confusion. Even where domestic work habits and forms prevail, year after year, contract drafters seem to add text rather than removing it. If no one pays attention, contracts continue to get more complex and more difficult to work with.

4.2 Experiments to Enhance Contract Clarity and Usability

At Aalto University[1], a multi-disciplinary research project was recently started seeking to develop and apply new, easier methods for cooperation, co-creation, contracting, and interaction.[2] Drawing from research in Proactive Law, information design, user-centeredness, and other fields, the aim is to develop, prototype, and test new approaches to commercial contracts in order to increase their clarity, understandability, and usability. The project looks into visualization and other possible means toward simpler contracting, enhanced user experience, and better productivity. In addition to the theoretical contributions, the goal of the research is to strengthen the participating companies' contracting capabilities and to enhance their ease of doing business.

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[1] Aalto University was created through the merger of three Finnish universities in 2010: Helsinki School of Economics, University of Technology, and the University of Art and Design Helsinki. The combination has opened up new possibilities for multi-disciplinary education and research.

[2] The project looks into contracting in the Finnish Metals and Engineering Competence Cluster (FIMECC) as part of User Experience & Usability in Complex Systems (UXUS), a 5 year research program financed by participating companies and Tekes, the Finnish Funding Agency for Technology and Innovation.

In the following sections, after a brief introduction to the emerging *proactive approach to contracting and law*, this approach is used as a framework for *information design*: the skill and practice of preparing information so people can use it with efficiency and effectiveness [16]. After introducing *legal visualization*, a Canadian contract example is used to illustrate how these disciplines can be merged and how the power of visualizations can be used to provide clarity and help prevent unnecessary legal problems.

4.2.1 The Framework: A Proactive Approach to Law

Traditionally, the steps in providing legal care have resembled those of medical care: diagnosis, treatment, and referral—all steps that happen after a client or a patient has a problem. Care has been reactive. You become sick, you seek treatment. You encounter a dispute, you turn to a lawyer.

In the practice of medicine, the emphasis is increasingly on preventing illnesses before they occur. Even in other professions, such as quality management, prevention has long been known to be more effective than control and reactive corrective action. The old proverb "an ounce of prevention is worth a pound of cure" is true even when it comes to the legal field.

While mainstream legal practice and research are mainly concerned with court decisions and the past—notably past failures—a growing number of legal practitioners and researchers are calling for a paradigm shift. The time has come to give up the reactive approach and to adopt a *proactive approach:* one which looks at contracts and the law in a different way, looking *forward* rather than looking *back*. This shifts the focus from courts and litigation to ways in which contracts and the law are used and how they operate in everyday life. While responding to and resolving problems remain important, preventing causes of problems is vital, along with serving the needs and facilitating the productive interaction of citizens and businesses [17, § 1.4].

The proactive approach has its origins in and is greatly inspired by *Preventive Law*, an approach that emerged in the United States as early as in the 1950s. The idea was first introduced by Louis M. Brown, a U.S. attorney and law professor. One of his fundamental premises was that in curative law, it is essential for the lawyer to predict what a *court* will do, while in Preventive Law, it is essential to predict what *people* will do 18–20. In his ground-laying treatise *Preventive Law*, he notes a simple but profound truth: "It usually costs less to avoid getting into trouble than to pay for getting out of trouble" [20, p. 3].

The approaches specifically called *Proactive Law* and *Proactive Contracting* emerged in the late 1990s. The pioneers were a group of Finnish scholars, practitioners, and business clients who wanted to merge quality and risk management principles with forward-looking legal skills to improve their contracting processes. The network of enthusiasts grew, and the early experiments led to a series of publications, bi-annual conferences, and eventually to the formation of the Nordic School of Proactive Law (http://www.proactivelaw.org) [3, 4, 21, 22]. In 2007, the Proactive Law conference held in Turku led to the formation of the ProActive ThinkTank (http://www.proactivethinktank.com): a forum for discussion, development, and promotion of the proactive management of relationships, contracts and risks, and the prevention of legal uncertainties and disputes [23].

The proactive approach received a major boost when the European Economic and Social Committee (a consultative body created to advise the European Parliament, the European Council, and the European Commission) recognized the desirability of the proactive law approach in a 2009 opinion directed toward improving regulation at EU level [17].[3]

The proactive approach has two dimensions, both of which emphasize *ex ante*, forward-looking action: (1) a *preventive* dimension, seeking to prevent problems and disputes, and (2) a *promotive* dimension, seeking to secure the respective actors' success in reaching their goals. When used *proactively*, contracts communicate crucial information inside and between organizations; they help share, minimize and manage cost and risk; and, in case of a dispute, contracts work as a record and evidence of what has been agreed and provide a means to resolve the dispute. Further, when used *preventively*, contracts communicate the deal and its terms clearly so as to avoid future disputes over their meaning [12, p. 111].

The proactive approach emphasizes the importance of collaboration between legal professionals and other functions and disciplines [24, p. 54]. In contracting, the focus is on the users of contracts and how they can be enabled to reach their goals and prevent disputes. The goal is to embed legal knowledge and skills in business strategies and everyday actions to actively promote business success, ensure desired outcomes, and balance risk with reward [25, p. 24]. To succeed, contract users need easy access to relevant contractual information. Current contracts—lengthy legal documents full of dense text—do not necessarily provide such access. This is where *information design* and *visualization* enter the picture.

4.2.2 Information Design: Beyond Plain Language

While many tend to favor plain language in contract design, conventional contract drafters still consider legalese superior. They talk about the benefits of language that has been "tested", and so has a clearly established, "settled" meaning. Change could be risky. But this refers to language that has been litigated. Which raises the question: In the first place, why rely on language that resulted in litigation?

Kenneth Adams, a recognized expert on contract drafting, is a strong opponent of legalese. In his words, "[t]he fog of legalese makes it more likely that a contract will contain a flaw that leads to a dispute or deprives a client of an anticipated benefit"

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[3] In addition to the English language version, the EESC Opinion is also available in all other official EU languages: 23 languages altogether. The Section for the Single Market, Production and Consumption, under the leadership of Jorge Pegado Liz, was responsible for preparing EESC's work on the topic, and the author of this chapter, Helena Haapio, acted as Expert in this work.

[26, p. xxv]. In addition to Adams' work, several studies confirm the benefits of *plain language* and its preference among different groups of readers—clients [27], judges [28, p. 13], and the public [29].

It is obvious that plain language alone cannot solve the problems of legal complexity or make contracts or the law intelligible to the non-lawyer [30]. In the words of Professor Thomas D. Barton, Coordinator of the National Center for Preventive Law at California Western School of Law, one recurring barrier is the "exaggerated and largely unnecessary separation between the business goals that clients seek to achieve, and the legal methods by which contractual relationships are created and managed" [31].

The challenges of complexity are not limited to contracts and legal issues, of course. Suggestions about ways to overcome similar challenges can be found in other fields. Communication management research, for instance, has outlined major elements that can help make complex messages clear to their audiences: making the context clear, providing a clear structure, reducing the message to its essence, making the message ambiguity-free, and wording the message in a way that resonates with the audience [32]. Plain language and *plain design* seek to provide clarity and remove the barriers that prevent messages from being understood [11, 33]. In this respect, the research and practice of *information design* (sometimes also called *message design*), with its theoretical and practical approaches, is of particular interest, its main goal being clarity of communication [34, p. 30].

The theoretical component of information design, *infology*, encompasses studies of the way a combined verbal and visual representation should be designed and produced in order to achieve optimum communication between a sender and a group of receivers. The practical component of information design, *infography*, in turn, represents work with design and execution of structured combinations of words, pictures, and graphic design. The goal is comprehensible, clear, and consistent texts, clear illustrations, and a clear typography and layout that aid attention, perception, interpretation, understanding, and learning for the intended receiver [34, p. 38–39].

4.2.3 Legal Visualization: Beyond Text in Legal Design

Some pioneers have already gone beyond text in legal design. In Central Europe, *visualizing legal information* has developed into a research field in its own right. In the German-speaking countries, the terms *legal visualization* (Rechtsvisualisierung), *visual legal communication* (Visuelle Rechtskommunikation), *visual law* (Visuelles Recht), and *multisensory law* (Multisensorisches Recht) have been used to describe this field of growing research and practice [35, 36].

In the United States, the use of visualizations has been studied, for instance, in the context of improving the comprehension of jury instructions [37, 38] and facilitating the making of complex decisions related to dispute resolution [39, p. 154–161; 40]. Visualization has also been noted to play a role as a persuasion tool in various settings, from the court room [41, 42] to the board room.

In Canada, recognizing the need for new ways to inspire public access to the law, the Government commissioned a White Paper in 2000 proposing a new format for legislation. The White Paper [33] by David Berman, a communication designer, also introduced the concept of using diagrams to help describe laws, stating that this concept is "revolutionary, and likely the most innovative information design feature in the new design" [33, p. 23]. Among the people who would find diagrams useful, the author mentions individuals needing to know if the general provisions of a piece of legislation apply to them and senior government officials who need to gain a quick appreciation of a particular piece of legislation. In the process of creating a flow chart diagram, Berman's team also discovered inconsistencies that were not accounted for in the legislation, suggesting that if rendering laws into diagrams was part of the process of drafting, the resulting legislation would in some instances be substantively improved [33, p. 24].

Somewhat surprisingly, visual elements such as timelines and photos have recently made their way even to court decisions, both in Europe and in the United States: In Sweden, the judgment of the Court of Appeal for Western Sweden (Gothenburg) [43] includes two timeline images showing the chain of events that are crucial to understand the facts of the case. This judgment won the plain language award, *the Plain Swedish Crystal 2010*, not only for being written in a pedagogical and innovative way, having a clear structure, good paragraphing, clarifying summaries, and subheadings, but also for the fact that reading it was facilitated by bullet points and images [44]. In the United States, an Opinion by Judge Richard Posner of the Chicago-based 7th U.S. Circuit Court of Appeals uses the ostrich metaphor to criticize lawyers who ignore court precedent. Two photos are shown in the Opinion: one of an ostrich with its head buried in the sand, another of a man in a suit with his head buried in the sand [45, p. 5–6].

A convincing example of visualizing the law is the work of the Street Vendor Project carried out by Candy Chang, a designer, urban planner and artist, in collaboration with the Center for Urban Pedagogy in New York. Having noted that the "rulebook [of legal code] is intimidating and hard to understand by anyone, let alone someone whose first language isn't English", they prepared a visual Street Vendor Guide called "Vendor Power!" that makes city regulations accessible and understandable. The Guide features diagrams of vendors' rights and the most commonly violated rules along with some text [46]. Figure 4.2 ("Before") and Fig. 4.3 ("After") illustrate the difference between text and visual guidance.

In the Wolfram Demonstration Project, the use of visualizations has been explored in the area of legal rules applicable in a Battle of the Forms situation. Such a Battle arises in the not uncommon situation in which one company makes an offer or bid using a pre-printed form which contains its standard terms, and the other party responds with its own form and standard terms. Both parties then hope that a contract will be based on *their* terms rather than those of the other party. The applicable law may lead to a negative surprise to one party or both, including the possibility of no contract being formed. The visual demonstration contributed by Seth J. Chandler illustrates Article 2 of the Uniform Commercial Code that governs domestic sales of goods in the United States. The user can choose various details, and the output shows the most likely judicial finding as to whether a contract exists and the terms

Fig. 4.2 A typical page from New York city administrative code [47]

"Before..."

New York City Administrative Code -

Title 20
Consumer Affairs

§ 20–465 **Restrictions on the placement of vehicles, pushcarts and stands; vending in certain areas prohibited.** a. No general vendor shall engage in any vending business on any sidewalk unless such sidewalk has at least a twelve-foot wide clear pedestrian path to be measured from the boundary of any private property to any obstructions in or on the sidewalk, or if there are no obstructions, to the curb. In no event shall any pushcart or stand be placed on any part of a sidewalk other than that which abuts the curb.

b. No general vendor shall occupy more than eight linear feet of public space parallel to the curb in the operation of a vending business and, in addition, no general vendor operating any vending business on any sidewalk shall occupy more than three linear feet to be measured from the curb toward the property line.

c. No vending vehicle, pushcart, stand, goods or any other item related to the operation of a vending business shall touch, lean against or be affixed permanently or temporarily to any building or structure including, but not limited to lamp posts, parking meters, mail boxes, traffic signal stanchions, fire hydrants, tree boxes, benches, bus shelters, refuse baskets or traffic barriers.

d. No vending pushcart, stand or goods shall be located against display windows of fixed location businesses, nor shall they be within twenty feet from an entranceway to any building, store, theatre, movie house, sports arena or other place of public assembly.

e. No general vendor shall vend within any bus stop or taxi stand, or within ten feet of any driveway, any subway entrance or exit, or any corner. For purposes of this subdivision, ten feet from any corner shall be measured from a point where the property line on the nearest intersecting block face, when extended, meets the curb.

f. Each general vendor who vends from a pushcart or stand in the roadway shall obey all traffic and parking laws, rules and regulations as now exist or as may be promulgated, but in no case shall a general vendor vend so as to restrict the continued maintenance of a clear passageway for vehicles.

g. (1) No general vendor shall vend on any street which is in a C4, C5, or C6 zoning district, or in the area bounded on the east by Second Avenue, on the south by Thirtieth Street, on the west by Ninth Avenue and Columbus Avenue and on the north by Sixty-fifth Street, except that as chairperson of the street vendor review panel established pursuant to section 20–465.1 of this subchapter, the commissioner of the department of small business services or his or her designee may receive applications from any person, group, organization or other entity to permit general vendors on any street within said area or said zones, or to prohibit general vendors on any other street. Such applications shall be considered by the street vendor review panel in accordance with the procedures enumerated in section 20–465.1 of this subchapter.

(2) No general vendor shall vend on any street which is in the area including and bounded on the east by the easterly side of Broadway, on the south by the southerly side of Liberty Street, on the west by the westerly side of West Street and on the north by the northerly side of Vesey Street.

(3) Upon issuance of a new general vendor license or a renewal of an existing license, the commissioner shall provide a copy of subchapter twenty-seven of chapter two of this title and of the rules of the city of New York implementing such subchapter to such new or renewal licensee

Fig. 4.3 Street vendor guide. Accessible city regulations [46]

of that contract, along with a graph that explains the argument that will be advanced in support of the judicial finding [48].

4.3 Time for a Visual Turn in Contracting?

In an increasingly visual world, with "the visual turn" now found across a range of disciplines, such as technology, medicine, and economics, [49, p. 72–80] one would expect to see far more visual material used in contracts, contract negotiations, and in communications about contracts.

One of the reasons for the dominance of text may be the fact that with few exceptions, lawyers are typically accustomed to conveying their thoughts and ideas using words only [4, p. 146]. Also, when it comes to contracts and legal information, there seems to be a deeply-rooted preconception that readers want to see documents that "look legal" in order to deem them legitimate [50]. A similar (mis)conception is probably one of the highest barriers to the adoption of visual language in those documents: graphics don't "look legal" [11].

Up until recently, unlike visualizing legal information, visualizing contracts has remained an almost unexplored research area. When legal scholars or law and economics scholars deal with related issues, such as contract complexity and interpretation, they do so mainly from an *ex post* point of view, focusing on questions encountered by lawyers litigating disputes or by judges and appellate courts resolving them [51, 52]. Research related to legal risks in the context of contracts conducted at University of Oslo, Norway, Faculty of Law offers an exception: In a case study, a group of lawyers, managers, and engineers were asked to analyze the risks related to a contract proposal using a method based on graphical language and diagrams. The case study showed that graphical language was helpful in communicating risk amongst the case study participants. However, the need for simplicity and usability also led to some limitations and the need for a combination of graphical and natural language for improved decision-making [53, p. 237–262].

Knowledge visualization in the context of risk management in itself is not new. It has been researched, for instance, in Switzerland, at the University of St. Gallen Institute for Media Communications and Management. Their research findings related to risk communication and communication of knowledge between experts and decision makers [54] are relevant for continued research in the context of contracts: here, ways to enhance communication between managers and their legal advisors and managerial-legal decision making are focus areas.

As already stated, the ultimate goal of contracts is the performance the parties expect. Contracts are made *for business results*. Like in all communication, clarity of thought is required first. To achieve desired results, the results should be clear. If they are not clear, how can they be shared, articulated in a contract, or achieved? The path to *results* begins from clarity of thought and expression and, then, ideally, flows as follows [55]:

Clarity → Understanding → Fast decisions → Action → Results

Research outside the legal field tells us that unclear communication is often the result of unclear objectives, ill-aligned processes, and fuzzy roles or responsibilities. It is difficult to convey clear messages without having systematic, well thought out communication processes in place. Therefore, clarity in *organizing* must precede clarity in communication. According to Eppler and Bischof, communicators should also become aware of the importance of communicating with a human touch and embracing story-telling, as well as visualization, whenever possible [56, p. 57].

Research evidence in other fields also shows that visual elements can play an important role in enhancing clarity, supporting understanding, sharing knowledge, and retaining information [32, 57–59]. Visualizations have an impact on attitude and behavior, and they can be used in business to leverage both the *emotional* response of the readers and to enhance their *cognitive* abilities to understand the content [60, 61, p. 2].

At the Human–Computer Interaction Lab at the University of Waterloo, Ontario, Canada, researchers developed and tested what they called *textured agreements*: visually redesigned software agreements that employ vignettes and iconic symbols to accentuate information and highlight its relevance. These techniques showed promise in improving the software agreement process, yet the results also suggested caution: while summaries are effective at conveying a synopsis of the agreement, they can lead users to ignore the full agreement [62].

While further research is needed in the context of contracting, early experiments suggest that the contracting community could benefit from a more visual approach to knowledge sharing and presentation. Case law is full of examples illustrating that successful contracts cannot be based on one-sided assumptions, unexpressed expectations, or unclear goals. The following example illustrates *lack of clarity* and how visualization could have helped to prevent it.

4.3.1 How Visualization Could Have Prevented a Legal Problem

At times, the interests of the parties to a contract negotiation are widely misaligned. One party wishes to have a long-term commitment, while the other wishes to be able to walk away from the deal with short notice. The parties' different expectations relating to the intended duration of their relationship can lead to a less than amicable end of the contract. Due to their different perceptions, the parties are likely to differ on the interpretation of contract terms, especially those that are vague or poorly written. In the following example from Canada, a termination clause was interpreted differently by the two parties. It would have been best for the parties to have discovered their different views of the contract at the negotiations stage, but they did not. In this case, the lack of clarity led to an 18-month dispute over the meaning of a single comma in a clause. More than a Million Canadian Dollars were at stake [10, 63].

In 2002, Rogers Cable Communications Inc. (Rogers) entered into a Support Structure Agreement (SSA) with Aliant Telecom Inc. (Aliant), in which Aliant gave Rogers access to and use of certain telephone poles at a fixed rate. In order to raise its rates in 2005, Aliant gave Rogers 1 year's notice to terminate the contract. Rogers objected, stating that the contract had a minimum duration of 5 years. In addition, Aliant increased the annual rate of US$9.60 per pole to US$28.05 per pole [64]. The misunderstanding revolved around a single clause in the SSA:

> 8.1 This agreement shall be effective from the date it is made and shall continue in force for a period of five (5) years from the date it is made, and thereafter for successive five (5) year terms, unless and until terminated by one year prior notice in writing by either party.

As regards the initial term of the agreement, Rogers thought that it had a 5 year deal. Aliant was of the view that even within this initial term, the SSA could be terminated at any time with 1 year's notice. The validity of the agreement and the money at stake all came down the meaning of the final comma. In 2006, the Canadian authority CRTC (Canadian Radio-Television and Telecommunications Commission) sided with Aliant: "Based on the rules of punctuation," it stated, "the plain and ordinary meaning of Sect. 8.1 of the SSA allows for the termination of the SSA at any time, without cause, upon 1 year's written notice" [65].

However, the dispute did not end there. The parties' agreement was based on a model SSA that had been issued by the CRTC in both English and French. There was a difference between the French and English language versions of Sect. 8.1.[4] Rogers submitted that the French version of Sect. 8.1 provided clear evidence that the parties intended to restrict termination without cause to the end of the term. In response to Rogers' appeal, the CRTC reviewed the French-language version of the model SSA. In 2007, the CRTC sided with Rogers and held that the contract ran for a 5-year initial term and could not be terminated unilaterally before the expiration of the first term [66].

One would think that the duration of a contract would be of such great importance that the parties and their lawyers would have made sure that what the parties intended would have been clearly stated in the contract. In this case, neither party had drafted the problematic clause; they had relied on a model SSA. In hindsight, it is easy to say that they should have had a closer look at the clause before setting the price and other terms and signing the agreement. Also, the drafters of the SSA model form should have used clearer language. Breaking the clause into two sentences would have been a way to avoid the ambiguity [67]. Had the language been clearer, the parties would probably have noted upfront their differing understandings. Yet expectations are hard to manage or align if they are not visible. As illustrated in the chart below (Fig. 4.4), visualizations can help make the invisible visible.

Simple timelines, as in the chart above, would have shown the parties their different understandings. This would have allowed them, during the negotiations, to come to a mutual understanding and remove the ambiguity. A simple chart could have prevented the dispute and saved the parties from spending considerable time and legal fees on resolving the dispute. As already stated, in the words of Louis M. Brown, the Father of Preventive Law: "It usually costs less to avoid getting into trouble than to pay for getting out of trouble" [20, p. 3].

4.3.2 Examples of Contract Simplification and Visualization

While contract visualization is a new research field, some organizations and individuals have already applied visualization to contracting processes [69, 70] and

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[4] For the Parties' English language SSA, see http://www.crtc.gc.ca/public/partvii/2005/8690/rogers/051102.pdf. The French language version of Clause 8.1 of the model SSA is cited at http://www.crtc.gc.ca/eng/archive/2007/dt2007-75.htm.

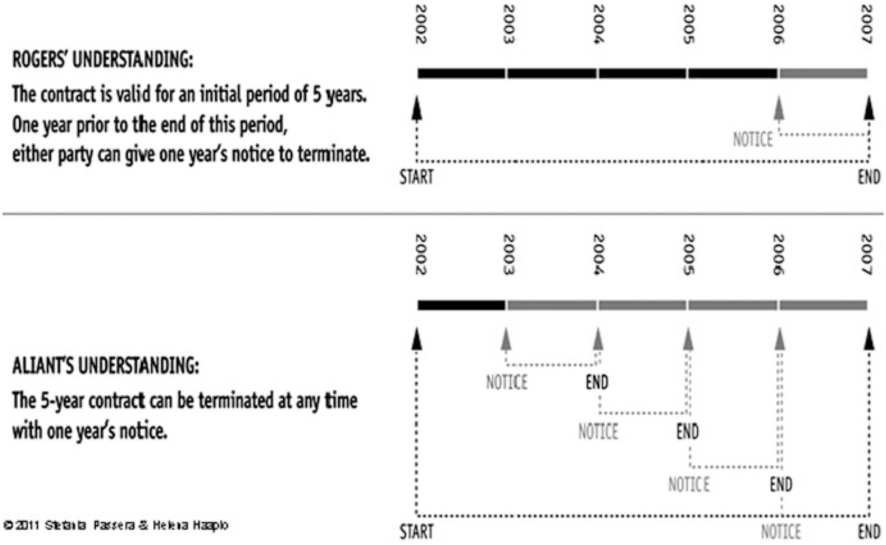

Fig. 4.4 Different understandings of a contract clause [68, p. 339]

documents [53, 68, 71–76]. Experiments exist that prove how credit card agreements and other consumer contracts can benefit from a new, more user-friendly approach. In 2011, the U.S. Consumer Financial Protection Bureau (CFPB) launched a new "Know before You Owe" project aimed at simplifying credit card agreements so that the prices, risks, and terms are easier for consumers to understand. The CFPB website shows a simplified prototype credit card agreement and offers a database where existing credit card agreements can be viewed to compare [77]. Further projects have aimed to simplify, for example, an online game's terms of service, a rail network's disclaimer, and a law firm's standard terms of engagement [78, 79].

A noteworthy example of using visuals to guide the use and interpretation of complex contracts comes from the U.K.: the NEC family of contracts. This family consists of several contracts designed for procuring a diverse range of works, services, and supply and their associated guidance notes and flow charts. The latter two are not part of the contract documents but assist in their understanding. Originally launched in 1993, and then known as the "New Engineering Contract", the NEC has been praised for its collaborative and integrated working approach to procurement. It has been said that the implementation of NEC3 contracts has resulted in major benefits for projects both nationally and internationally in terms of time and cost savings, and improved quality [80, 81].

The findings of legal and business practitioners, too, show that flowcharts and other non-textual tools can add value and improve productivity and efficiency in the corporate contracting process [71–73]. Published examples include the Outsourcing Contract Dashboard developed by DLA Piper's U.K. Office: a web-based contract assessment and reporting tool designed to help provide a simple, visual answer to the

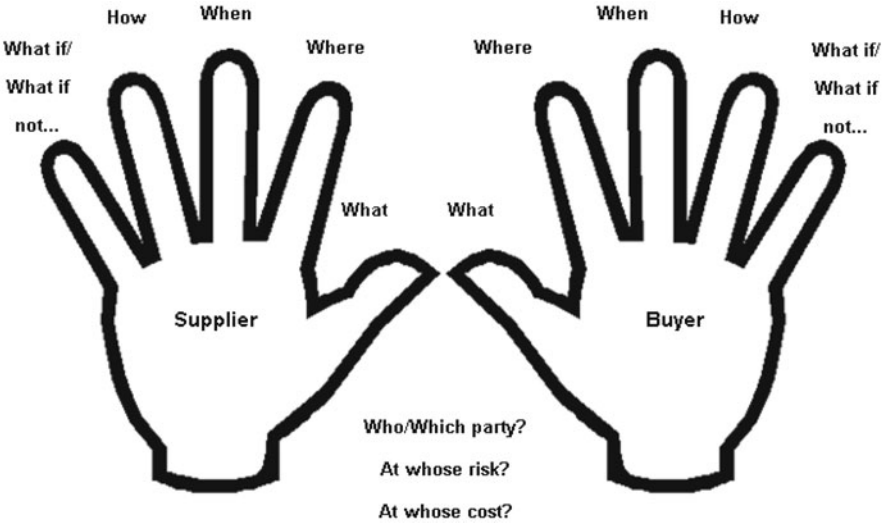

Fig. 4.5 Hand tool for better contracts [12, p. 135]

question "how good is this contract?" [82]. One of the early pioneers, Susanne Hoogwater of Legal Visuals, has developed the Visual Contract Index, a legal dashboard for accessible contracts, waivers, and terms and conditions [83, 84].

When teaching cross-border contract law to business managers and students, the Author has experimented with visualizations and visual metaphors, with the aim of curing *contract phobia,* changing attitudes, and making contracts' *invisible terms* visible [39, 85–88]. Here, the concept *invisible terms* is used to refer to terms (such as implied terms, implied warranties, and statutory default rules) that do not appear in the contract but become part of it, unless they are expressly excluded or amended. A lawyer familiar with the context knows and "sees" the *invisible terms*, while a non-lawyer does not [39, 85, 86]. Many legal problems could probably be prevented, if visualizations would show the presence and impact of such terms. Especially in international dealings, problems are often encountered not because of what the contract *says*, but because of what it *does not say*. Such gaps can be risky, especially for a supplier who wants to balance risk with reward and avoid excessive, unlimited liability exposure [86, pp. 32–33].

Not all tools need to be sophisticated. Let us use task allocation as an example: an important area that needs to be captured and articulated in a contract. The Author's simple "hand tool " (Fig. 4.5) lists the trivial-sounding but crucial questions that must be answered when creating or reviewing contractual rights, responsibilities, and remedies: who/which party shall do—what—where—when—how—and, last but not least, what if/what if not. Often it is also worthwhile to ask who bears the risk and cost of doing things.

The “hand tool ” (Fig. 4.5) lacks professional polish. It confirms the fact that lawyers (like the Author) need partners, tools, and guidance in order to create visualizations. If the emerging research in progress reaches its goals, tools and guidance will become available that will help change the text-only communication habits of lawyers. The early findings suggest that many benefits can follow, both for the legal profession and for its clients.

Like the contract puzzle (Fig. 4.1), the “hand tool ” illustrates that risk and contingencies are not what contracts are made for; contracts are made to help get things done and establish a framework for success. While it is important to have safeguards and minimize the negative consequences of failure, a *contract cannot and should not be developed in isolation from the overall scope, business deal, and relationship. Success requires managerial-legal collaboration and communication. The future will show how visualization can help in this endeavor.*

4.3.3 A Sea Change Waiting to Happen

Contracts seek to enable, shape and guide collaboration and regulate future conduct. To work as intended, contracts need to be read, understood, and followed. For most people, this is neither easy nor enjoyable.

So far, contract design has been widely seen as lawyers’ work. Lawyers, in turn, have seen their contract-related work as something focusing on the legal aspects of business, with the goal of protecting their client in the case of a dispute, preferably allocating all risks to the other party. The result: contracts that are confrontational, prepare for worst case scenarios, and look like statutes that no non-lawyer wants to read.

What if we could change this? What if contracts were seen as *business tools*—or, alternatively, as *sales tools* or as *communication tools*—rather than as legal tools? To design such contracts, a new mindset would be called for: a *designer-mindset*, rather than a *lawyer-mindset*. Contract clarity and usability would be high on the agenda, so that the work product would truly support its users in performing their tasks and achieving their goals. If designers have freedom to experiment, the work product might look very different from how a typical contract looks today.

At the same time, the perception of how a contract should look and what looks “legal” may very well be changing. Recent research indicates that law, too, has entered the digital age and that visual communication technologies are transforming the practice, theory, and teaching of law [35, 36, 42, 43, 87–90].

The early results of the ongoing research at Aalto University suggest that visualization offers a promising new way to support effective contract -related communication: it helps increase awareness and interest, make complex messages clear and understandable, facilitate cross-professional communication, and improve contracts’ usability and user experience [10, 11, 91]. The use of images can lead to better access and understandability, making complex information easier to find, more interesting, and easier to work with [10, 11].

For someone who is not prepared for a sea change, it is perhaps comforting to know that contract clarity and usability can also be improved with minor changes. For instance, not all contracts have a table of contents. One can be added to provide the reader with an easy overview of the different parts of the contract. When the contract draftsperson has developed the content, an information designer can help make the structure clearer, for instance by using typography and layout with distinct types of headings and icons. Restructuring the text to follow the reader's (business user's) logic rather than the traditional draftsperson's (lawyer's) logic can be more demanding and is likely to require cross-professional collaboration.

Clarity and usability have many dimensions, and visualizations come in many forms, shapes and functions. What works for business and project managers may not work for judges or lawyers, or vice versa. To gain wider acceptance among business and legal professionals, more examples are needed, preferably from different contexts and industries, varying from commercial contracts to government and consumer contracts and from publicly-made regulations (administrative and legal codes) to privately-made rules. Further research is also required into what kinds of visualizations are most helpful for different audiences, contexts and goals; what tools are available to convert text into images; and what principles should guide the selection of the tools and visualizations.

In addition to management, legal, and design scholars and professionals, cognitive psychologists and communication experts will be needed to assure that the chosen visualization tools and methods provide optimal communication and decision support for the different users and messages. Continued research and user studies will be needed in order to recognize the opportunities and challenges and to establish good practices. Before this can happen, many researchers', business managers', and lawyers' mindsets, attitudes and working habits need to be changed. Visualization seems to offer tools for this purpose also.

The growing corporate interest in exploring the topic further is certainly encouraging for researchers and practitioners alike. While the theoretical foundation is only starting to emerge and it is too early to predict what the future will hold, from a practitioner's point of view, the only limit is one's imagination.

4.4 Conclusion

Contracts are complex, just as the business they seek to describe. Sometimes contracts cover complex projects and topics no single professional can master. Sometimes they use terminology that is incomprehensible for the non-expert. Often they are voluminous, dense documents that touch many professions and disciplines.

Yet complex projects do not necessarily need complex contracts. Like any other communications, contracts can be made more easily understandable. In light of the growing number of examples, *information design* and *visualization* may finally be on their way to contracting processes and documents.

If contracts fail, a lot is at stake, including good-will and reputation. Yet contract problems are not inevitable: using a *proactive approach* to contracting and the law, problems can be prevented and the likelihood of successful business relationships can be increased. Information design and visualization offer tools that can help in this venture. They also offer an opportunity to enhance collaboration and communication across functions and disciplines.

Despite the obvious benefits, challenges still remain for someone wishing to develop new and easier methods for contracting. One of the major challenges is the current "dual ownership": while contracting (as part of selling, purchasing, alliancing, networking, and so on) is a business process and business management is in charge of its outcomes, contracts often seem to fall into the sole domain of lawyers. Changing the ways contracting works requires the involvement of both business management and legal professionals. Both need to change their current ways of working. If they don't, contracts are likely to continue to get more complex and more difficult to work with for their internal and external users.

The time has come to give up the legally dominated text-only communication habits in contracting and adopt a more user-friendly approach. This Chapter proposes *contract visualization* as an emerging topic for research and practice, capable of providing new and unexplored tools for enhanced clarity and usability. The goal: easy-to-use contracts that increase the probability of successful business relationships with predictable outcomes and no negative surprises.

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Chapter 5
From Culture to Text to Interactive Visualization of Wine Reviews

Andreas Kerren, Mimi Kyusakova and Carita Paradis

Abstract On the basis of a large corpus of wine reviews, this chapter proposes a range of interactive visualization techniques that are useful for linguistic exploration and analysis of lexical, grammatical and discursive patterns in text. Our visualization tool allows linguists and others to make comparisons of visual, olfactory, gustatory and textual properties of different wines for example from different countries, from different grape varieties, or from different vintages. It also supports the visual exploration of sensory descriptions as well as confirmatory investigations of text and discourse. Besides a more technical discussion of our visualization approach, we also provide a more general overview of text and corpus visualizations and highlight linguistic challenges that we had to address during the development phase.

5.1 Introduction

Documents and texts from the World Wide Web or from other digital resources present human beings with the challenge of managing and making sense of large amounts of complex textual information *within* cultures as well as *across* cultures. This challenge pervades our private and societal lives, trade and industry, research and innovation. Based on a relatively large corpus of wine reviews, or tasting notes as they are also called, from world famous Robert Parker's *Wine Advocate*, this chapter is a case study of how interactive visualization of textual data and related information might be made useful both in academia and in society at large. Through the lens of the wine reviews, within the broader culture of wine writing, wine production, wine consumption, wine trade and aesthetics, we show that suitable visualization techniques offer the tools to capture discursive usage patterns that represent interactions of different dimensions of language structure that may characterize text and discourse with the obvious implication that these tools can be used also within other socio-cultural practices.

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The great challenge for wine critics is of course to translate the sensory perceptions evoked during the tasting event into knowledge representations in writing, so that they can be understood by their readers.

In spite of the fact that viticultural knowledge and sensory pleasures related to wine consumption go back thousands of years, the high status of wine as a prestige consumable and an index of social status is a relatively recent phenomenon—"wine is becoming a cultural icon in an emerging hedonistic sub-culture accessible to an ever larger number of consumers" [3, 15, 24]. The emblematic impact of prestige consumables in contemporary society may be seen as a result of social and discourse practices associated with "you are what you say about what you eat" or, in the context of fine wine, "you are what you say about what you drink" [26]. Among wine lovers, it is common that the experience of wine is first and foremost seen as an aesthetic pleasure similar to the experience of art or music. The wine correspondent of *The Guardian* [11] makes use of a passage from Evelyn Waugh's *Brideshead Revisited* [48] which highlights the combination of pompous snobbery and paucity of sensory vocabulary. One of the many things that Charles Ryder, one of the main characters in the book, discovers through his relationship with Sebastian Flyte is a serious acquaintance with wine:

> We warmed the glass slightly at a candle, filled it a third high, swirled the wine round, nursed it in our hands, held it to the light, breathed it, sipped it, filled our mouths with it, and rolled it over the tongue, ringing it on the palate like a coin on a counter, tilted our heads back and let it trickle down the throat [. . .] it is a little, shy wine like a gazelle. Like a leprechaun. Dappled, in a tapestry window. Like a flute by still water [. . .] and this is a wise old wine. A prophet in a cave [. . .] And this is a necklace of pearls on a white neck. Like a swan. Like the last unicorn. [48]

While there are many different types of wine writings, such as general reportages, editorials, advertisements and technical texts produced by oenologists and chemists, wine reviews represent a type of text written by wine journalists and connoisseurs aimed at both wine consumers and producers. Wine is a complex domain of aesthetic knowledge and tasting practice. It is complex in that it involves all of the sensory perceptions, *vision*, *smell*, *touch*, and *taste*, all of which engender emotional reactions and aesthetic responses. It is the task of the wine reviewer to communicate these experiences in a way so that they can be understood by their readers. This means that sensory perceptions have to be transformed into expressions that will have to pass through the readers' cognitive system in order to be interpreted.

As we will see later, wine reviewers' descriptions of the tasting event follow the journey of the wine from its appearance in the glass, through the nose and the mouth, and finally into the gullet. In contrast to the more synthetic or holistic descriptions of wine provided by the passage from *Brideshead Revisited*, the main body of Robert Parker's wine reviews are what Herdenstam [14] refers to as analytical descriptions. Such descriptions involve a decompositional approach to the tasting experience. The Aroma Wheel is a famous terminological attempt at a descriptor system, using descriptors from the vegetal, chemical and geological spheres. It was developed by oenologists at the University of California, Davis, for descriptions of smell [29]. The Aroma Wheel has been further developed for both smell and taste and for both whites and reds by the German Wine Institute [2]. The use of descriptors from such domains as fruit, minerals and spices is not wine lingo, but a necessity due to the relative lack of specific vocabularies for sensory domains [34, 37]. Aroma Wheel descriptors are primarily limited to objects. However, this is also true of color descriptions, as pointed out by Wittgenstein in *Remarks on Colour*:

> When we're asked "What do 'red', 'blue', 'black', 'white', mean?" we can, of course, immediately point to things which have these colours—but that's all we can do: our ability to explain their meaning goes no further. [50]

The aim of this chapter is to propose an interactive information visualization (Info Vis) tool to be used on text. Our contention is that visualization provides overviews and better understanding in equal measure. The tool has been developed on the basis of some 84,000 wine reviews from the *Wine Advocate*.[1] Thanks to the capacity of the tool to handle large quantities of data, it is useful for exploratory purposes as well as for confirmatory investigations of text and discourse, which in the case of the present data will increase our knowledge of the genre of reviewing in general and wine reviewing in particular [20, 35].

The remainder of this chapter is organized as follows. Section 5.2 gives a general overview of the challenges addressed. In Sect. 5.3 we discuss related approaches within the more general field of information and text visualization as well as more specifically in representing sensory descriptions. In Sect. 5.4, we describe our database of wine reviews and corresponding metadata. Our own approaches to the visualization of wine tasting notes by using information visualization techniques are presented in Sect. 5.5. Initial results are briefly outlined in Sect. 5.6 including a small use case description. We conclude in Sect. 5.7 and suggest some investigatory paths for future work.

5.2 Challenges

As already indicated in the previous section, wine reviews are descriptions and evaluations of wines written by professional wine tasters. They have a strict rhetorical structure, consisting of three parts, starting with production facts and ending with an assessment and a recommendation of prime drinking time. The middle of the text, which is the most important part, is devoted to an iconic description of the wine tasting procedure from the taster's inspection of the wine's visual appearance through smelling, tasting and feeling its texture, i.e., from *vision* through *smell*, *taste*, and *mouthfeel* (*touch*) [33], cf. sample review (1).

> (1) This great St.-Estephe estate has turned out a succession of brilliant wines. The 2005, a blend of 60 % Cabernet Sauvignon and 40 % Merlot, has put on weight over the last year. An opaque ruby/purple hue is accompanied by a sweet nose of earth, smoke, cassis, and cherries as well as a textured, full-bodied mouthfeel. While the tannin is high, there is beautifully sweet fruit underlying the wine's structure. It will require 8–10 years of cellaring after release, and should drink well for three decades. (Wine Advocate 170, April 2007)

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[1] https://www.erobertparker.com/entrance.aspx.

The visual appearance of the wine in (1) is described in terms of its clarity and color using the descriptors ‘opaque ruby/purple’. The olfactory perceptions are primarily described through concrete objects, e.g., ‘earth, smoke, cassis, and cherries’, but also in terms of a gustatory property, ‘sweet’, while taste and mouthfeel are described through various gustatory and tactile properties (‘high’ (tannin), ‘sweet’ (fruit), ‘textured, full-bodied’). Because almost all wine reviews describe the wines in terms of four different perceptual modalities, i.e., visual appearance, smell, taste and texture, they are a gold mine for linguistic explorations of descriptions of human sensory perceptions in discourse. Of particular interest are the descriptions of olfactory perception. There is no specific olfactory vocabulary, neither in English nor in (most) other languages of the world. Olfactory descriptions have to be made using words from other domains. In wine reviews, words for taste or words for objects such as fruit, herbs or flowers of different color are used. In general, dark objects are used in descriptions of red wines and pale objects describe white wines. In other words, olfactory descriptions are primarily made on the basis of the smell of objects and also their color and taste. Exploring patterns for perceptual descriptors and the context of their use in wine reviews provides useful information not only about the relations between descriptors of odor and other modalities, but also about language, perception and cognition in general [28].

Advances in visualization offer important possibilities for organizing, presenting and analyzing linguistic data, in which case visualization techniques provide a way to view language in other formats than as linear stretches of letters. Visualization techniques offer the tools to capture lexico-semantic usage patterns and to represent interactions of different dimensions of language structure that characterize different texts and discourses. As demonstrated in the beginning of this section, descriptions of wines in wine magazines are short texts with a very strict rhetorical structure. The language of such texts is of interest to linguists at various different discursive levels. Linguists want to know what kind of words are used to describe the wines’ visual properties, what kinds of descriptors are used for olfactory, gustatory and tactile perceptions. They are interested in what words and expressions are used in the texts. For instance, what kind of temporal expressions are employed in different parts of a text, and what expressions of personal opinion, such as ‘should’, ‘drinkable’, ‘recommend’ are used in the texts, where in the text, and why. More generally, linguists take an interest in how all linguistic patterns combine into what might be our understanding of the discourse beyond the text itself. In other words, visual imagery provides a way to represent things that would otherwise go unnoticed. The added value of the visualization tool presented here is that it can be used interactively. The data can be easily explored, and because parameters and combinations of data and metadata can be changed, many questions regarding the potential of the data receive on-the-spot answers. As a result, new patterns emerge that can generate new research hypotheses about language use in different genres and text types.

Our tool supports the visual analysis of the corpus of wine reviews from the Wine Advocate. The wine reviews are available in the form of two databases that contain a large number of wines, metadata about the wines, and the actual reviews. In order for linguists to arrive at a better understanding of different text types, different discourses and their vocabularies, large corpora are of crucial importance. At the same time, it is also a challenge to identify linguistic patterns in large corpora, to organize the data, to make statistical calculations and to present the data to readers in intuitive and clear ways. Our contribution is to find solutions to some of these challenges. The first challenge is that we have to be able to represent large amounts of multivariate data. For that purpose, advanced interaction techniques are essential, because they ensure the opportunity for selecting a subset of tasting notes and for getting detailed information about the tasting notes in order to proceed with further analyses. Secondly, we have to find an efficient way to interactively visualize the text of individual wine reviews, which brings us to the field of interactive text visualization. Thirdly, a number of compatible visualization approaches have to be combined in order to efficiently explore the language used in the descriptions of the wines.

5.3 Related Work

The general design of our visualization tool is based on standard coordinated and multiple view visualization techniques that are presented in Sect. 5.5.1. An excellent starting point for related work of this kind of visualization techniques is the annual Other series on Coordinated & Multiple Views in Exploratory Visualization (CMV) or the work of Roberts [36]. In order to specify the layout of our tool and to define the functional requirements, we were inspired by the FilmFinder tool for exploring movie databases [1]. It was one of the first tools, which integrated the concept of a two dimensional scatter plot with color coding, filtering, and details provided on demand (dynamic queries). The developers realized different encoding and interaction techniques for the representation of multivariate data.

For the purpose of information visualization of complex textual data, we use different well-known techniques and interaction approaches as described in the next subsection. Here, we decided to provide a more general view on text and document visualization to embed our work in a broader context. Related work that concretely addresses the (visual) representation of wine attributes and/or descriptions is given in Sect. 5.3.2.

5.3.1 A Brief Overview on Text and Document Visualization

At present, we have access to texts in many different ways. We find them in printed books and documents, in online books, electronic documents like PDFs, the World Wide Web or other digital libraries, patient records, source code of programs, patents, emails, diagrams, etc. The availability of texts and documents is overwhelming, and people want to actively deal with them to solve specific problems. Typical questions are: what documents contain a text about a specific topic? Or, are there similar documents to those that I already have? Sometimes, we only want to search for a single word in a large text, or we look for interesting patterns. Such patterns might show how a text was written by an author, or if it was written by several authors even if not indicated in the header of the document. In this context, the visual analysis of specific metadata, e.g., comments, size, or number of words is also important. The great interest in text and document visualization is also reflected by the increasing number of Others and workshops that offer a place to discuss techniques and tools for visual text analysis, such as the Workshop on Interactive Visual Text Analytics for Decision Making held at VisWeek 2011 in Providence, USA, or the AVML (Advances in Visual Methods for Linguistics) in York, UK, 2012.

5.3.1.1 Text Representations

Information visualization is capable of supporting the aforementioned tasks in several ways. First, we focus on text visualization, i.e., on tools for and approaches to the visualization of a single document.

Tag Clouds provide information about the frequency of words contained in a text [17]. The approach uses different font sizes for each word in the text to indicate how often a certain word is used in comparison with the other words. Several extensions and related approaches exist, such as *Wordle* or *ManiWorlde* [21, 46]. *SparkClouds* extend the original tag cloud idea with a temporal variable by so-called "sparklines" [23]. Thus, trends can easily be identified and analyzed. In our tool, we use a simple tag cloud implementation to represent the word frequency in a group of wine reviews.

The research project *Many Eyes* provides alternative methods for data analyses using innovative visualization techniques [16]. One of the approaches for supporting text analysis is the representation of a given text as a *Word Tree* [47]. The purpose of this visualization method is to afford an insight into the different contexts in which a word is encountered in an unstructured text. We used this concept in one of the text visualizations of our tool to facilitate rapid exploration of the wine tasting notes (cf. Subsection 5.5.1).

An approach for visual literary analysis, called *Literature Fingerprinting*, was presented by Keim and Oelke [18]. It supports the visual comparison of texts by calculating features for different hierarchy levels and by creating characteristic fingerprints of the texts. Such features might be word/sentence length or measurement of vocabulary richness. A similar idea for the representation of wines is described in Subsection 5.3.2. However, no feature analysis was performed in this case; just wine attributes (color, production year. . .) are used for the visual mapping.

Special Cases In the field of software visualization, there are several ideas about how to represent textual information, i.e., the source code in this case. Besides classic techniques such as line indentation or code coloring used in order to represent code structure and keywords (depending on the programming language), the well-known *SeeSoft* approach [8] maps each source code line to one pixel row. The color coding of this pixel row represents statistical measurements or other metadata, for example, age of modifications. If the source file is too long to fit on the screen, the vertical arrangement of the rows representing the lines is folded and continues in the next column.

5.3.1.2 Corpora Representations

A collection of documents is usually called a *corpus*. Corpora can be structured to some extent (software packages, wikis . . .) or relatively unstructured (emails, patents . . .).

Early approaches, e.g., *Lifestreams* [9], simply arranged documents according to specific attribute values such as time tags. More recent works analyze the documents by metrics, such as similarity, and perform cluster analyses or compute so-called self-organizing maps (SOMs). An SOM (or *Kohonen Map*) applies techniques from the field of artificial neural networks to map n-dimensional data objects to simple geometrical structures, typically in a 2D grid. In our case, the data objects are the documents and the n-dimensional attributes are defined with the help of keywords from the title or the abstracts. In a typical SOM representation like WEBSOM [22], the number of documents that fall into a specific area (i.e., the density) is mapped to a color gradient, and categories are represented by simple labels.

Conceptually similar (by looking at the result) is *ThemeScapes* [49] that follows a natural landscape metaphor. Single documents are categorized and then applied to a document map as topic areas, whereas the documents themselves are shown as small dots. “Mountains” in the landscape represent document concentrations in a thematic environment (density), height lines connect concept domains, and interaction is possible through tool tips, zooming and panning, etc. There are many more recent approaches that make use of the same metaphor, such as [30].

Dengel et al. [7] regard document collections as information space and use a 3D metaphor for the visual representation. Depth is used to distinguish important documents from unimportant ones, i.e., a document is drawn as an icon and appears more in the foreground if it is important. It is also possible to visualize relationships and cluster analysis results using this approach.

In order to carry out comparisons of text documents using tag clouds, Collins et al. [6] introduced the so-called *Parallel Tag Clouds*, where tags are arranged on vertical lines for each document. Identical words are highlighted by connection lines. Another way to compare documents was described by Strobelt et al. [44]. They developed the so-called *Document Cards* which are compact visual representations that show documents’ key semantics as a mixture of images and important key terms. The technique is also transferable to use on mobile devices.

Salton and Singhal analyzed the relationships between text documents according to different topics. They developed a tool called *Text Theme* [38] to represent such correlations visually. Single topics can then be identified and be compared with the help of textures or color coding.

In contrast to most of the approaches discussed in this subsection, our tool operates more on the syntactic level, i.e., higher-level themes or entire tasting notes cannot be compared directly. Thus, our tool was originally not designed to focus on the significance of specific entities extracted from the tasting notes but rather on the exploration of their content and linguistic constructions.

Special Cases If the document collection is related to time-series, a usual task is to find thematic changes over time. There are several approaches that address temporal text analysis. One of them is *ThemeRiver* [12] which uses a river metaphor as a representation for the information flow over time. The themes themselves are stripes in the river that start at the first appearance of a theme and end if it is no longer contained in any documents like a pigment thrown into a river and distributed in the streaming. The thickness of a stripe represents the number of documents with that theme.

Stasko et al. developed a visualization tool for analyses of textual reports called *Jigsaw* [43]. The goal of their tool is to aid investigative analysts to faster understand the content of reports in order to predict possible threats and to prepare defensive plans accordingly. The main analysis units in their work are pre-defined entities in the texts and the goal of the implemented visualizations is to represent relations and connections between these entities.

5.3.2 Representing Wine Descriptions and Tastings

Using both corpus methodologies including visualization of the data and experimental psychophysical techniques, Morrot et al. [28] investigated the interaction between visual appearance and odor determination in wine description and wine tasting. Their work presents the results of a study carried out with the help of a tool called ALCESTE, which is based on statistics about the distribution of words in a corpus of text to determine groups of words that co-occur in the same context. They found that the descriptors used to characterize white and red wines were different in terms of the colors of the objects used in the descriptions respectively (i.e., dark objects describe red wines and pale objects white wines). In addition to the corpus study, they also carried out a psychophysical experiment, which confirmed the corpus data, demonstrating the impact of vision on the human odor perception. In comparison to ALCESTE, our visualization tool gives users more possibilities to browse the text, to filter out uninteresting cases, and to interact with the visualizations. Thus, it does not afford pure statistical numbers only, but gives analysts an opportunity to explore the data set and to get a better understanding of the structure and content of the texts.

Another visualization approach, called *Wine Fingerprints*, has been discussed by Kerren [19]. In contrast to the tool presented in this paper, *Wine Fingerprints* focus on wine attributes, such as wine color, rating, grape type, price, aroma, and not on the actual wine reviews. These data form a multivariate data set, part of which can be hierarchically structured into a so-called aroma hierarchy. Two different types of fingerprints based on a rectangular or radial drawing approach respectively are shown in Fig. 5.1. The *Wine Fingerprints* approach has various applications for business and industry in that it can create visual patterns of combinations of wine attributes and

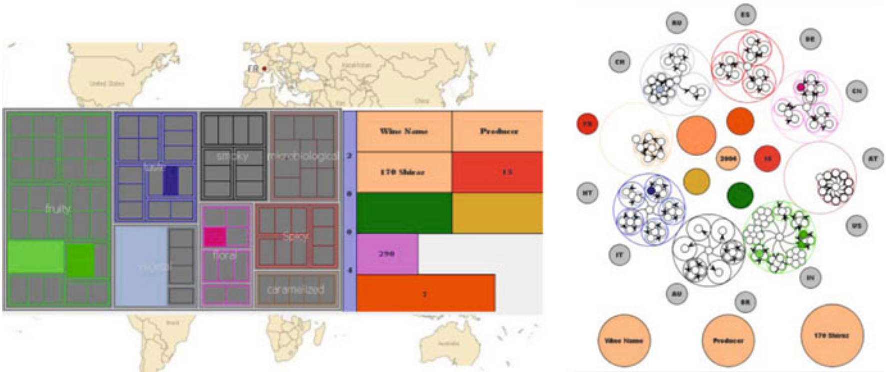


Fig. 5.1 On the left-hand side, a wine fingerprint is shown using a *rectangular* drawing approach as well as a *treemap* layout [40] for the aroma hierarchy. On the right-hand side, a wine fingerprint is displayed using a *radial* drawing approach as well as a *balloon tree* layout for the aroma hierarchy [19]

support comparisons of visual, olfactory and gustatory properties of different wines from different parts of the worlds, from different grapes, from different vintages etc. Both customers and companies can make visual comparisons of wines and select wines on a pictorial basis instead of on the basis of a list of multimodal perceptual attributes.

5.4 Notes on the Data Set

Text annotation by part of speech, so-called tagging, and sentences structure exploration of the wine reviews are indispensable for analyses of the sensory vocabulary and the context of perceptual descriptors use. Word classes (also called parts of speech) are linguistic categories of lexical items defined by their syntactic distribution in natural languages. Each word class has a corresponding abbreviation called word-class tag or word tag [39]. Typical examples of word classes are “adjective” and “noun” with abbreviations “JJ” and “NN” respectively. Word classes are essential for some of the approaches we apply in tasting notes analyses as they are a basic criterion we use for organizing the data in text visualizations.

The wine tasting notes are stored in two databases that contain information about different wines as well as the tasters’ comments about them. In each database, the tasting notes are represented in different ways. The first database contains descriptive information about the wines, their unique ID number, their origin, vintages, wine ratings, dryness, color and the complete original wine review. The second database contains the same tasting notes including ID numbers, but they are segmented into words with their respective word-class tags. The latter database was built from the former, the original database, by using the *WineConverter* tool, developed by Ekeklint and Nilsson from the language technology group at Linnaeus University in Sweden

Table 5.1 Statistical numbers derived from the wine databases

Number of tasting notes	84,864
Total number of words used in the tasting notes	8,332,666
Number of different words used in the tasting notes	46,000
Maximum length of the tasting notes	496
Number of word classes	43
Number of vintages	104
Range of wine rating values	1–100

(formerly Växjö University). The result of this segmentation is a new structuring of the wine tasting notes where each word is described by additional information that accurately specifies its position in the text of the full tasting note. The location of each word in a tasting note is determined by the following information: ID number of the tasting note, number of the corresponding sentence in the tasting note, position of the word in this sentence, the word itself, and the word tag given to this word.

In order to get a better overview of appropriate visualization approaches for representing the tasting notes and their attributes, we had to take the great amount of analyzed data into consideration. Table 5.1 provides a list of substantial statistical numbers derived from the data set to give an idea about the sheer quantity of the data to be visualized.

5.5 Visualization Framework

In order to provide an overall perspective of the analyzed wine reviews, we follow Ben Shneiderman's mantra of information visualization : "overview first, zoom and filter, details on demand" [41]. This gives users an initial overview of the data explored and the possibility to proceed with investigations of its subsets. For this, we combined several visualization approaches to achieve our goals: scatter plots, tag clouds, word trees, bar charts/histograms, and a world map. The scatter plot is used to be the main entry point for using our tool as described in the following sections.

5.5.1 Visual Representations

Scatter Plot The purpose of this visual representation is to give a first overview of the data. Because of the large number of tasting notes (cf. Table 5.1), we decided to use a scatter plot for their initial display, i.e., each single tasting note is represented by a blue circle. This approach also saves space and gives an idea about the distribution of the tasting notes on the basis of the values of two selected wine attributes, see Fig. 5.2a. Attributes currently supported by the scatter plot visualization are all possible pairs of "Wine Rating", "Wine Vintage", "Color Class", "Tasting Notes Length", and "Wine Country".

This house makes rather restrained yet rich , flavorful vintage port and a very good tawny called Nimrod . Their vintage ports seem slow to develop , and while they never quite have the voluptuous richness of a Dow , Graham , or Fonseca , they have a unique mineral-scented

Fig. 5.2 A snapshot of the main window of the application after starting. Note that one tasting note was selected in the scatter plot; its tag cloud is shown in the *bottom right* corner

Filter Panel After getting an overall view of the data, users are given the opportunity to interact with the visualizations in order to find the best subset of elements to be further analyzed. *Dynamic Queries* are a widely used concept in information visualization for aiding the solution of this task [1]. This approach offers a simultaneous display of query and result. It is useful for dynamic exploration of the data. Following this concept, different types of filters were integrated for some of the attribute values to be used for finer delimitation of the visualized elements on the scatter plot, see Fig. 5.2b. More details on the effect of various filter possibilities are given in Subsection 5.5.2.

Bar Charts and Histograms Getting statistical information helps analysts to better understand the visualized data and to find the desired set of tasting notes. Bar chart diagrams are traditional approaches for statistical data visualization. In this work, they are supplied in order to show the number of tasting notes that correspond to the values of a specific wine attribute (Fig. 5.2c).

Text Visualization The visualization approaches that we apply for the representation of tasting notes are word trees and tag clouds.

Word Tree The word tree visualization facilitates rapid querying and exploration of text bodies [47]. In our tool, a word tree describes the sequence of words and phrases used in a group of tasting notes. The structure of the word tree is organized into two main groups of nodes: word tags and words. There are three prerequisites for proceeding with the word tree visualization:

- users need to select a group of tasting notes for further analyses,

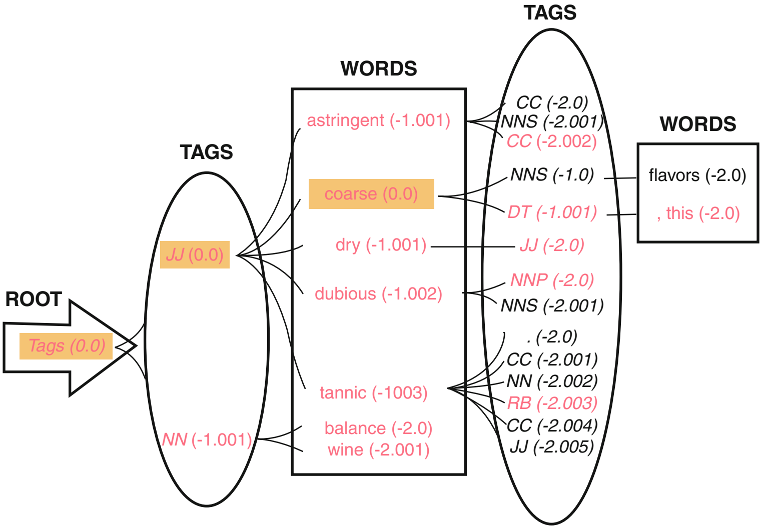


Fig. 5.3 A word tree that shows the node organization into two main groups: word tags and words. Furthermore, there is another partition of the tree nodes as well: nodes that contain data from the root tasting note (text colored in *red*) and nodes that contain data only from the other tasting notes (text colored in *black*). The DOI value of each node is given in brackets on its right side

- a specific tasting note for deriving the initial data (from now on referred to as *root tasting note*), and
- the word classes of the words in this root tasting note that they would like to analyze (to be chosen with the help of the tag checkbox panel shown in Fig. 5.2e).

The first three levels of the word tree contain data from the root tasting note. The other levels consist of data from the whole group. The color of the text of each node indicates whether it is contained by the root tasting note or not. Red color of the text means that it is part of the root tasting note, but it can be met in other tasting notes as well. Black color of the text implies that it is certainly not contained by the root tasting note. The root node of the tree is artificially added, and it contains the static text "Tags", which suggests that the following level is composed of word tags. The second level contains the selected word tags that correspond to words in the root tasting note. The third level consists of all the words from the root tasting note that belong to the word tags on the previous level. Figure 5.3 gives an example of the word tree and the organization of its nodes. The levels of the tree alternate with each other to represent either word tags or words that correspond to the tags on the previous level. The children of each node representing a word class are the words from the analyzed group of tasting notes that belong to this word class. For instance, the word tree in Fig. 5.3 displays two (selected) word tags of the root tasting note, i.e., "JJ" (adjectives) and "NN" (nouns, singular common). By looking at the children of "JJ", the user can see that the root tasting note has four adjectives, e.g., "coarse". Then, by looking at the next two deeper levels, the user can see that "coarse" has two successors: one noun (plural common; “NNS” → “flavors”) in another note from the analyzed notes group (black) and one determiner (“DT” → “,this”) in the root tasting note.

Our word tree visualization represents a large data set of words and word tags. It is restricted by the size of the display and people’s perceptive capabilities. To cope with these restrictions, our implementation applies the idea of Degree-Of-Interest (DOI) trees that provide a solution of these problems. They combine focus & context visualization techniques and degree-of-interest calculations to find a proper layout that fits within the bounds of the display. The technical idea is the use of a DOI function, which assigns a number value (DOI value) to each node indicating how interested the user is in this node. This value is then used as a criterion to determine, which of the nodes should be visible, which of them are in focus and how they should be displayed [4, 13]. The nodes in focus have the greatest DOI value and are slightly magnified. The size of all other nodes is directly proportional to their individual DOI value. An exception to this rule is the tree element that was selected last, which is the most magnified element, in spite of the fact that it has the same DOI value as the other focus nodes. Figure 5.3 demonstrates a degree-of-interest tree where the DOI values of the nodes are given in brackets on the right side of the node label.

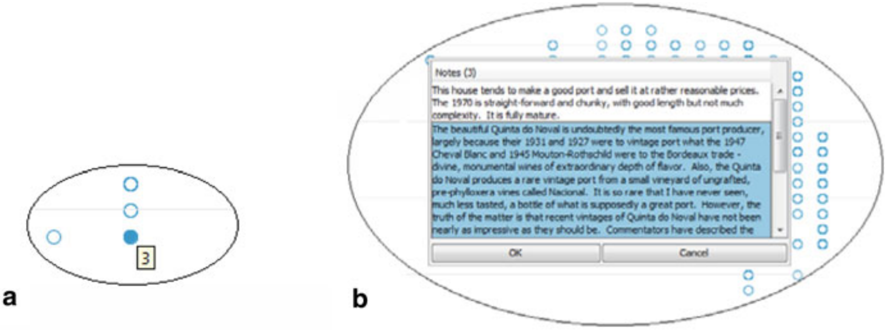
Tag Clouds The tag cloud visualization makes use of different font sizes for the words in a corpus of texts to give a hint about the frequency of their usage. There are two prerequisites for the application of tag cloud visualizations of a tasting note. A group of tasting notes needs to be defined for further analyses, and one of them has to be selected for its text visualization. The text of the selected tasting note is then visualized by using the tag cloud metaphor, where each word has a different font size depending on how often this word occurs in the whole group of tasting notes, cf. Figure 5.2d.

World Map Visualization The origin of wines is important information and should be visualized in a way that gives the user a rough overview of wine-producing countries. A natural approach for visualizing it is an interactive world map indicating the density of wine production in different countries. Figure 5.6 shows a world map representing information about the wines produced in different parts of the world that have been tasted and described in the tasting notes. The color saturation is directly proportional to the density of wines produced in each country.

5.5.2 Interaction and Coordinated Views

We combined the visualization approaches described in Sect. 5.5.1 with appropriate techniques for user interaction to build an efficient tool for analyzing wine tasting notes. The subsequent subsections give a notion about the user interface and the overall layout of the application. More precisely, there are five particular views intended to build an efficient overview visualization as displayed in Fig. 5.2:

1. a scatter plot (showing the distribution of tasting notes),
2. filters (to reduce the complexity by filtering),



This house tends to make a good port and sell it at rather reasonable prices. The 1970 is straight-forward and chunky, with good length but not much complexity. It is fully mature.

The beautiful Quinta do Noval is undoubtedly the most famous port producer, largely because their 1931 and 1927 were to vintage port what the 1947 Cheval Blanc and 1945 Mouton-Rothschild were to the Bordeaux trade - divine, monumental wines of extraordinary depth of flavor. Also, the Quinta do Noval produces a rare vintage port from a small vineyard of ungrafted, pre-phylloxera vines called Nacional. It is so rare that I have never seen, much less tasted, a bottle of what is supposedly a great port. However, the truth of the matter is that recent vintages of Quinta do Noval have not been nearly as impressive as they should be. Commentators have described the

Fig. 5.4 Overlapping tasting notes in the scatter plot view. **a** Tooltip help. **b** Tasting note selection

3. bar charts and histograms (to show statistical data),
4. tag clouds (for text visualization), and
5. tag checkbox panel (to select specific word classes).

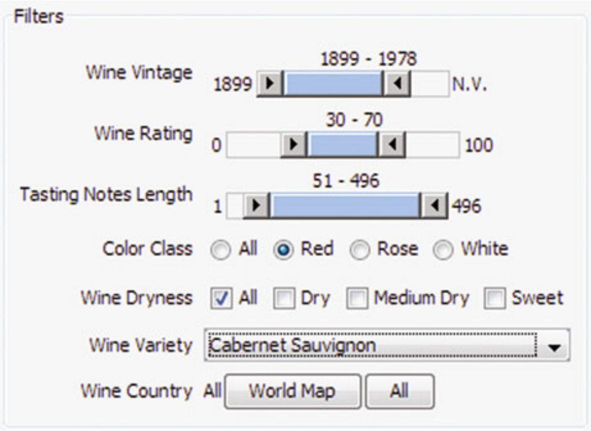
The above views (1–5) are coordinated by standard highlighting and brushing techniques.

Distribution of Tasting Notes The scatter plot axes on the left and bottom sides of the display correspond to one wine attribute each. Range sliders [5] are added to the axes in order to make it possible for the users to change the range of the wine attribute values and therefore the scope of the tasting notes visualized in the scatter plot. The number of visible tasting notes can be observed at the upper left corner of the scatter plot (8,486 in our screenshot example of Fig. 5.2a). Another possibility given to the user is to change the wine attributes plotted on the *x*- and *y*-axis by selecting other attributes from the combo boxes at the top of the display.

There is a drawback that appears as a consequence of the scatter plot concept and the data stored in the database: it might happen that more tasting notes share the same values for both of the wine attributes plotted on the axes. Such tasting notes overlap when they are visualized at the same spot in the scatter plot. This makes the selection of an element from the display more complicated. We added a tooltip to each element to give the user a hint about the number of overlapping tasting notes at the specific position (Fig. 5.4a). Thus, an individual element can be selected from a popup list of the overlapping tasting notes, as shown in Fig. 5.4b. The selected tasting note differs from the others because of the filled blue circle in the scatter plot as well as the blue background color in the popup list. In case of overlaps, the selected element is visualized on top of the others, which guarantees that it is always visible.

Instantaneous Response of the System Information exploration is an interactive process between users and visualizations. Thus, it needs to be well supported and incorporated into the system's potentialities. This process consists of series of questions and answers, and furthermore, each succeeding question depends on the prior

Fig. 5.5 Types of filters implemented in the application



Filters

Wine Vintage: 1899 - 1978 (1899 … N.V.)
Wine Rating: 30 - 70 (0 … 100)
Tasting Notes Length: 51 - 496 (1 … 496)
Color Class: ○ All ● Red ○ Rose ○ White
Wine Dryness: ☑ All ☐ Dry ☐ Medium Dry ☐ Sweet
Wine Variety: Cabernet Sauvignon
Wine Country: All

answer [42]. The means that our visualization tool supplies for asking questions are filters. To provide an adequate environment for data analyses, the system performs an instantaneous response to the users' actions. Changing the value of a filter has an immediate effect on the displayed visualizations and users do not need to perform any superfluous actions to request refreshing of the displays. This feature is essential for performing efficient data analyses.

Filtering Filters are used to facilitate the task of the users to interact with the visualization and to find the best subset of elements to be further analyzed. Figure 5.5 shows a screenshot example of filters supported by our tool, which in this case selects only those tasting notes whose corresponding wines have a vintage between 1899 and 1978, a rating between 30 and 70 points, a length between 51 and 496 words, red color, no specific dryness, geographical information, and are made from Cabernet Sauvignon grapes.

The world map filter is a realization of the geographic visualization approach described in Sect. 5.5.1. It provides users with the opportunity to filter out tasting notes on the scatter plot depending on their origin (Fig. 5.6). Different standard functionalities such as zooming in, zooming out, and panning to a specific region of interest are supplied to assist working with the map. Users have the option to select a country on the map and our tool visualizes only those representations of tasting notes of wines produced in the specified region.

To provide better software maintenance, we use a specific property file that contains a list of wine attributes and their required filter types. In this way, filters are dynamically created on the basis of this information and can be easily added or removed.

Statistical Information The property file also contains a list of wine attributes that can be represented by bar chart diagrams. Figure 5.7 presents snapshots of histograms implemented in the application. An individual bar chart or histogram is created for each of the listed attributes showing the number of visible tasting notes corresponding

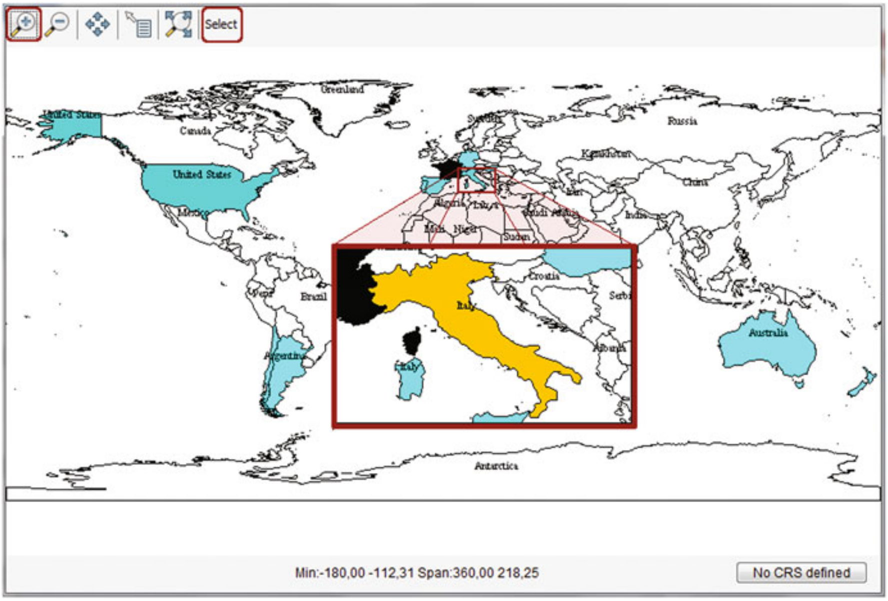


Fig. 5.6 World map providing information about the wines produced in different countries. It is also possible to use this view as an interactive filter for the specification of single countries

to each of their values (Fig. 5.7a). Only one of the diagrams is visualized at a time in order to save space. We added range sliders to the *x*- and *y*-axes to assist users in changing the range of visualized attribute values and to get a closer look at a specific section of the diagram, see Fig. 5.7b and c where the vintage range was modified.

Word Frequency Analysis After the selection of a tasting note in the scatter plot view, its text is visualized using a tag cloud approach (cf. Sect. 5.5.1). The font size of each word is estimated according to the frequency of its occurrence in all elements visible at the same time, including the selected one. Figure 5.8a shows a tag cloud example generated by our application.

The tag checkbox panel contains all word tags available. A coordinated interaction exists between the tag cloud view and the checkbox panel. On the one hand, when the user selects a word from the tag cloud visualization, all words of the same class, i.e., with the same word tag, are highlighted in the tag cloud together with the tag itself in the tag checkbox panel. Figure 5.8b demonstrates this interaction after selecting the word “Last” in text of the tasting note. On the other hand, when a word tag is checked in the checkbox panel, such as “DT”, it is highlighted together with the words corresponding to this tag in the text.

Sentence Structure Analysis The basic concept and structure of the word tree visualization was described in Sect. 5.5.1. Figure 5.9 presents an additional example of a word tree generated by our system. The visualization consists of three basic components: (a) a display containing the word tree, (b) a text area presenting the

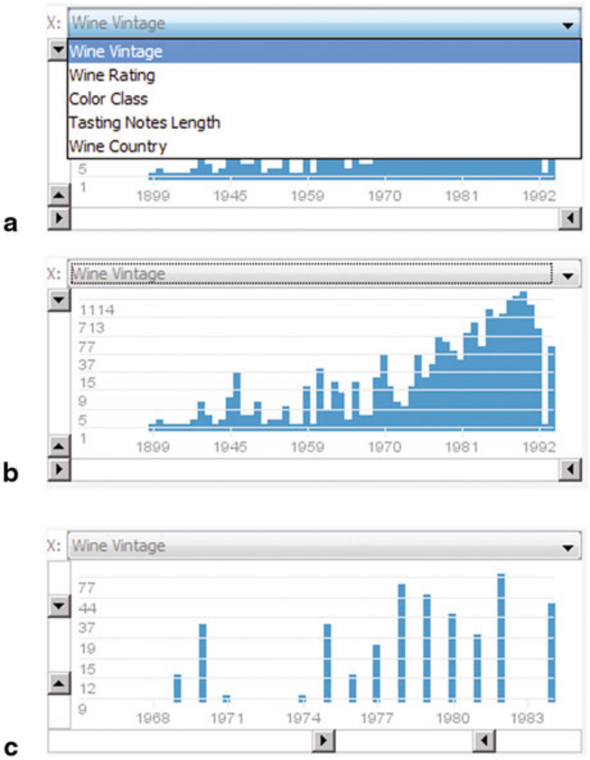


Fig. 5.7 Screenshots of an interactive histogram for attribute "Wine Vintage". **a** Attribute selection. **b** "Wine Vintage" histogram. **c** "Wine Vintage" histogram with modified range

text of the root tasting note, and (c) a text area presenting the currently constructed sequence of words. All nodes that build a path from the root node to the currently selected node are in focus. Selecting a node from the tree changes the focus to the nodes contained by the path from the root to this node. A smooth animation is used to change the state of the tree to the newly selected focus [13]. The nodes in focus are highlighted with another background color and slightly enlarged. In the example, the node selected is "raspberries", and therefore, all nodes from the root to the node "raspberries" are in focus. These nodes constitute a sequence of words which forms part of one or more tasting notes in the current scatter plot. This sequence is displayed at the bottom of the word tree, and it is also highlighted in the root tasting note, if included there.

In Fig. 5.9, the actual sequence of words is "glass, offering aromas of ripe raspberries." The node labels are in red since they are contained in the root tasting note. Often, the tree depth and width exceed the display bounds. It is not possible for all the nodes to be visualized in the space available. In order to surmount such problems, different techniques are integrated into the visualization, e.g., zooming and panning controls [13].

There is a close relation between word tree visualization and the scatter plot. The word tree is constructed according to all combinations of words beginning with words

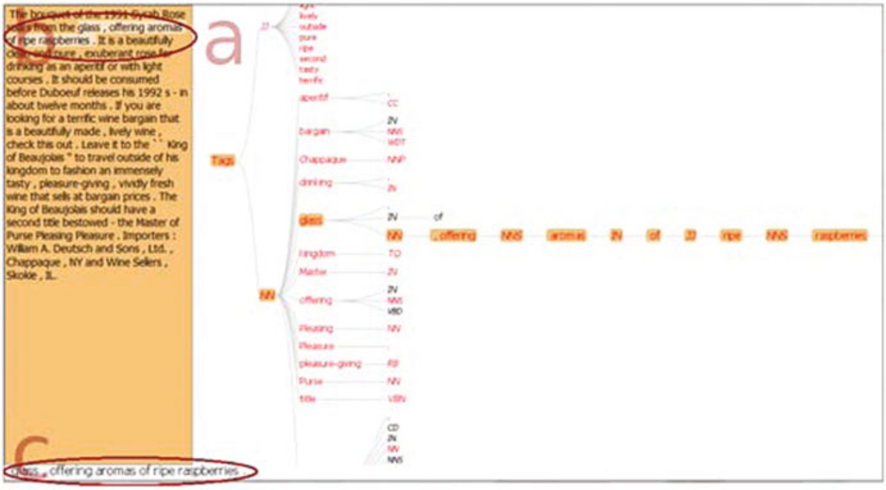
Last Tasted 6 / 92 It appears that 1948 remains one of the most under-rated vintages in Bordeaux history . Eclipsed in stature by 1945 , 1947 , and 1949 , there w pla for this year . Virtually every 1948 I have ever tasted , while not possessing the sheer

Count: 5924, Tag: IN

☐ # ☐ $ ☐ CC ☐ CD ☐ DT ☐ EX ☐ FW ☐ IN
☐ JJ ☐ JJR ☐ JJS ☐ LS ☐ MD ☐ NN ☐ NNP ☐ NNPS
☐ NNS ☐ PDT ☐ POS ☐ PRP ☐ PRP$ ☐ RB ☐ RBR ☐ RBS
☐ RP ☐ SYM ☐ TO ☐ UH ☐ VB ☐ VBD ☐ VBG ☐ VBN
☐ VBP ☐ VBZ ☐ WDT ☐ WP ☐ WP$ ☐ WRB

Last Tasted 6 / 92 It appears that 1948 remains one of the most under-rated vintages in Bordeaux history . Eclipsed in stature by 1945 , 1947 , and 1949 , there was never any hoopla for this year . Virtually every 1948 I have ever tasted , while not possessing the sheer

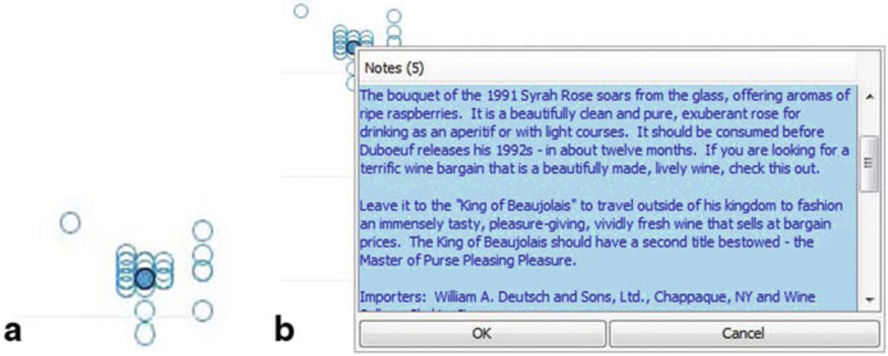
Fig. 5.8 Word frequency analysis. **a** Tag cloud visualization implemented in the application. **b** Tag cloud interaction together with the tag check box panel



The bouquet of the 1991 Sycab Rose leaps from the glass , offering aromas of ripe raspberries . It is a beautifully clean and pure , exuberant rose for drinking as an aperitif or with light courses . It should be consumed before Duboeuf releases his 1992 s - in about twelve months . If you are looking for a terrific wine bargain that is a beautifully made , lively wine , check this out . Leave it to the `` King of Beaujolais " to travel outside of his kingdom to fashion an immensely tasty , pleasure-giving , vividly fresh wine that sells at bargain prices . The King of Beaujolais should have a second title bestowed - the Master of Purse Pleasing Pleasure . Importers : William A. Deutsch and Sons , Ltd. , Chappaque , NY and Wine Sellers , Skokie , IL .

glass , offering aromas of ripe raspberries

Fig. 5.9 Word tree visualization consisting of three basic components. The tree node labels corresponding to words that are contained by the root tasting note are colored in *red*



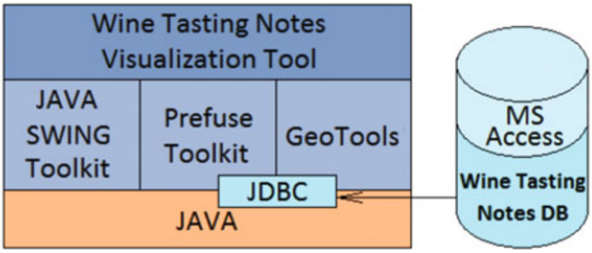
The bouquet of the 1991 Syrah Rose soars from the glass, offering aromas of ripe raspberries. It is a beautifully clean and pure, exuberant rose for drinking as an aperitif or with light courses. It should be consumed before Duboeuf releases his 1992s - in about twelve months. If you are looking for a terrific wine bargain that is a beautifully made, lively wine, check this out.

Leave it to the "King of Beaujolais" to travel outside of his kingdom to fashion an immensely tasty, pleasure-giving, vividly fresh wine that sells at bargain prices. The King of Beaujolais should have a second title bestowed - the Master of Purse Pleasing Pleasure.

Importers: William A. Deutsch and Sons, Ltd., Chappaque, NY and Wine

Fig. 5.10 Highlighting of tasting notes in the scatter plot that contain the selected sequence of words constructed by the word tree

Fig. 5.11 Software architecture of the tool



from the root tasting note and followed by words from the whole group of tasting notes visualized in the scatter plot. This means that each sequence of words specified by the word tree exploration is contained in at least one tasting note of the current scatter plot selection. This relation is indicated by highlighting (using a black circle) those tasting notes in the scatter plot that contain the sequence of words construed by the word tree (Fig. 5.10a). The tool makes sure that highlighted elements are always visible. To distinguish them, their texts are in blue in the popup list of overlapping tasting notes. In the example given, there is only one tasting note that contains the sequence “glass, offering aromas of ripe raspberries” and its text is in blue in the popup list, see Fig. 5.10b. It should be noticed that this is the same tasting note that has been selected for a root tasting note of the word tree since its background color is blue as well.

5.5.3 Implementation Aspects

The tool’s software architecture can be represented by four logical layers as shown in Fig. 5.11. Because the original database containing the wine tasting notes was created using Microsoft Access®, we decided to continue to use this database management system (DBMS). The programming language that we applied for the implementation of the application is JAVA. We used four open source JAVA libraries to implement the required functionalities. The JDBC library was employed for establishing connectivity between the JAVA programming language and the database [32]. The graphical user interface was created with the aid of the JAVA Swing Toolkit [31]. We made use of the *Prefuse* Toolkit for the following interactive visualizations: the scatter plot, the bar chart diagrams and the word tree [45]. The world map visualization was created by the functionalities of the JAVA GIS Toolkit *GeoTools* [10].

Scalability Issues The selected visualization approaches are appropriate for representing large amounts of data. From a theoretical point of view, there is almost no restriction placed upon the number of visualized tasting notes. The scatter plot and the bar chart diagrams provide different interaction techniques that give users the opportunity to focus on a subset of elements for further exploration. The tag cloud visualization represents the text of one tasting note using different font sizes for its words. With an increase in the number of tasting notes, the proportions between the font sizes of the words in the visualized text will be affected—not the number of the words. This feature makes the tag cloud visualization even more attractive. The word tree facilitates for users to explore the correlations beginning from a set of visible words and proceeding with other words which appear as a result of previous choices. This approach allows the exploration of unbounded sets of words. However, increasing the number of tree nodes makes it more complicated to browse through the tree and to preserve the mental map [27]. Because there is no upper limit for the number of wines tasted produced in the visualized countries, the world map is not restricted by the amount of visualized data either.

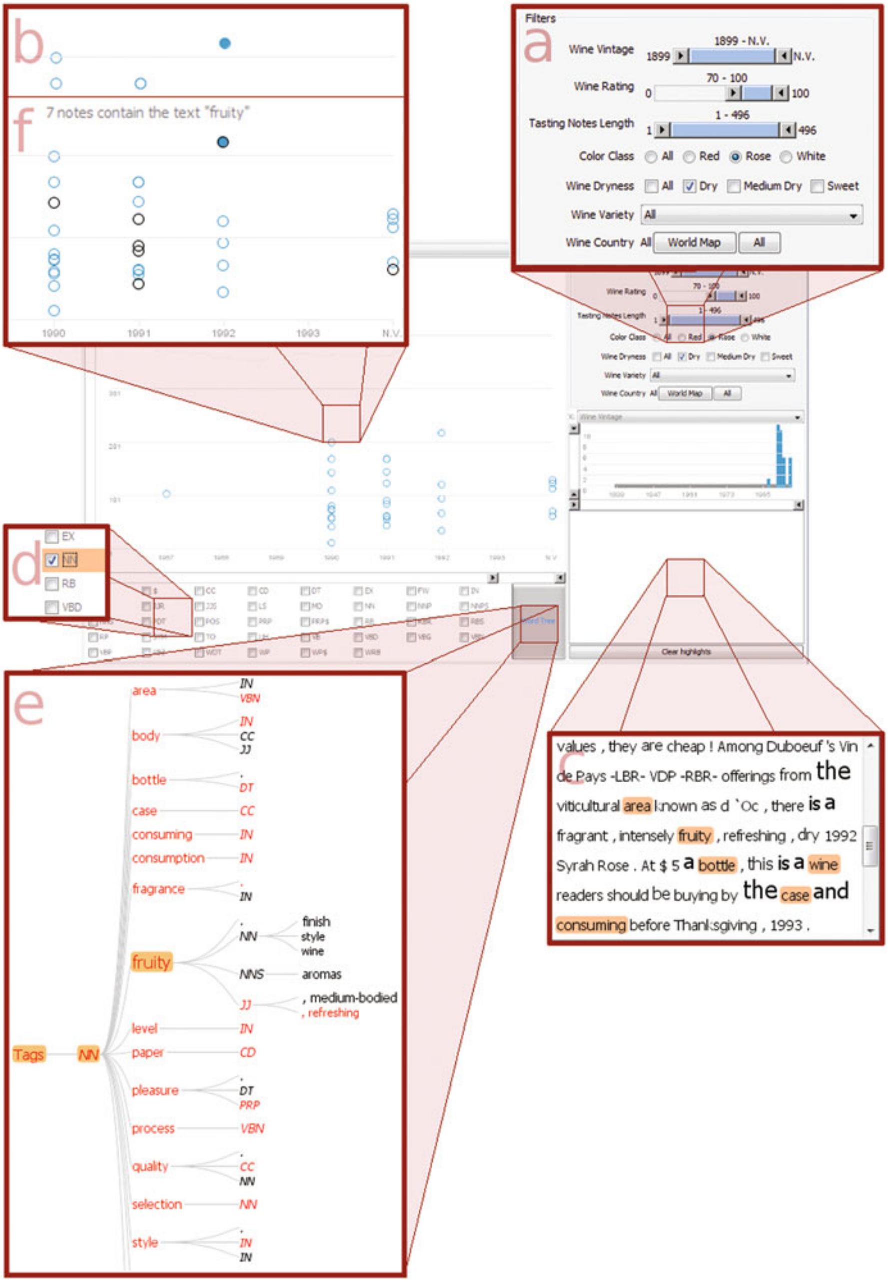
Having said this, our implementation currently imposes some restrictions on the functionality of the tool. The scatter plot together with the filters, the tag cloud visualization and the bar chart diagrams perform well for a number of up to 3,000 tasting notes. For more elements, the tool becomes slower and thus less interactive. One way of improving the application's performance is to migrate the database to another, more efficient DBMS. The current DBMS and the database schema are in fact the main bottleneck of our implementation. Because of the inappropriate design of the original wine database, the word tree visualization cannot be efficiently built for more than 60 tasting notes. In order to overcome this restriction, the design of the database should be modified in such a way that it represents the tree structure of the words in the tasting notes. The response time of the world map view for standard user interactions takes about six seconds, which is a relatively long time. Here, we have to find out whether the *GeoTools* Toolkit API may provide a solution to this performance problem or if we have to move to another library.

5.6 Results

Our tool offers possibilities for linguists to explore, analyze, and present large and complex data sets for investigations of the structure of texts and discourses and of the lexical resources that languages have for the expression of different meaning domains. Not only can visual images communicate concrete information, but they can also represent abstract information in the form of visual imagery, which is of particular significance in the case of wine descriptions of subjective sensory perceptions, which by nature are transient and volatile. Through these techniques, textual data can be visually represented and interactively explored at a glance at the same time, which is clearly innovative in linguistic research. The most essential part of wine descriptions is concerned with the description of transient sensory perceptions. They are captured by our visualization approaches in the form of scatter plots, tag clouds, word trees, and bar chart diagrams. Given the availability of tagged corpora, dynamic visualization techniques open up linguistic advances through typological comparisons across different text types, different times, and different languages. For instance, with the aid of the various filters of metadata, we can explore linguistic patterns across subsets of tasting notes, subsets of ratings of wines, or subsets of grapes. We can also apply filters, such as "only tasting notes containing more than 400 words", "only sweet wines" or "only wines from Spain" in various different combinations. The tool provides direct feedback in the form of interactive visualizations and is immediately able to answer questions such as: Do tasting notes have the same format across time? Or how do wines pattern that are described with the attribute 'sweaty saddle'? The tool thus offers the possibility for linguists to explore different variables and get an immediate response to queries about, for instance, distributional differences across expressions in the texts or metadata in relation to the changes analysts make using the different filter settings. In addition to all the above functions, statistical information related to choices that we make in the form of bar chart diagrams and tag clouds can be obtained. This functionality is particularly important for various types of analytic improvements, more accurate parameter settings and for subsequent formulations of new hypothesis for corpus investigations of text.

5.6.1 Use-case

A possible use-case scenario that shows the functionality of our tool could be a case in which a linguist analyzes the words and phrases in the descriptions of odors of dry rosé wines with relatively high ratings. The focus of the user's interest could be descriptors that are most frequently used in a positive sense to represent olfactory descriptions of dry rosé wines. This process of analyses requires a course of successive actions illustrated in Fig. 5.12. First, the linguist sets the desired values of the filters in order to select the definite set of tasting notes to be analyzed (e.g., wine ratings between 70 and 100 and wine dryness set to dry, see Fig. 5.12a). Then, the user selects an appropriate tasting note to start his/her study from. A good starting point could be a long tasting note, since it contains more details and therefore more descriptors (Fig. 5.12b). Referring to the tag cloud visualization of the tasting note and considering word frequencies and their lexical meaning in the specific context (Fig. 5.12c), the user selects word tags corresponding to words that are related to olfactory perceptions (Fig. 5.12d). In order to further analyze the words and phrases in the whole set of



Filters

Wine Vintage 1899 - N.V. (1899 – N.V.)

Wine Rating 70 - 100 (0 – 100)

Tasting Notes Length 1 - 496 (1 – 496)

Color Class ○ All ○ Red ● Rose ○ White

Wine Dryness ☐ All ☑ Dry ☐ Medium Dry ☐ Sweet

Wine Variety All

Wine Country All

7 notes contain the text "fruity"

values , they are cheap ! Among Duboeuf 's Vin de Pays -LBR- VDP -RBR- offerings from the viticultural area known as d `Oc , there is a fragrant , intensely fruity , refreshing , dry 1992 Syrah Rose . At $ 5 a bottle , this is a wine readers should be buying by the case and consuming before Thanksgiving , 1993 .

Fig. 5.12 Use-case scenario. Zoomed areas illustrate the process of interaction; the individual steps are marked with *reddish* letters tasting notes used to describe dry, rosé wines, the linguist builds a word tree as shown in Fig. 5.12e. He/she then selects the path in the tree, observing the structured organization of the visualized text in relation to his/her own association of the phrases with olfactory perceptions. This process of interactive exploration of constructions in language combines the power of human cognitive processing with the speed and accuracy of computer processing which makes it very productive and effective. After constructing a relevant sequence of words, the linguist returns to the tasting notes on the scatter plot and observes the number of elements that contain the same phrase (i.e., the tasting notes highlighted in the scatter plot, see Fig. 5.12f). This interaction between the visualizations facilitates fast perception and comparison of the numbers represented. The user can continue this process and repeat the same actions or select another tasting note in order to explore more words and phrases with comparatively high frequency of use. In this way, the linguist can identify and describe patterns of aroma descriptors that are most commonly used in positive assessments of dry, rosé wines.

5.7 Conclusions and Future Work

This work is concerned with various approaches for visualizing wine tasting notes that can be used to support linguistic analyses. Our data sources are large databases containing tasting notes and metadata related to the wines tasted. Linguists are interested in the language of such texts and the possibilities offered by the language to describe sensory perceptions to better understand descriptions of them. The purpose of our tool was to visualize these data in a way that would help linguists to get a better picture of wine descriptions. All solutions presented in this paper were carefully discussed with linguists during their development.

There are several improvements that can be made to enhance the visualization tool for wine tasting notes. In Subsection 5.5.3, we discussed several problems with the current DBMS and the database schema. An improvement of this situation would be one of the first candidates for the next software revision.

Another issue would be the tag clouds that can be improved. There are function words that occur very frequently in general language like “a”, “the”, “of”, etc. They are visualized by the largest font sizes and therefore attract more attention of the users than other words that are more important and more interesting for linguistic analyses. An obvious solution to avoid this problem would be to create a user-defined black list of words that could be disregarded and excluded from the calculations. The tool could thereby avoid their overestimation. Additionally, it would be helpful to compare tasting notes with respect to their word usage. For this purpose, specific techniques, such as parallel tag clouds, could be added to the system.

The world map visualization and its performance could also be improved. It would be useful to add more interactive features to the map visualization. For example, the map could be extended by visualizing vintages, i.e., time-series data. Another idea would be to add an interactive control for tracing the wine production density in different countries on the basis of the wines' vintages. Range sliders or other controls could be integrated to change the time period of the data visualized on the map.

Finally, we recognize that our visual analyses are also related to tasks in the field of Sentiment Analysis. It would be very interesting to develop our tool also in this direction, see for example the handbook chapter [25].

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Part III
Art

Chapter 6
Colorscore: Visualization and Condensation of Structure of Classical Music

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Abstract It is not always easy to quickly understand musical structure of orchestral scores for classical music works, because these works contain many staves of instruments. This chapter presents *Colorscore*, a technique for visualization and condensation of musical scores. *Colorscore* supports two requirements for composers, arrangers, and players: overview and arrangement. *Colorscore* divides each track of the score into note-blocks and determines their roles. *Colorscore* then displays all the note-blocks in one display space to provide the overview, so that novice people can quickly understand the musical structures. In addition, *Colorscore* supports vertical condensation which reduces the number of displayed tracks and horizontal condensation which saves the display space. It is especially useful as hints to rearrange music for smaller bands.

6.1 Introduction

Listening to the music necessarily takes time, and therefore it also takes time to understand the contents and structures of music.

It may be hard work for many of players, conductors, and composers to understand the overall contents of works for large orchestras in a short time. One of the main reasons is that such works are usually written as scores consisting of tens of staves of notes and hundreds of pages, and therefore, readers must look at the many staves of instruments at one time, and turn over the pages frequently. This task may be hard for junior high school or high school students who aim to enter the music departments of universities. Or, there have been more than a thousand of amateur

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orchestras at least in authors' country, and again, it may be a hard task for amateur players and conductors.

Meanwhile, many people may want to rearrange such works to other styles of ensembles or bands. There have been already many musical works that are rearranged by various styles of bands. For example, "Pictures at an Exhibition" was originally composed for the piano by Mussorgsky, then arranged for orchestra by Ravel, and recently played by various bands including a brass quintet (Canadian Brass) and a 3-piece rock band (Emerson, Lake, and Palmer). Again, it may be difficult for beginners to effectively rearrange such orchestral music to other styles of ensembles or bands, because it needs deep knowledge and experiences, or a long time, to reconsider the contents and structures of orchestral music.

We think visualization techniques are useful for solving the above problem; because they have the potential to provide an overview of musical information and interactive mechanisms to observe important portions of musical works. Time-varying, multidimensional, and hierarchical data handlings are very active issues in visualization techniques, and we think these concepts are useful for representing time variation and structures of musical works.

Existing musical visualization techniques are briefly categorized into note-based visualization and acoustic-based visualization. Here, instrument-by-instrument note information is necessary to analyze roles of the instruments and musical structures including repetitive structures, while alternating or deriving the roles among the instruments. Acoustic-based visualization can be applied to analyze such information, if we can recover instrument-by-instrument note information from acoustic information. However, it is generally difficult to divide acoustic information into instruments, and therefore it is difficult for acoustic-based visualization to display information for each instrument. Also, it is often difficult to perfectly recover notes from acoustic information. From these viewpoints, we think note-based visualization which can display the note information of each instrument is more useful for understanding the structure of musical works. Moreover, we expect note-based music information retrieval techniques can be applied to analyze the roles and structures of musical works and the condensation of musical works for large orchestras or bands. It is useful if such techniques are combined with note-based visualization techniques to effectively and intuitively display informative roles and structures, and interactively condensed musical works based on their roles and structures. We think such features of note-based visualization techniques can contribute to make users intuitively understand the contents and structures of the music and assist in the arrangement of orchestral music.

This chapter presents "*Colorscore*," a technique for visualization and condensation of musical structures of MIDI-based classical music data. *Colorscore* consists of the following components: role determination, overview, and interactive condensation. *Colorscore* first divides the notes of each track into blocks based on the rests in the tracks. It then determines the roles of blocks by matching them to predefined patterns of melodies and accompaniments. *Colorscore* draws all the blocks into a single display space, for the overview of musical structures, while it assigns independent colors to blocks based on their roles. It also provides two mechanisms of interactive condensation to save the display spaces. One of the mechanisms is "vertical condensation," which reduces the number of displayed tracks, by keeping only note-blocks that match the predefined patterns well. The other mechanism is "horizontal condensation," which shrinks the bars if no roles are changed at that time.

We believe *Colorscore* to be especially useful for beginner or amateur players, composers, arrangers, and conductors. We expect the overview provided by *Colorscore* will provide a quick understanding of a musical score, because the entire score may be viewed in a single display space. Also, we think that the visual condensation presented by *Colorscore* will help in music arranging by suggesting hints to arrangers for smaller bands, because it displays the structures of music as a smaller number of tracks.

As an aside, the title of this chapter *Colorscore* has two meanings: one is "SCORE" with "COLOR", and the other is "COLORS" to "CORE" blocks of the score.

6.2 Related Work

There have been many techniques for visualization of musical structures or scores. Many of such works [1–3] are used for visualization of acoustic data, not MIDI data. Since audio source separation is still a difficult problem, such works cannot visualize musical structures track-by-track. Some of the early note-based music visualization works [4] were also simple representations, not detailed track-by-track visualizations. *Colorscore* is quite different from these works because it aims to visualize the roles of note-blocks of each track in the orchestra separately within one display.

On the other hand, several recent works focus on visualization of track-by-track information from a musical score. *comp-i* [5] visualizes musical structures of MIDI data in virtual 3D space. However, *comp-i* does not analyze roles of note-blocks. *ScoreIlluminator* [6] improves the readability of musical scores by assigning colors to phrases of tracks based on their similarities. However, *ScoreIlluminator* does not take the roles of the phrases into account for assigning colors. Moreover, *comp-i* and *ScoreIlluminator* do not support condensation of a musical score. *BRASS* [7] realizes accordion-like interactive visualization, by partially expanding or shrinking the musical score, which looks similar to condensation of *Colorscore*. However, it does not take roles of phrases into account for expanding or shrinking. Against such related works, *Colorscore* realizes colored visualization and condensation of musical scores based on roles of note-blocks.

6.3 Technical Components of Colorscore

This section presents the procedures and technical components of *Colorscore*. As a preprocessor, *Colorscore* analyzes musical structures to divide each track into multiple note-blocks and determines their roles and transitions. Then, *Colorscore* displays the roles of note-blocks in multiple colors. Also, *Colorscore* can interactively condense scores by vertically or horizontally packing the displayed information.

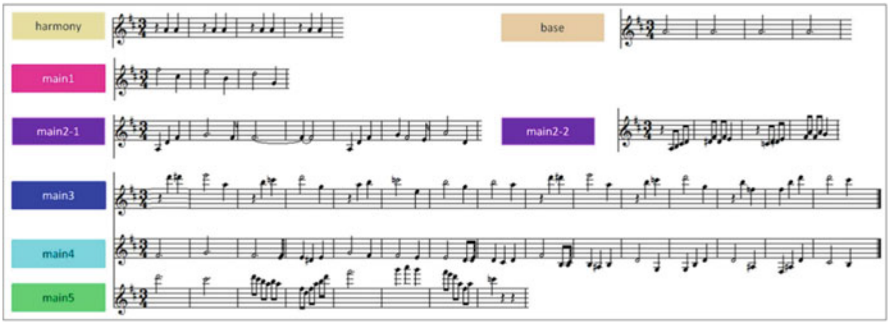

Fig. 6.1 Example of patterns

6.3.1 Analysis of Musical Structure

Colorscore supports standard MIDI file (SMF) as input data. It contains note information of MIDI, including pitch, strength, duration, and timing. *Colorscore* first reads the SMF file and then divides each track of the score into note-blocks. Then, *Colorscore* determines roles of note-blocks by matching their notes to patterns given by users.

6.3.1.1 Providing the Patterns to Determine the Role

First of all, *Colorscore* requires the patterns used to determine the roles of note-blocks. In this chapter, "pattern" means a short set of notes which consists of just one track in MIDI format. Figure 6.1 shows examples of patterns given by an expert user. *Colorscore* determines whether each block plays melodies or accompaniments as part of a musical "role." As regards to melodies, *Colorscore* assumes input of basic phrases for several main melodies. At the same time, *Colorscore* assumes input of only typical rhythms for the accompanying phrases such as harmonic or bass accompaniments: it does not analyze transitions of intervals for accompaniments. We consider that accompaniments are often characterized by repeated rhythm, rather than by transition of intervals, and therefore we designed *Colorscore* to input patterns of accompaniments as rhythms.

6.3.1.2 Generating the Initial Note-Blocks

After providing user-given patterns, *Colorscore* generates rough note-blocks called "initial note-blocks." *Colorscore* generates initial note-blocks in the following way:

1. Treat a track as a single block.
2. Scan a block and divide it into two blocks at a whole note rest.
3. Repeat 2 for all blocks until all whole note rests are eliminated from the blocks.
4. Repeat 2 and 3 for all tracks.

6.3.1.3 Pattern Matching of Blocks with Patterns

Colorscore matches each initial note-block (see Sect. 6.3.1.2) to user-given patterns (see Sect. 6.3.1.1). In this step, *Colorscore* calculates distances between the patterns and each note-block, and chooses the pattern closest to the note-block. It determines whether a note-block has the role which is the same as the chosen pattern, if the distance between the note-block and the pattern is smaller than the predefined threshold. To calculate the distance between the i-th pattern and the j-th note-block, our implementation applies the following distance $D(i;j)$ metric [6]:

$$D(i;j) = w_1 D_{RA}(i;j) + w_2 D_{MA}(i;j) \tag{6.1}$$

Here, w_1 and w_2 denote constant weights, $D_{RA}(i;\ j)$ is the cosine of timing which features the rhythm, and $D_{MA}(i;\ j)$ is the cosine of transition of the notes, which features the melody. $D_{RA}(i;\ j)$ corresponds to the cosine of *RA* vectors between the i-th pattern and the j-th note-block. Here, the *RA* vector is an n-dimensional vector denoting the timing of note-on events of note-blocks or patterns. To generate a *RA* vector, *Colorscore* divides note-blocks into n pieces by the constant note. It then assigns a positive number if there is a note-on event, otherwise it assigns “0.” Consequently, *Colorscore* generates the *RA* vector as an n-dimensional binary vector. $D_{MA}(i;j)$ corresponding to the cosine of *MA* vectors between the i-th pattern and the j-th note-block. Here, the *MA* vector is an $(n-1)$-dimensional vector denoting the pitch transition of note-on events. To generate an *MA* vector, *Colorscore* calculates the difference of pitches between the k-th and $(k+1)$-th pieces as the k-th element value of the vector. Here, it takes a positive value if the pitch gets higher, otherwise a negative value. Figure 6.2 (upper) shows an example of *RA* and *MA* vectors. Here, the bars in Fig. 6.2 (upper) are divided into nine segments by quarter notes. Values of the *RA* vector take 3 at the first beat, and 2 at the third beat. The *MA* value is calculated based on chromatic distances between two tones.

If the length of the note-block is longer than that of a pattern, as it may often happen, then the note-block only partially matches the pattern. Considering such a situation, *Colorscore* first extracts parts of the note-block, where the lengths of the parts are equal to the pattern, and calculate $D(i;j)$ applying each part. If one of the parts matches the pattern, *Colorscore* divides the note-blocks into two or three note-blocks, so that one of them corresponds to the part that matches the pattern. Then, *Colorscore* applies the same process to the remaining note-blocks.

Colorscore applies the above-mentioned process to every note-block of every track. Here, *Colorscore* determines that a part of the j-th note-block matches the i-th pattern, if the $D(i;\ j)$ is smaller than a predefined threshold D_0, where D_0 is a function of n. On the other hand, *Colorscore* treats note-blocks which do not match to any patterns as decoration note-blocks, and draws them in gray.

The procedure to assign roles is as follows:

1. Calculate *RA* and *MA* vectors of the i-th pattern.
2. Calculate *RA* and *MA* vectors of the j-th note-block.

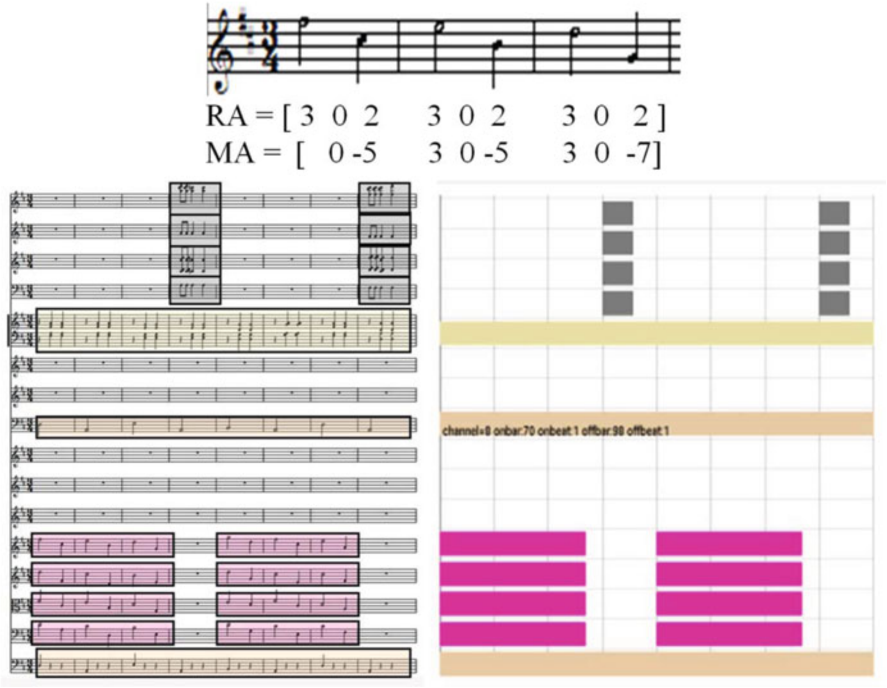

Fig. 6.2 (*Upper*) *RA* and *MA* vectors. (*Lower-left*) Result of note-block generation and role determination. *Pink* blocks denote the main melody, *yellow* and *flesh* blocks denote accompaniments, and *gray* blocks denote decorations. (*Lower-right*) Visualization by *Colorscore*

3. Extract a part of the note-block, where the length of the part is equal to the i-th pattern, and then calculate $D(i; j)$ between the part and the i-th pattern.
4. If $D(i; j)$ is smaller than D_0:
    a. Divide the j-th note-block if necessary.
    b. Assign the role of the i-th pattern to the matched note-block.
5. Repeat 3 and 4 for all possible parts of the j-th note-block.
6. Repeat 2–5 for all note-blocks.
7. Repeat 1–6 for all patterns.

6.3.2 Visualization of Note-Blocks

Colorscore visualizes the result of note-block generation and role determination. Figure 6.2 (lower-left) shows the result of the analysis drawn on a traditional musical score, and Fig. 6.2 (lower-right) shows the result of visualization by *Colorscore*. It vertically draws the tracks, and horizontally draws the blocks in each track. It assigns colors to the note-blocks based on their roles. Our implementation assigns high-saturation colors to melodies, low-saturation colors to accompaniments, and gray to unmatched note-blocks.

6.3.3 Vertical Condensation

Our current implementation of *Colorscore* condenses scores into 1, 2, 4, or 6 tracks. The following is the processing flow to generate a 1-track condensed score:

1. Let $i = 1$.
2. Search for blocks starting from the i-th bar.
3. If corresponding blocks are found:
    a. If main melodies are contained in the blocks: specify the block most similar to a given pattern, let $i =$ (the ending bar of the block) + 1, and go to 2.
    b. If main melodies are not contained in the blocks: let $i = i + 1$, and go to 2.
4. After completing 2 and 3, repeat 2 and 3 to match blocks of unfilled bars with given accompaniment patterns instead of main melody patterns.
5. After completing 4 repeat 2 and 3 to match blocks of unfilled bars with decoration blocks instead of main melody or accompaniment patterns.

The processing flow is more complicated to generate n-track ($n > 1$) condensed scores from the original scores consisting of N ($N > n$) tracks. In this case, *Colorscore* firstly generates $(n+1)$ borders $\{M_0, \cdots M_n\}$, where $M_0 = 0$, $M_n = N$, and $M_i < M_{i+1}$. It then applied the aforementioned processing flow, to generate the i-th track of the condensed score from the tracks between the $(M_{i-1} + 1)$-th and the M_i-th tracks of the original score.

Our current implementation can save the vertical condensation results as MIDI format files.

6.3.4 Horizontal Condensation

Colorscore horizontally saves the display space based on transition of roles. It shrinks bars if no note-blocks end or change their roles, while it keeps other bars longer. For example, *Colorscore* shrinks the second and third bars from Fig. 6.2 (lower-right) because no note-blocks change their roles at that time. Also, it keeps the fourth bars longer, because new note-blocks start at that time.

6.3.5 User Interface

Our implementation of *Colorscore* provides user interfaces for the following four features: drawing, playing, vertical condensation, and horizontal condensation.

Drawing Our current implementation can partially draw the results by specifying the starting and ending bars on its user interface. It also features a slider to specify the threshold value of similarities between extracted blocks and given patterns. Users can selectively draw blocks which are sufficiently similar to the given patterns by using the slider.

Playing Our current implementation features a play button so that users can listen to the works from an arbitrary bar. It also draws a vertical red line in a drawing area to indicate where it is playing.

Vertical Condensation Our current implementation features buttons for the selection of 1, 2, 4, or 6 tracks to enable vertical condensation. It can also save the condensation results as a MIDI format file, so that we can play them or look at them as notes.

Horizontal Condensation Our current implementation features a slider to control the ratio of widths between shrunk and remained bars.

6.4 Results

This section introduces examples of our visualization results applying the MIDI data of “Valse des fleurs” composed by Tchaikovsky.

6.4.1 Visualization

Figure 6.3 (upper) shows an example of a visualization result of whole MIDI data which contains 16 tracks. *Colorscore* represents the musical structure in a single display space, even though a sample miniature score of “Valse des fleurs” occupies 33 pages. Many traditional classical musical works have two themes and form musical structures while repeating and varying these two themes. Also, they may contain several additional melodies delivered from the themes. Considering such composition techniques, we prepared five melody patterns to visualize the music. We also prepared typical Waltz patterns for harmonic and bass accompaniments. These patterns are shown in Fig. 6.1.

We can observe various orchestration techniques from the visualization results as well. We can see when roles are switched across the tracks, or shared by several numbers of tracks, along the variation of the music. We can also observe combinations of multiple melodies at the same time.

6.4.2 Vertical Condensation

Figure 6.4 displays a part of the visualization result from Fig. 6.3 (upper), corresponding to bars 314–328. It also shows a result of vertical condensation. It reduces

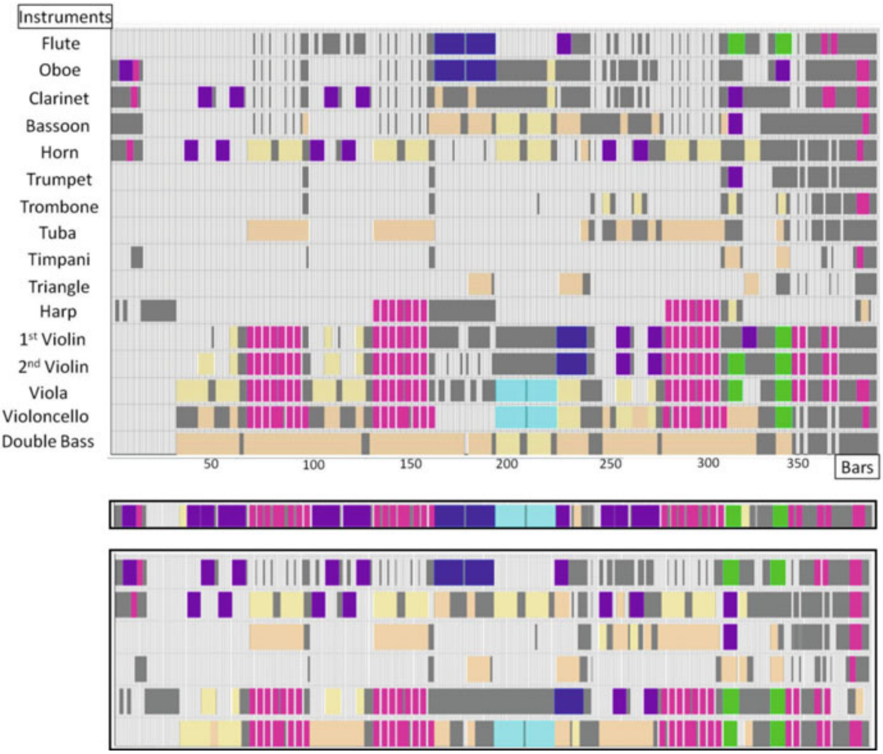

Fig. 6.3 (*Upper*) Visualization result of "Valse des fleurs" by Tchaikovsky. (*Center*) Vertical condensation into 1 track. (*Lower*) Vertical condensation into 6 tracks

the number of tracks from 16 to 1, 2, 4, or 6, and note-blocks from 29 to 4, 6, 11, or 13. This result shows that a melody drawn in pink is played two bars after a melody drawn in purple. *Colorscore* retained this structure even in the 1-track condensation result. On the other hand, it retained bass patterns in the 2-tracks result, and other blocks in the 4- and 6-tracks results. These results show that *Colorscore* adaptively realizes level-of-detail control of condensation. We think this feature is convenient because we can interactively generate condensed scores step-by-step while visually observing musical structures.

6.4.3 Horizontal Condensation

Figure 6.5 shows a part of the visualization result from Fig. 6.3 (upper), corresponding to bars 211–250. It also shows a result of horizontal condensation. It reduces the width of the visualization space to approximately 60 % of the original width. However, it does not shrink the timings when roles of note-blocks change. For example, it

Fig. 6.4 Vertical condensation into 1, 2, 4, or 6 tracks. Melodies drawn in *purple* and *pink* are preferentially retained when the number of tracks are fewer

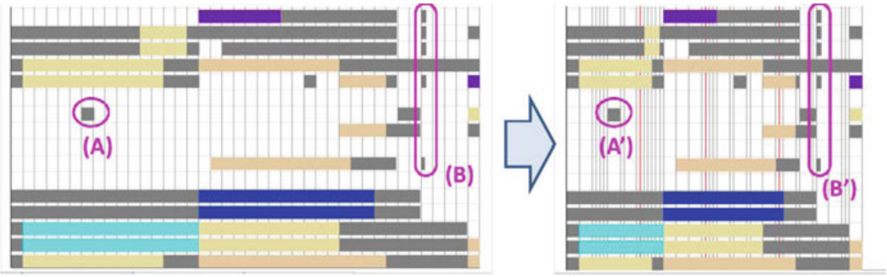

Fig. 6.5 Horizontal condensation. The bars (A) and (B) remained wider while other bars get narrower

keeps the length of short note-blocks (highlighted by circles in (A) and (B)) after horizontal condensation, indicated as (A′) and (B′) in Fig. 6.5. With this functionality, *Colorscore* can draw longer music in a limited display space, while preventing us from missing changes in roles. We think it is useful for various purposes of music understanding: For example, students majoring in conducting can practice signals to players just before they have new roles.

6.5 Evaluations

This section introduces two kinds of evaluations to demonstrate the effectiveness of *Colorscore*.

Table 6.1 Precision and recall of answers of novice examinees

	Group A	Group B	Groups A + B
Average number of marked bars	11.83	12.11	11.93
Average number of marked correct bars	9.44	8.44	9.11
Precision	0.81	0.70	0.77
Recall	0.79	0.70	0.76

6.5.1 *Understanding of Novice Examinees*

As a first evaluation, we tested novices' understanding of musical structure. First, we showed the visualization results from Fig. 6.3 (upper) to examinees. Then, we asked them to mark bars in the visualization they thought at which there was a transition in the score. At the same time, the three authors marked bars similarly, and designated a set of bars as being correct if two or more author's results were in agreement. Consequently, 12 bars were considered as correct answers.

We then calculated precision and recall of the examinees' answers. Table 6.1 shows test results. We tested 27 university students divided into two groups. "Group A" contained 18 of the examinees who had experiences in playing musical instruments and reading notes, but did not have experiences in reading scores. The second group, "Group B," contained 9 of the examinees who did not have such experiences.

The data summarized in Table 6.1 indicates that the rates for correct answers were overall good; however, differences between the two groups were not negligible. We analyzed further how experienced examinees correctly marked and nonexperienced examinees incorrectly marked bars. Figure 6.6 (1)–(12) shows all answers which authors designated correct, and Fig. 6.6a–c shows typical wrong answers. Here, correct rates of answers (5), (8), (10), and (12) were lower than 0.7.

Bars (5) and (10) in Fig. 6.6 were very mistakable because *Colorscore* only colored for the violoncello, though same phrases are played by the violin and the viola. Many experienced examinees would improperly assign bars (5) and (10) in Fig. 6.6 because they focused on the colors of the next blocks; however, many nonexperienced examinees missed them as well, marking (b) in Fig. 6.6 instead of the correct answers. We still think this result is informative because it shows the change of roles of the violin and the viola between the repetitions of the phrase. However, we may need to modify the pattern-matching method to reduce such mistakable visualization results for nonexperienced people.

Also, the correct rates of assigning bars (8) and (12) in Fig. 6.6 were low. We think one of the reasons of the low correct rates is that no note-blocks were colored just before (8) and (12), and therefore it was not easy to find them for examinees.

Figure 6.6a–c are three typical types of wrong answers. We think (a) can be interpreted as correct answers instead of (1) in Fig. 6.6. As discussed above, bars marked as (b) are mistakable due to pattern-matching results. Also, bars marked as (c) are mistakable because they are end-points of colored note-blocks. Many experienced examinees did not select these bars, because the examinees could imagine the context of the music. On the other hand, many nonexperienced examinees selected them.

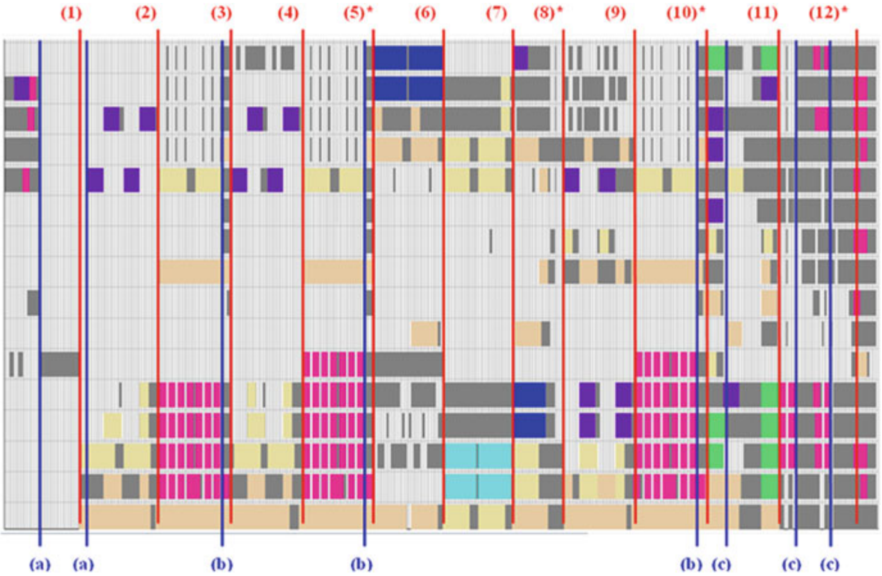

Fig. 6.6 Result of the user test. (*1–12*) are answers authors assumed as correct. *Asterisks* denote the answers those correct rates were not good (less than 0.7). (*a*), (*b*), and (*c*) are typical wrong answers

As future work, we would like to observe user tests more and improve *Colorscore* reflecting these tests. Especially, we would like to carefully discuss how the visualization results are mistakable for nonexperienced people.

6.5.2 *Feedbacks from Music-Computing Researchers*

We showed the visualization results from Fig. 6.3 (upper) to music-computing researchers and asked for feedback. We asked three researchers majoring in music computing who play in amateur orchestras, including authors of musical visualization techniques [5, 7]. This section summarizes their comments and suggestions.

6.5.2.1 Discoveries from the Visualization Result

Respondents pointed out that they discovered features of the music from the visualization result as follows:

1. Coloring is so effective that it is easy to understand the musical structures. For example, the theme indicated in pink appears three times and finally arranged in the Coda. Other repetitions are also easy to understand.

2. Coloring is also effective to understand the roles of the musical instruments. Examples are as follows: The theme indicated in pink is mostly played by the strings. The double bass and the tuba do not play any melodies. The trombone and percussions have long rests.
3. It is easy to visually compare the roles of specific track with others. For example, when the horns play the theme, the violoncello and the double bass play accompaniments in many bars. When the horns play harmonies, strings play melodies, and woodwinds play decorations.
4. It is easy to understand that the music gets more sensational in the latter part.

These discoveries were exactly what we expected, and we felt confident about the effectiveness of *Colorscore*.

6.5.2.2 Possible Applications

Respondents pointed out that *Colorscore* can be used in the following applications:

1. Additional musical information displayed for music player software, devices, or digital score software.
2. Education of music structure understanding.
3. Reference for staging, camera work, and choreography.

We expect that *Colorscore* can be used in the above applications. Further development will be required to add functions so that *Colorscore* may be used in the above applications.

6.5.2.3 Concerns

Respondents pointed out that they felt concerns about the visualization result and functionalities of *Colorscore* as follows:

1. Since *Colorscore* horizontally shortens the musical score, beginners may feel that the first and the last bars are too close, and the top and the bottom tracks (usually the piccolo and the double bass) are too distant.
2. When we apply *Colorscore* to music much longer than “Valse des fleurs,” it may be difficult to show the whole music in one display space. Authors need to test *Colorscore* with longer music and examine its effectiveness.
3. Effectiveness of visualization results may depend on the number of patterns. They may be misunderstood if the number of patterns is too small and therefore the same colors are assigned to moderately similar note-blocks. On the other hand, it may be difficult to distinguish the roles of note-blocks if too many colors are used.

The first and the second comments suggest that we need to have tests with more varied users and music and improve *Colorscore* based on the results of these tests. The third comment suggests that we need to examine what kinds of melody and accompaniment pattern definitions are effective for *Colorscore*. Also, it may be interesting to integrate *Colorscore* with automatic theme-finding techniques.

6.5.2.4 Potential Future Issues

Respondents indicated that the following would be potential future issues:

1. Display of the specific tracks or note-blocks as staff notation.
2. Sound of harmonies or chords at arbitrary points.
3. A function that, when users click arbitrary note-blocks or interactively input melodies, allows *Colorscore* to jump to display the bars corresponding to the specified note-blocks or melodies.
4. Navigation for novice users for the most important parts of the score.
5. User interfaces and animations to smoothly control and display during condensation.

We have not developed the above interactive functions yet, but we see them to be very important.

6.5.3 Arrangement by Vertical Condensation

This section discusses the validity of the *Colorscore*'s arrangement by vertical condensation, by comparing the notes generated by *Colorscore* with those arranged by an expert. Figure 6.7 (upper) shows musical notes of "Valse des fleurs" arranged by an expert for a piano solo by novice players. Figure 6.7 (lower) displays musical notes of the same work automatically generated by *Colorscore*. We carefully compared the two notes and found the following similar and different features:

- Retained main melodies are completely similar.
- *Colorscore* sometimes misses a part of the bass accompaniments.

We found that main melodies are adequately retained in the results by *Colorscore*. On the other hand, *Colorscore* sometimes missed important parts of accompaniments, because it did not retain as many notes as possible, although the retained notes are playable. It is necessary to improve the musical structure analysis module of *Colorscore* to consider characteristics and tone ranges of instruments, if we are to completely solve this problem. Another solution to the problem is the expanding of *Colorscore*'s user interfaces. Interactive specification of tracks to be retained, and modification of the condensation results by adding, moving, or deleting blocks, should be useful in solving this problem.

Fig. 6.7 (*Upper*) Arrangement by an expert. (*Lower*) Condensation by *Colorscore*

6.6 Conclusion and Future Work

This chapter presented *Colorscore*, a visualization and condensation technique for MIDI-based classical music data. This chapter introduced three components: role determination, overview visualization, and condensation. This chapter also introduced user evaluations and discussed its effectiveness and problems.

As short-term future work, we would like to develop additional functions discussed as potential future issues in Sect. 6.5.2. Also, we would like to test *Colorscore* with a greater variety of users and music to find more issues for improvement. Especially, we have not yet tested condensation functions with examinees and therefore have not discussed these issues well. Such additional tests will be helpful for our future enhancement.

Following are our long-term future issues. We are interested in more detailed information display of note-blocks. Especially, we would like to represent differences of note-blocks painted in the same colors by assigning independent textures or glyphs.

We are also interested in development of horizontal condensation so that it can detect repetition of note-blocks and shrink repeated note-blocks.

As discussed in Sect. 6.5.2, it is an essential problem that we must manually input melodies and accompaniment patterns, and therefore visualization results may strongly depend on that input. We would like to investigate how *Colorscore* can integrate with automatic theme or pattern discovery techniques, so that *Colorscore* can provide visualization results that do not depend on users' input.

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Chapter 7
The Implications of David Hockney's Thesis for 3D Computer Graphics

Theodor Wyeld

Abstract The debate on whether optics were used to construct perspective images during the Renaissance was reignited by the artist David Hockney's book *Secret Knowledge of the Masters*. While others have already discussed this in length, what Hockney brings to the debate are his insights as an artist. What this chapter attempts to do is to explore his thesis in terms of its implications for 3D computer graphics—the latest extension to the Renaissance perspective. Hockney's assertion that artists from the quattrocento onward painted from mirror and lens-projected images has its implications for the projected images of 3D computer graphics today. Just as technology informed the Renaissance artist on ways of seeing and representing natural phenomena, 3D computer graphics today uses algorithms to simulate these same phenomena. However, neither process can ever approach the absolute clarity of Nature. Attempts to replicate natural phenomena in images are quests for realism—begun in the Renaissance and continued in 3D computer graphics. However, the various techniques used can only ever make the images produced seem real or at least real enough. In the case of the Renaissance artist, this was in the form of painterly techniques to generate the illusion of clarity. For 3D computer graphics, while the mathematical algorithms are adjusted to simulate nature they often simply imitate the quattrocento Masters' techniques. However, while the Renaissance artist never lost sight of their role in interpreting what they see, 3D computer graphics is supposed to be underpinned by the certainties of its apparent scientific veracity. Hence, is this certainty deserved or is it merely that science and art intertwined in ways that mean one is simply reliant on the other?

7.1 Introduction

In Hockney's [8] book, *Secret Knowledge, Rediscovering the Lost Techniques of the Old Masters*, he reveals how the Renaissance Masters transformed their art from Gothic symbolic spiritualism to a naturalistic realism using optical devices. This is not a new concept—it has been reported by others [3, 6, 7, 9, 10, 20], but, as an artist,

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Hockney has, in a very practical way, recreated the conditions for optically projected images using mirrors and lenses and applied his theories directly.[1] What is of interest to the author of this chapter is how, in a similarly projected manner, contemporary 3D computer graphics appears to be underpinned by its scientific veracity but actually appears to simulate many of the techniques first developed by the Masters of the Renaissance. It is the Masters' techniques for producing depth, light, and shade that also inform the 3D computer algorithms used in creating computer-generated realistic scenes. Indeed, the perspective itself which, first formularised in the Renaissance, underpins the computer frustum matrix.

Hockney asserts that the lens/mirror projection of the Renaissance was used for establishing the rules of linear perspective. A number of optical devices were available for projecting images onto an adjacent surface at the time—the lens, concave mirror, pinhole, and so on. Hockney claims the projected image those devices produced allowed artists to capture fleeting expressions directly—by tracing its projection—thus accounting for what seems to be a dramatic shift to realism in the fifteenth century.[2] It is this same realism that is captured in today's computer algorithms used for generating a perspective image 3D computer graphics programmers rely on scientific methods for observing how light behaves. However, as Tufte points out, how they choose to 'represent' this behaviour is subject to interpretation—in a similar manner to that which the Renaissance Masters made of what they observed. Hence, scientific fact and artistic technique appear to be conflated in the space of their mutual representation—each informing the other. This is further confirmed by the terms used in texts describing the various 'realism' algorithms driving 3D computer graphics.

7.2 The Projected Image

Despite Brunelleschi's clear interest in optics and Alberti's awareness of classical optics, Leonardo is perhaps the earliest clear link we have with the *direct* use of optics [8, 9, 17] in the construction of Renaissance perspective images. Leonardo's use of optics was, unlike Brunelleschi's direct tracings of nature, in order "to re-make nature on the basis of *understanding*, rather than direct imitation" [8, p. 234, *my italics*]. In his endeavours to understand Nature, Leonardo's model for the eye—based on the camera obscura—included placing a spherical lens behind an aperture. It was the image formed by Leonardo's 'eye-camera' that he used to establish a standard for a naturalism which painters later aspired to in terms of perspective, proportion, light and shade, colour, and so on. Although Kepler first formulated a theory of

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[1] His thesis is based on the premise that the use of optical devices in the quattrocento developed both ultra-real representations of Nature and de-natured (by its optical sub/in-version) what was seen in these projections.

[2] Little hard evidence exists for the actual application of optical mirrors in the construction of perspectival images (central to Hockney's thesis); although the necessary technology was clearly available (Hockney claims many of the techniques for its application remain hidden due to the secrecy of the various competing guilds).

vision whereby a 'real' optical image was formed within the eye, "a picture that exists independently of the observer" [17, p. 55], it was Leonardo's 'camera-eye' that was responsible for a shift from an interpretation of reality in painting to the literal imitation of a 'raw' natural reality around the late fifteenth century. This raw imitation can be seen in Dutch realist art and also in the composition of Caravaggio's *tableau vivant*, or 'the living picture'.

Leonardo's lens-based system involved not just the technology available but an aspiration to a 'naturalism'. Conceptually, artistic representation was henceforth redefined as *literal* imitation. According to Hockney, this was based on a developing culture that optical devices created images using the geometry of light to deliver a more objective imitation than the human eye could perceive. Hence, once the artificially made image was widely used it provided a model for an 'objectification' of nature. This age of objectification can be seen to extend from the Renaissance till today—through the fine arts until the "mid-nineteenth century, when their sovereignty passes to photography and later the cinema, . . . TV" [8, p. 252], and 3D computer graphics—"if nature is constructed ... let us reconstruct it in a computer" [2, p. 189]. Renaissance artists caused a profound change in the way the world was visually understood and organised—eventually influencing Galileo, Harvey, Descartes, and Newton's views [3].

While many authors [3, 9, 16, 17] tend to agree that the availability of optics influenced the production of the perspective procedure in the Renaissance, others argue [7, 11, 20] that the increasing orderliness of a mercantile environment and society influenced a more rigorous approach to the representation of space and objects within it. Whether an increasingly mercantile society or the availability of optics was more instrumental in the rise of perspective is difficult to determine. Hockney claims that studies of optics both provided a *mechanism* and basis for establishing the *rules* of perspective construction, suggesting this was more influential. But if we accept Panofsky's [16] premise that art invariably reflects a society's values, then a systematised economy and political system tends to suggest the unsurprising appearance of a systematised artistic style. Regardless of which impetus initiated it, a perspectival view of the world would have had a profound re-structuring of how the world *could* be seen. For Hockney, the use of a lens or concave mirror to project an image onto a 2D surface, pre-dating photographic perspective construction, supports the seemingly *dramatic* shift to a 'photo-realistic' representation in art around the middle of the fifteenth century. Without assistance from a lens or mirror, he suggests, incredibly difficult feats of 'eyeballing' would have been necessary for the realism achieved in Renaissance art. It is difficult to imagine how this could have been achieved by the increasing orderliness of a society alone.

As evidence for his thesis, Hockney points out how Jan van Eyck's *Arnolfini Wedding* of 1434 contains a convex mirror. This type of mirror, if silvered on the reverse side, would provide the very concave mirror required to generate the series of projected images necessary for the painting's production.[3] Using a concave mirror,

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[3] A concave mirror can be used to project a focused image from an opening in a wall onto a darkened interior wall.

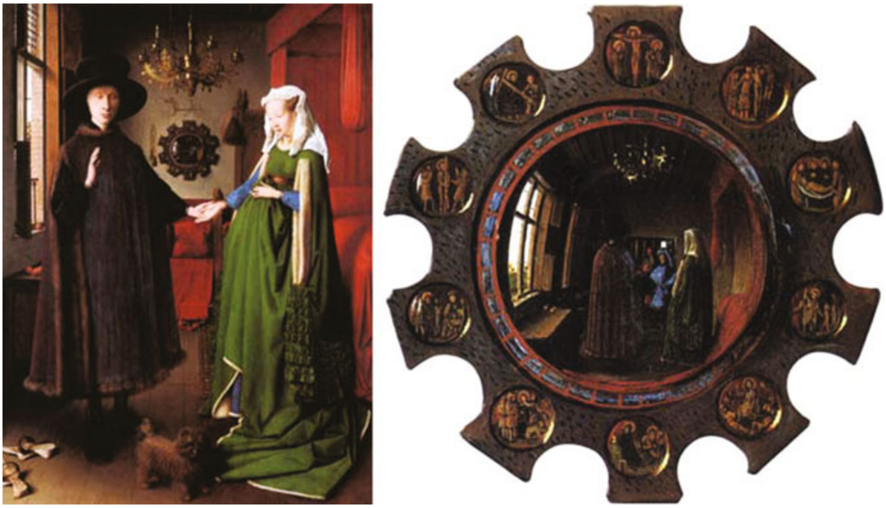

Fig. 7.1 *Left*: *Arnolfini wedding* (1434) van Eyck [30]. *Right*: Detail of Jan van Eyck's *Arnolfini wedding* (1434). If the mirror in Eyck's *Arnolfi wedding* of 1434 is turned around and silvering applied to the back then it is conceivable that concave mirrors were available adding currency to Hockney 's thesis that they were used to project images onto a canvas suitable for painting

and its subsequent projection, each object in the scene could have been individually rendered in a sharply realistic manner directly onto the canvas (see Fig. 7.1).

Indeed, a number of devices can be used to mechanically construct a perspective: the camera obscura, the camera Lucida, a concave mirror, grids, screens, Brunelleschi's peephole, pinhole projections, and so on. What they all tend to do is to map the projected view onto a flat plane. The interest in mapping space to the Renaissance artisan-engineer coincided with its military and general surveying use. Around this time, "the perceived importance of revealing a mathematical structure present in the reality of experience, ultimately an ontological interest, fuelled both surveying and the arts" [17, p. 238].

Hockney claims that optical tools are necessary to account for the shift to a less awkward portraiture after the fifteenth century in European art. This appears to be supported by Caravaggio's (1594) *Boy Bitten by a Lizard*. He questions how long the boy could have held his expression. He claims the artist would had to have used a camera Lucida to capture 'fleeting' expressions using notations initially, and analysing these at length after the model had departed—"to 'eyeball' this . . . (the artist) would have to have (had) a very good visual memory" [8, p. 240] (see Fig. 7.2).

If artists' use of optical devices in the construction of perspectival pictures coevolved with the shift to a geometrised world around them,[4] this would indeed have heralded a fundamental shift in artists' otherwise naive appreciation of the *structure*

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[4] The systematic, rectilinear, organisation of an emergent urbanism—reflected on a larger rural scale—was fuelled by merchant capitalism: rural roads flanked by Cyprus pines in Tuscany and played out in the dialogical and physical relationship between merchants and the metayers (see [11]).

Fig. 7.2 *Left*: *Boy Bitten by a Lizard* (1594) Caravaggio [30]. *Middle*: *The Death of Cleopatra* (1658) Cagnacci [26]. *Right*: Cagnacci's *The Death of Cleopatra* in black-and-white. According to Hockney, optical projections create strong contrasts of light and shade—a deep chiaroscuro—illuminating objects in the scene. The lack of recession in the space, he claims, is due to the depth of field of the mirror or lens used in the projection

of their environment. In particular, they would have been able to represent the world in a more sophisticated way *because* of optics and its *implied* geometry—objects in depth related by size and distance rather than by hierarchical religious importance. Using such optical devices, artists would no longer be representing the world around them that they perceived but re-presenting a projected view of the world. By tracing, and in some cases painting, directly onto the surface of the projected image this method would have profoundly changed the way artists depicted Nature henceforth. Light would become an inspirational fundament in itself, so much so that it would dictate settings—strong light was needed to produce a projection suitable to paint from. Though little hard evidence is available to substantiate Hockney's thesis, it is a compelling theory and has profound implications for the way 3D computer graphics has derived *its* cues from the masters—from the Masters' re-presentations of projected surfaces to simulations on the computer monitor of the Masters' illustrative methods and techniques.

Where Renaissance optics and today's 3D computer graphics methods coalesce is in their common aim for a '*photographic*' realism. For example, if we reduce Cagnacci's *The Death of Cleopatra* (1658) to a black-and-white reproduction, its photographic-like qualities become more apparent (see Fig. 7.2). The lighting is similar to what we associate with photography. We both recognise this quality in his work because it appears to follow the photographic method and because we have become so familiar with the modern lens-projected image. Hockney's use of the analogy of a black-and-white photograph to demonstrate his point is confirmed by Gombrich's [5, p. 91] assertion that using a black-and-white photograph-like reproduction of an artist's work helps "separate the code from the content."

Perhaps just as computers today remove much of the drudgery in 'setting-up' a perspective, Renaissance artists used optical projections to overcome the difficult *mathematical* construction of their perspective compositions—an artist could merely trace a 'live' image and fill in the surfaces later. To an artist 600 years ago, these optical projections would have demonstrated not only an immediate and easy method for ‘capturing’ their subject matter, but also a new and vivid way of looking at and representing the material world. It was a tool which would have helped make images that were intensely realistic and thus powerful.

If such images were indeed constructed using a mirror or lens method, then it can be deduced that the mathematical axioms produced for linear perspective by artists and artisan-engineers to “make metaphysical subject matter appear more tactile and therefore empirically believable, . . . (demanded that space should) be perceived as having the same physical properties and . . . (obey) the same geometric rules” as optics [3, p. 18]. This, in turn, would have furthered, more generally, the notion of a rigorous scientific application to the ‘observed’ world. Today, the optical imitation of nature in the realm of 3D computer graphics follows the same perspective-construction algorithms as their Renaissance counterpart. Pioneered in the 1960s, by Roberts and Coons, these algorithms ushered in an era of efficient, human error free, perspective construction. The methodology, though digital, is essentially a re-configuration of the pre-existing perspective paradigm. The computer-generated *objectification* of the world around us has henceforth become even more pronounced than its Renaissance inception.

While the post-Renaissance invention of photography in the nineteenth century meant the time consuming process of manually constructing perspective was eliminated, the automation of perspectival imaging using 3D computer graphics algorithms has since completed the perspectival process first realised in the Renaissance. Computers which allow the projection of 3D points in space onto a 2D plane using perspective-generating mathematical algorithms reduce real objects to virtual objects consisting of Alberti’s planes, surfaces, and lines. The coordinates of each vertex are stored in computer memory. So too is the virtual camera, its point of view, direction of sight, and relationship to a projection plane. Point by point a perspectival image is generated by the computer. As colour was added in the 1970s and 1980s, other algorithmic procedures were developed adding depth cues such as hidden line and surface removal, shading, texture, shadows, reflections, and so on. From software to hardware, the various ‘Virtual Reality’ algorithms have been hardwired to specialised computer chips and video processors. It has since become increasingly easy to interactively manipulate virtual objects in virtual space with the progression of successive software and hardware graphics acceleration programmes. The emergence of this paradigm, the reduction of human vision to a single function and the commercial and military investment in its research, highlights contemporary society’s dependence on this type of vision [12]. If we follow Hockney’s thesis, then this dependence on the visual monism of perspectival representation and its ‘naturalisms’ appears to stem from the fact that after 1500 almost all art displays the tones, shading, and colours found in optical projection.[5] If we now compare this, the Masters’ use of projected light, with that used in computer-generated images, we can conclude that

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[5] In support of Hockney’s thesis, his experiments with a window and mirror arrangement reveal the similarly sharply contracted pupils of the subjects of his experiments and those depicted by Jan van Eyck and others. This suggests that, as Hockney found, a strong light such as the full sun is needed to generate a ‘natural-looking’ projection against the wall of an adjacent room.

Fig. 7.3 *Left*: Detail of *Kitchen Scene with Christ in the House of Martha and Mary* (1618) Velazquez [30]. *Middle*: *Still Life with Game Fowl* (1602), Cotan [29]. *Right*: Computer-generated architectural interior. Velazquez used a strong light source to capture his subjects in paint. This is also a hallmark of the use of a projected image according to Hockney [8]. If we now compare Velazquez' technique with the computer-generated super-realistic image, similar qualities emerge suggesting 3D computer graphics borrows heavily from the Masters' techniques for creating the *illusion* of realism. Cotan achieves a super-real image due to the 'concentrated realness' of its projected image

they both emulate a reality which, while not entirely scientifically definable as real, we have come to recognise such images as 'real enough'.

While espousing the virtues of a scientific rigor in their imitation of Nature, many 3D computer graphics programmers seem to borrow much of their illustration *direction* from the Masters of the quattrocento. This is despite an apparent ignorance of art history in general. For example, if full sun was required to produce a decent projected image onto an adjacent wall in the Renaissance, and the images created were what 3D computer graphics now bases *its* realism on, then it calls into question what is promoted as 'scientifically adduced as real' in 3D computer graphics and what has merely been borrowed from the Masters and considered sufficiently 'real' or convincing. However, according to Tufte [23], science and art are conflated in the space of representation; hence, it would appear there is no conflict in the computer-graphic 'artistic' representation of scientific fact. However, unlike the sameness that pervades 3D computer graphics, the absolute *subjectivity* of vision is reflected in how painters *made use* of the projected image. Velasquez, for example, used the rich colours and tones that a projected image does not provide (see Fig. 7.3). Painters made choices like this consciously; hence, the differences between painters' subjective *interpretation* of what they saw in the projected image. In another example, Cotan's objects are almost super-real (much like the tonal accuracy and brilliance achieved in 3D computer graphics; see Fig. 7.3)—"the camera obscura does just that—making objects assume an uncanny look of concentrated 'realness'" [8, p. 245]. But what is this 'realness'? In painters' quest for a super-realism, they used techniques which encourages one's perception to conceive a realness which does not exist. Tricks and techniques such as shading and highlights enter the artist's repertoire of representation which we have become accustomed to over time. They establish a metaphor for the effect of light on objects. In 3D computer graphics, lens flare—something photographers try to avoid—is used to suggest a physical camera was used; raytraced or mapped shadows are used to indicate strong or soft light;

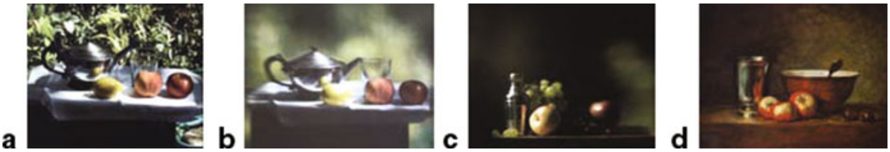

Fig. 7.4 **a** Photographed setting [8, p. 104]. **b** Projected image [8, p. 104]. **c** Projected image [8, p. 105]. **d** Chardin's painting of a projected image (?) [27]. These examples demonstrate natural light contrasted with painters' light, brightness, and highlights, all of which is emulated in 3D computer graphics. It is worth noting here that there is an implied assumption that the first image, the photographed setting, provides a neutral control by which we can compare the others. The *actual* setting, on the other hand, would imply different meanings, least of which includes the presence of Hockney himself!

fog is used to indicate depth; or, blur to introduce motion, and so on—not things we see in reality but merely metaphors created by successive artistic techniques for generating a super-realism. In this sense, we can see how in the Renaissance, the apparent "unrivalled visual fidelity of the camera obscura would have been of interest to any artist striving for a naturalistic appearance in his paintings" [8, p. 241]. And, this has its corollary in the successively more precise lighting effect algorithms in 3D computer graphics today.

In particular, if lighting which was so influential in the early Masters' paintings—highlight, shading, specularity, and so on—is now used as a basis for 3D computer graphics algorithms, then this also affects the way we perceive images created by 3D computer graphics. For example, natural light versus painter's representation of light which in turn appears in 3D computer graphics as 'modelled' light may be interpolated from Hockney's projected images (see Figs. 7.4a and 7.4b) as affected by its new planar qualities—no longer seen as reflected directly from the objects themselves, but rather their ephemeral castings on an adjacent flat surface. If we compare Hockney's setting (Fig. 7.4a) with its projection (Fig. 7.4b) and then another of his projected images (Fig. 7.4c) with that of Chardin's painting (Fig. 7.4d), striking similarities occur between Chardin's painting and Hockney's projected setting—the tonal quality, highlights, and depth of field. This highlights the potential for a conflation of styles and conventions in the Renaissance Masters' techniques and 3D computer graphics methods if we consider the projected computer-graphics image to be the corollary of the physically projected image.

Highlights and tones are simplified by optical projection. Hue, Saturation, and Volume (HSV) algorithms for lighting in a 3D computer graphics programme are derived from a scientific analysis of how light behaves. Optical projection provides the model for these algorithms in 3D computer graphics, and they are then applied in a painterly manner. Just as the use of optics apparently caused oil paint to be used in different ways (highlights using blending of paint, and strong contrast with the translucency of the paint itself to simulate the effect of a projected image [8]), these painterly effects have, in turn, provided the impetus for the algorithms which drive 3D computer graphics today: bump mapping, highlighting, caustic reflections/refractions, and so on.

What distinguishes Renaissance art and computer-generated imagery is the ability to juxtapose real and imaginary objects using digitally manipulated images. For example, as is demonstrated in *Jurassic Park*, *The Matrix*, and *Lord of the Rings* to name only a few. They show how computer modelled 'creatures' can be seamlessly blended with a photographed landscape background. This begs the question of what is real and what is imaginary. In other words, the power of 'real' photographic and digital media is clear when we accept it as 'scientific', constructed by instrument, precisely measured, and objective, thus demanding of our trust. Moreover, despite its ability to be manipulated, or the multiple interpretations scientific data can be subjected to, we *need* to trust these images because our whole contemporary cultural perceptual system is aligned with it.

Yet, despite the current fetishism surrounding 'realistic' 3D computer graphics, and its apparent reliance on the Masters' chiaroscuro techniques, today's graphics programmers, invested with the skills of its production, learn their trade with almost no professional exposure to art history. Their 'art' is one of technique alone. Based on 'scientific' observation and analysis, innovation in image production is instead, controlled by the technician's fascination with what is *feasible*. These innovations are then used by advertisers and merchants for their persuasive and entertaining powers alone [22]. This 'optical' imitation of the world in Western art is exceptional. It appears normal because of the way we represent space in our century. Our history of the ubiquitous use of photography, film, and TV, to inform our culture further aids its acceptance [8]. Perhaps, in an ironic twist, it may be that, over time, with this exposure to the proliferation of lens-based images, we have become unknowing connoisseurs of optical techniques and hence are able to 'recognise' what Hockney claims in his thesis—that the early Masters' work was optically based—*because* we are able to recognise how closely it resembles modern *photographic* imagery. We have become acculturated to the world as constructed visually through the photographic image—a lens-based projected view of the world.

7.3 Where 3D Computer Graphics Emulates the Masters' Techniques

From Renaissance artists' treatment of 3D space to computer-modelled space, computer programmers have used Renaissance Masters' works as models for the generation of their digital equivalents. They have created a new 3D *computer graphics* paradigm. For example, according to Mitchell [14], wire-frame, point construction, primitives (cone, sphere, cube, and cylinder) and carved solids are the essential elements which composed twentieth century Modernist painting and sculpture. This is also the same methodology Alberti applied in his fifteenth-century treatise and, according to neural network theorists; how our eyes reduce the redundant information we receive in an attempt to manage the complexity of visual information. And, in turn, successive techniques have been employed to simulate this in painting and 3D computer graphics alike.[6]

Just as the Renaissance painters "found ways to render effects of light on surfaces with increasing exactitude ... Leonardo later made them seem quite naïve and unconvincing," and in time Lambert, Gourard, and Phong rendering will be supplanted by more powerful reality renderings in 3D computer graphics [15, p. 161]. Where once the Renaissance artist's exploration of 3D space followed simple perspective rules, 3D computer graphics now automates the same 3D representation of space. The successive rewritings of rendering algorithms which have added lights, highlights, shading, shadows, and so on, reify the same embellishments of artistic space that Western culture has been immersed in since the Renaissance. Where 3D computer graphics and traditional art differs, however, is in the complex dialogue implied by the artist's personal deviations from the computer's attempts at mathematically precise imitations of Nature. The artist's dialogue includes looking at, and representing Nature beyond, and in addition to, the scientifically adduced principles of optical devices. Unlike 3D computer graphic's mathematically constructed images, artists may not necessarily proceed in the same manner in every instance. For example, where Dutch realist painters, such as Van Eyck, relied on Nature reflected mirror-like to teach its perfect imitation, Italians such as Pierodella Francesca and others used precise geometrical rules for *remaking* Nature based on a scientific appreciation of 'natural law'. Van Eyck viewed humans' understanding of Nature by its expression as a surrogate reality created in his projected images [8]. Despite a lack of a singular geometric precision, Van Eyck saw mirrors as surrogate realities facilitating a conceptual shift to lens-based, mirror-based, or device-based naturalism. It is in this *device-based* naturalism that we find the paradigm which most closely informs 3D computer graphics today.

3D computer graphics considered as simply an extension to a pre-existing representation of 3D space on a 2D surface—such as a perspective painting or drawing, or a photograph—produces the unsurprising result that many of the techniques of the Masters', and indeed photography, now appear as discrete rendering algorithms. Algorithms used to generate shading, shadows, and so on, designed to look similar to their hand-rendered chiaroscuro counterparts are hence, inherently not 'real', but rather literal referents to their traditional artistic metaphors—therefore, no more real than the artistic metaphors they attempt to emulate.

To support the apparent optical realism (i.e. scientifically verifiable realism) of the Masters' work includes both a physical and 3D computer reconstruction of Vermeer's

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[6] Neural network theorists suggest that our internal representation of the world is an abstraction or reduced encoding of our perception of solids comprised of coloured-in surfaces with continuous depth. Our ganglion cells separate retinal image edges encoding objects by their vertices followed by regions of uniform brightness and boundaries separating regions out which are subsequently painted in with brightness values [13].

Fig. 7.5 *Left*: Front cover of Foley et al. [4] *3D computer graphics: Principles and Practice*, (A computer-generated image). *Middle*: *The Music Lesson* (1670), Vermeer [31]. *Right*: Physical reconstruction of Vermeer's *The Music Lesson* room [21, p. 123]. Vermeer's music lesson room attracted so much attention by its apparent optical clarity that a room was constructed using his numerous art works as guides—including a 1989 BBC documentary. It could then be used to test the optical construction of his various paintings composed in the same room

The Music Lesson.[7] Photographs and still images are subsequently tendered as evidence that the painting followed optical and/or mathematical construction. But these real and virtual modellings do not support its photographic premise; rather it could be argued they merely demonstrate how closely both 3D computer graphics and photographs emulate the *Masters'* subjective 'interpretation' of reality (see Fig. 7.5).

Indeed, according to Richens [19, p. 2]:

> photorealism has been espoused by 3D computer graphics researchers because of its easy determinacy. If you specify all the light sources, the optical characteristics of all the materials, and simulate the physics of light with the utmost fidelity, then the resulting image is fully determined.

But as we know, "a more realistic picture is not necessarily a more desirable . . . one . . . . (Realism in 3D computer graphics is often) intentionally altered for aesthetic effect, or to fulfil a naive viewer's expectations" [4, p. 605]. Hence, the reliance on painterly techniques in 3D computer graphics to create a realism which is aesthetically pleasing, while appearing to be underpinned by scientific fact. Moreover, as Tufte (1997) reminds us, those vested with an interest in the representation of scientific fact are often, by necessity, also the purveyors of its artistic representation and vice versa.

A brief review of leading texts on 3D computer graphics [4, 14, 15, 18, 23, 25] confirms Tufte's assertion that, in relation to perspective, light, colour, surface, shade, reflection, and texture, most algorithms are indeed typically derived from their

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[7] It is an ironic truism that Foley et al. [4] chose as their subject matter for the front cover of 3D Computer Graphics a computer model of Vermeer's *The Music Lesson*. Perhaps they did not use another of van Eyk's paintings, such as *Chacellor Rolin* (1436), because it would have been too complicated. This begs the question of the complexity of the paintbrush compared with 3D computer graphics, and how much information can be conveyed in a single brush stroke. Perhaps the physically reconstructed room was chosen over alternatives also for the same reasons.

Fig. 7.6 *Left*: Hidden-line rendering. *Middle*: Flat-shaded rendering. *Right*: Shadow-mapped rendering

Fig. 7.7 *Left*: *The Virgin and Child with Saints and Donor* David (1510) [30]. *Right*: *Study of a Numerically Modelled Severe Storm* National Centre for Supercomputing Applications [23, p. 20]

traditional artistic equivalents. For example, Mitchell and McCullough [3] and Foley et al. [16] discuss the 'visual effect' of perspective projection used in 3D computer graphics as similar to that of photographic systems, and the common 'hidden-line rendering' is referred to as being generated by the 'Painter's Algorithm'. The hidden-line algorithm follows Alberti's intellectual programme, reconstructed in software, it mimics his descriptions of edge lines, outlines of surfaces, and curvatures (see Fig. 7.6).

Even the application of perspectival composition informs the *content* of 3D computer graphics. Tufte [23] identifies the strength of Renaissance techniques in the construction of perspectival images in digital media such as the common tiled grid in a Renaissance perspective (see Fig. 7.7). For example, in the case of a simulation of a cloud mass turning into a storm, the use of an exaggerated tiled grid as a perspectival cue is considered necessary to indicate its volumetric quality (see Fig. 7.7). In both, the tiles provide a scale and reference to a receding space—a technique first established in the Renaissance.

To produce more recognizable spaces and objects, Mitchell and McCullough [15] claim a standard architectural convention is used whereby light appears to arrive from over the viewer's shoulder (see Fig. 7.6). Where colour is used in both light source and surfaces, Foley et al. [4, p. 590] claim, the use of "Smith's HSV (hue, saturation, value) model . . . (also called the HSB model, with B for brightness) is user-oriented,

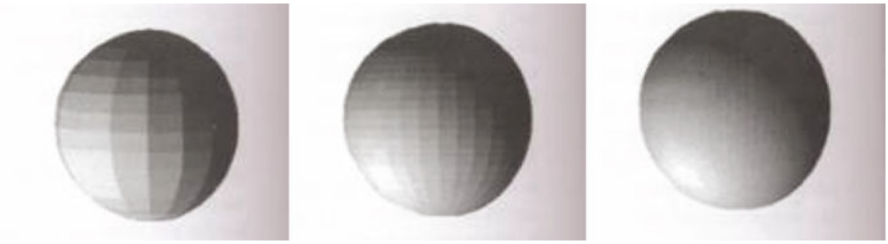

Fig. 7.8 *Left*: Lambert shading. *Middle*: Gourard shading. *Right*: Phong shading

being based on the intuitive appeal of the artist's tint, shade, and tone." Both rely on aesthetic qualities rather than scientific exactitude to produce their effects.

Mitchell and McCullough [15] extend the notion of an object's surface property as having some *artistic* quality by referring to Leonardo 's chiaroscuro techniques. For example, Lambert's cosine shading is described as similar to old-fashioned drawing books which used tonal media such as charcoal and watercolour to demonstrate depth on a surface; and, successive rendering algorithms have attempted to emulate the artist's chiaroscuro techniques with increasing precision such as Gourard and Phong—the blending of colour to produce tonal ranges across shaded areas with distinct highlights (see Fig. 7.8).

While Lambert's eighteenth-century cosine law is now used as a scientific basis for its computer-graphic algorithmic corollary—specularity—it reduces to a precise formula a fact known by painters regarding the incidental intensity of reflected light [15]. Painters have long known that their

> means for describing light, shade and colour . . . (are) absurdly limited when set beside the effects in nature. The painter's most glaring white comes nowhere near even a weak light source in intensity under the same conditions. We clearly need to collude with the artist, accepting the limitation of his means, if we are to read the golden disk of paint as a luminous setting sun . . .

such as that explored by Turner in his nineteenth-century light studies series [9, p. 338] (see Fig. 7.9). The incidental angle and spread of light that strikes a surface is algorithmically a function of the reflectivity and curvature of the surface. Yet, despite its algorithmic determinability, it can never approach the true brightness of sunlight when displayed on a monitor. Instead, it needs to be aesthetically exaggerated so that it 'looks right'.

Where most of the authors discussed here define an achievable 'realism' in 3D computer graphics what they are actually describing are illusions in the creation of a conceptual pipeline [4]—a conceptual pipeline that generates an acceptable realism that we have become accustomed to through an acculturation to its conventions and metaphors. The dichotomy of both a reference to artistic quality and scientific fact is common among the exponents of 'realistic' 3D computer graphics. According to Richens [18, p. 1], a 3D computer graphics package suitable for stage-set design or architectural documentation ". . . would require software specially adapted to the task." In support of this, he perpetuates the myth that a "computer simulation would

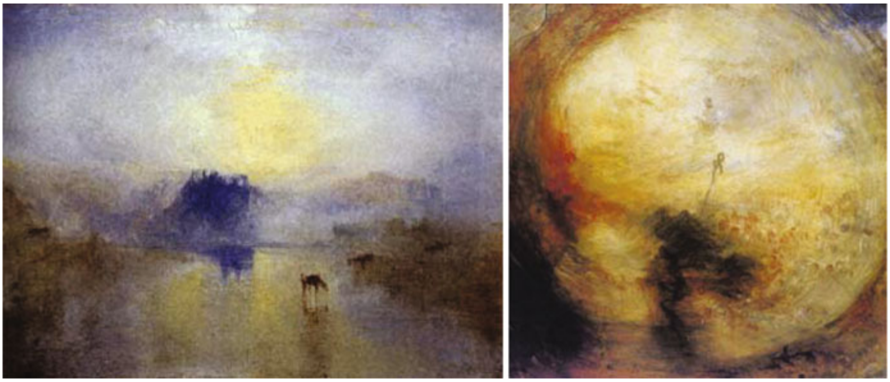

Fig. 7.9 Turner's nineteenth-century light studies. *Left*: *Norham Castle* (1845) [28]. *Right*: *The Morning after the Deluge* (1843) [28]. "Turner's paintings are filled with 'natural' light free from geometric constraints" [17, p. 228]

act like a scale model, . . . able to simulate lighting and the camera's eye" [18, p. 3]. He later qualifies this statement, however, by suggesting that simulated ". . . computer lighting . . . is *far* from physical reality" [18, p. 15, *my italics*]. Indeed, most rendering packages approximate reality at best and positively fudge it at worst. Something students of 3D computer graphics discover quite quickly.

The 'real' world is typically described by 3D computer graphics programmers in terms of its ability to be simulated. "A fundamental difficulty in achieving total visual realism is the complexity of the real world. Observe the richness of your environment. . . . The computational costs of simulating these effects can be high" [4, p. 607]. Here it could be suggested that the deft stroke of a paint brush generates a greater complexity in both its visual quality and its quality as a tactile surface. This is something which a computer-graphic image is yet to achieve (neither should it necessarily). Indeed, while modern computer *games* rely for their realism on the complexity of textures, often derived of photographic sources, the surfaces they are painted onto are ostensibly orthogonal. This hints at the trade-off between visual complexity and operational performance. For example, if we compare the complexity of Rubens' work with that of a 3D computer graphics-generated image, what is most striking about the painting is its organic tactility (though we cannot generate such a tactile surface in this document). This is in contrast to the sterility and orthogonality (i.e. artificiality) typical of 3D computer graphics images, despite the use of clothe and radiosity 'softening' algorithms (see Fig. 7.10). Moreover, the spaces used to expose 3D computer graphics tend to be orthogonal *because* of the perspective algorithms used for their generation.

Fig. 7.10 *Left*: *Samson and Delilah* (1618–1619), Rubens [30]. *Right*: Computer-rendered interior setting using radiosity and clothe algorithms [1]

7.4 On Reflection

If we accept Hockney's assertions that the Renaissance Masters painted directly onto images projected on a 2D surface from mirrors or other optical devices then what painters were illustrating was not always Nature directly but a projected vision of Nature—a Nature that could be observed and traced in detail. However, the quality of the image was by circumstance filtered and altered in ways that also affected the way artists approached the task of replicating and interpreting what they could see. By contrast, while 3D computer graphics technology appears to have borrowed from the lessons of the Masters in *its* representation and interpretation of Nature, it is underpinned by a scientific method. Yet, there also seems to be an accord between science and art in the construction of the 3D computer-generated image. This lies at its code—where art should be anathema to its logical construction. Nonetheless, the terms used to describe the algorithms for constructing 3D images suggest that its art and technological invention coexist in a symbiotic relationship. The software engineer can claim to have constructed an algorithm which simulates the rules of natural phenomena, but when it is described in terms used by the quattrocento Masters then the net effect is something both less than its Nature-inspired corollary and more than its retinal impression. It becomes a convention we agree to use to describe that phenomenon. Indeed, in more general terms, it is from the symbiosis of Art and Science that emerge the conventions and rules we use to describe the natural world around us.

The implications for a 3D computer graphics which continues to follow the Renaissance Masters' illustration cues is a reduction in the possible avenues for its artistic expression. Principle among the demons of such a slavish allegiance is the use of perspective. With its limiting of visual experience to a flattened representation of 3D, alternate dimensions of expression are lost. This is something the abstract expressionists of the twentieth century consciously rallied against. In time, however, their explorations have once again given way to the ubiquity of the omnipotent perspectival image. This is clearest in its latest manifestation, dynamic real-time perspectival technologies such as the Virtual Worlds of 3D computer games. Where cinematography expanded photography's dimensional repertoire to include time, multiuser Virtual World technologies expand the paradigm further with a social dimension and interactivity. Whether this proves to be a useful expansion or simply a novel, hence superficial, extension remains to be seen. Either way, perspective remains a potent metaphor for modern notions of a scientifically constructed objective reality.

What Hockney demonstrates and 3D computer graphics aestheticians could note, is that while the quattrocento painters still saw themselves as holding a privileged part of the work they created, they did not see their images as representing the totality of the real [24]. 3D computer graphics, by contrast, is an ostensibly sterile environment where few traces of an image's producer remain to inform the nature of its production. Perhaps the recent introduction of the social dimension to perspectival technologies such as in gaming, remote collaboration, interaction design, and so on, will signal the emergence of a new force where the novelty of the visual media becomes secondary to its implicit/explicit meaning and communication—much as the Renaissance Masters hoped their images would continue to communicate a message of religious harmony and spirituality.

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Chapter 8
Practice of Using Virtual Reconstruction in the Restoration of Monumental Painting of the Church of the Transfiguration of Our Saviour on Nereditsa Hill

Tatiana Laska, Irina Tsimbal, Sergey Golubkov and Yulia Anatolievna Petrova

Abstract St. Petersburg State University has developed a method for restoration of partially or completely lost monumental paintings. As an example and a practical application of this new technology a virtual reconstruction of the fresco paintings of the Church of the Transfiguration of Our Savior on Nereditsa Hill, a church that was almost completely destroyed during the Second World War was completed. The basic sources of virtual reconstruction were archaeological materials, archival and contemporary historical documents, architectural and art papers, and scientific research in this field. Two main methods were used in the process of virtual reconstruction: computer graphics technology and analog pictorial reconstruction. The first method makes it possible to accomplish the work of reconstruction with complete fidelity, whereas the second method helps to convey the artist's style, so as to reproduce the form, direction, and strength of the artist's touch and texture of the frescos. The results of the project can be used for further practical work for the restoration of the object. The methodology developed by authors of the project may open new possibilities for the restoration of other fresco ensembles.

8.1 Reconstruction of Art and Cultural Monuments

The historical sites of Russian monumental art, due to their centuries-long life, undergo inevitable changes in color and structure of their frescoes and destruction or alteration of their original architecture. Numerous natural, climatic, and anthropogenic factors cause considerable changes that result in either partial or complete destruction of the works of art. Despite the fact that it has been 65 years since the end of the Second World War, many ancient Russian art masterpieces have still not been restored to an acceptable state of display. A considerable amount of material is stored in museums waiting to be reinstalled in the interiors of churches.

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Today, the vast experience in the exploration and restoration of monuments as well as the use of modern technologies allows integration of information from specific areas of knowledge, making them easily accessible to the public. In our case, we refer to architectural monuments of ancient Russia. Information about these objects is dispersed across many sources such as books, articles, drawings, and sketches located in different storage locations, and sometimes even in different countries. All available information can be presented in an integrated database. In reproducing the lost and missing data on each monument, and updating the existing traditional art databases, single information sources based on the results of reconstruction will help in understanding the historical context and conditions under which the object was built. With enough data it becomes possible to represent a monument at various stages of its construction and development, to analyze and demonstrate options for its reconstruction, and to illustrate the features and history of its painting. The method of sequential computer reconstruction allows not just reviewing the virtual model of the monument, but also getting details associated with the whole life of the object.

Creation and demonstration of historical reconstructions, as a progressive method of presentation of ancient exhibits, makes it possible to achieve a new level of preservation and transmission of cultural heritage.

8.2 About the Nereditsa Project

The "Nereditsa Link of Times" research project is currently under development at the St. Petersburg State University. Major museums and cultural institutions such as the State Russian Museum, the State Historical and Architectural Reserve Museum of Novgorod the Great, the Institute of History of Material Culture of RAS, and the Ilya Repin St. Petersburg State Academic Institute of Fine Arts, Sculpture and Architecture take part in this research.

This project is dedicated to a unique monument of ancient architecture and art, the Church of the Transfiguration of Our Saviour on Nereditsa Hill. In 1992, this churchwas included in the UNESCO World Heritage List, along with several other monuments of Novgorod the Great and its surroundings [1].

The Church on Nereditsa Hill is one of the most famous monuments of ancient Russian culture. It was built by Prince Yaroslav Vladimirovich's order in 1198, and a year later, in 1199, its interior was decorated with fresco paintings. The exceptional artistic value and unusually unique iconography of the monument have earned it a worldwide fame. Similar to the St. Sophia Cathedral, representing the eleventh century, and the St. George Cathedral of the St. George's Monastery, representing the early twelfth century, the Church on Nereditsa Hill is considered to be a typological and stylistic architectural standard of the late twelfth century [2].

During the Second World War, the temple was almost destroyed. Only half of the masonry and 15 % of the frescoes were preserved. Based on the old drawings, it was possible to restore the upper part of the walls, arches, and the dome; but the rare frescos which had covered the entire church until the twentieth century have been irretrievably lost [3]. The archival materials that remain are:

- Preserved fragments of frescoes.
- Photographs of theinterior of the temple.
- Detailed descriptions of the monument, made by experts from the State Historical and Architectural Reserve Museum of Novgorod the Great and historians from St. Petersburg State University.
- Copies of frescos, carefully preserved in the State Russian Museum.

In combination with modern technologies, these materials provide a unique opportunity for a virtual revival of the lost masterpieces of ancient art—frescoes of the Nereditsa Church.

The Church of the Transfiguration of Our Saviour on Nereditsa Hill has been an object of scientific art research at St. Petersburg State University, Novgorod State Museum, and the State Russian Museum for many years. The first expedition to the church was organized by St. Petersburg University and the Russian Archaeological Society in 1910. After the architectural restoration in 1903–1904, a number of scholars, including Artamonov [4], turned to studying its paintings. After being almost destroyed by the Nazis, the Church was restored in 1958, and researchers' attention was again focused mostly on the architecture [5]. As a result, numerous research materials about the history of the church, its architectural features, and frescos have been collected.

Many thousands of fragments of frescos have been collected during restoration, architectural, and archaeological work. At present, they are kept in museum collections. It does not seem possible to restore the fresco decoration to its original form [6]. But using the methods of virtual restoration, we can achieve significant results in solving this problem. Three-dimensional computer graphics technology, art modeling, and virtual reality provide artistic reconstruction of the lost (partially or completely) cultural heritage with any specific scientific precision.

8.3 Virtual Reconstruction of the Church of the Transfiguration of Our Saviour on Nereditsa Hill

In 2008, the materials describing the history of the Church that were stored in various museums and archives were collected and investigated under the "Nereditsa. Link of Times" project. In 2009, the main publications on the history of the Church were collected and digitized, its frescos were analyzed, and its restoration history was described. In 2009, a three-dimensional model of the Nereditsa Church as well as artifacts and household objects associated with the history of the Church of Our Saviour on Nereditsa Hill were produced (Fig. 8.1).

Restoration of the Church's frescos remains a serious problem at this time. There are 325,000 fresco fragments that must be assembled (Fig. 8.2). Given the enormous complexity of the task and lack of effectiveness of the "manual" method of search and selection of fragments, it was decided to reconstruct the frescoes using computer technology. This method allows us to avoid mistakes and find a comprehensive

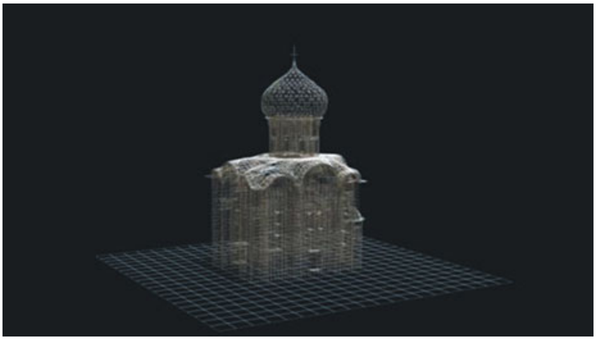


Fig. 8.1 A three-dimensional model of the church Spas-na-Nereditse

solution to the issue of reconstruction or restoration of the object. The choice of virtual reconstruction is appropriate according to practical needs of science and education. One of the most important points of the entire research is the question of choosing the method of reconstruction—analogue or computer reconstruction [7–9].

First Method: A Documentary Historical Reconstruction (Virtual Restoration) In this case, reconstruction creates a virtual object model based only on extant fragments. This model can be completed with some objects (e.g., fragments of frescos,

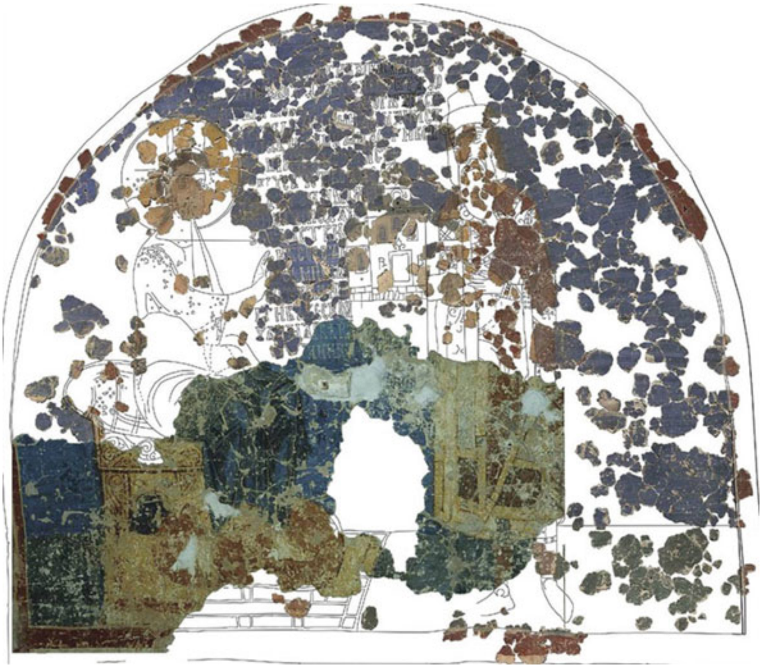


Fig. 8.2 The process of fresco's restoration

interior objects stored in museum's funds, and collections) if they are mentioned in archival documents. This method maintains historical accuracy, and abandons reconstruction of the lost fragments by analogy.

Second Method: Analog Reconstruction Extant ancient monuments, even preserved and restored, are often partially lost. Because of the lack of documentary evidence, their recovery is a problem that could be solved only through art and historical analysis. This ensures the authenticity of reconstruction. But in this case, the result cannot pretend to be an absolute reproduction of the original. Moreover, it should be clear that, based on various documentary sources of information, we can reach several possible versions of the analog reconstruction, and all of them will be equally grounded on theory.

Practical implementation of analog reconstruction requires involvement of experts in different fields of knowledge—not only specialists in computer graphics, but, first of all, artists, architects, and archaeologists. In fact, an authentic virtual analogue of the object cannot be created without a deep understanding of its architecture and proportions. This work requires highly professional, theoretical, and practical knowledge on the part of all project developers. To begin work on mural restoration we need to develop a methodology for the recovery of losses that combines two methods—use of documentary materials and restoration of color and form based on the study of analogues.

Specialists are attempting to determine the role of reconstruction in preservation and promotion of monuments. It is important to develop main principles of virtual reconstruction, such as:

- Applying the methods of complex restoration, when the monument is taken as a system of architecture, painting, interior and exterior spaces.
- Development of key theoretical principles of admissibility and limits of application of modern technologies in recreating monuments of historical and cultural heritage in terms of ethical, legal, and aesthetic aspects of reconstruction.
- Providing further reconstruction in accordance with these formulated principles on the basis of archival, historical, design, technical, literary, scientific, restoration, art, copied, and other materials using computer technology.

These main principles are being tested on the example of reconstruction of the lost paintings of the Church of the Transfiguration on Nereditsa in Novgorod the Great.

8.4 Reconstruction Method for the Church of the Transfiguration of Our Saviour on Nereditsa Hill

8.4.1 Collecting Supporting Information for the Project

The first project stage includes searching, analyzing, and structuring of archival, historical, technical, literary, scientific, art, and other documents that contain any information (e.g., photographs, drawings, pictures, descriptions) about the frescos of the church. Basic historical materials of the Nereditsa Church are kept at the State Russian Museum, the Novgorod State Museum, the Institute of History of Material Culture Sciences, and methodological foundation of the State Academic Institute of Painting, Sculpture, and Architecture named after I. E. Repin. The leading experts are historians, art historians, restorers, and muralists. Keepers of these organizations have assisted the authors of the project and helped find, analyze, and collect considerable important information.

At the stage of collecting information about the object, it is very important to find as many facts about the monument as possible in order to create the most complete description possible. Qualitative archival photographic and illustrative material, knowledge of the exact coloring of paintings, and permanent free access to all fragments of the frescos make the process of reconstruction more accurate, correct, and fast.

More than 1,000 archival photographs of the church were investigated. Most of them are stored in the Novgorod State Museum. These photographs capture all stages of restoration of the temple, which took place at the beginning of twentieth century. Collections of unique architectural details and structural elements of the temple, such as plinfy, brick, stone, etc. were analyzed in the Novgorod State Museum. According to the curvilinear shape of the wall surface, these materials are needed for correct scaling of photographs and elimination of distortions. Also, this information is important for the analysis of the character of wall surfaces as well as a basis for painting.

The authors have carefully studied the unique materials—fragments of frescoes, collected in the restoration workshops of the Novgorod Museum, which present the process of actual restoration of the frescos of the church. Archival materials stored at the Institute of History of Material Culture of the Russian Academy of Sciences were also studied by the authors—material consisting of photonegatives and photographs taken in the church before the Second World War.

The main source of information about the coloring of paintings was the watercolor paintings that have been stored in the collections of the Russian Museum. These images are in fact the copies of frescoes made before the War. Copies of frescoes, created in various Russian churches, are stored in the methodological foundation of St. Petersburg State Academic Institute of Painting, Sculpture and Architecture. These materials are also necessary for re-creation of color palette of fresco painting.

8.4.2 Measurements of the Existing Interior and Exterior

Before starting any restoration project it is necessary to measure the object of study and to make various photographs taken from various sides. Complex building measures include:

- Front, side, and back elevation measurements
- Measurements of the inner space of the building
- Measurements of interior objects.

Available measuring technologies are:

- Combined methods of laser scanning and digital photogrammetry (for exterior and interior measure, architectural details measure, and drawings).
- Combined methods of laser tacheometry and laser scanning (for measuring drawings, section drawings, and sweeps).

The exterior and interior of the Nereditsa Church were completely measured. The results were presented as drawings of the building and its interior (drawings were prepared in AutoCAD and have the same system of axes, coordinates, and heights).

8.4.3 Making Photographs of the Existing Interior

The entire interior of the church and extant fragments of frescos were photographed. It was important to take all photographs frontally, using the same scale, so that afterward they can be easily inserted into a single picture without distortions.

8.4.4 Making Photographs and Scanning Extant Fragments of Frescos Kept in Museum Collections

Elements of paintings, which were kept in museum's collections, were also studied and photographed. In the process of analog fresco reconstruction, photographs of existing fragments are used as the main working material. Given the dependence of fresco appearance on church lighting, we could not obtain an objective impression of fresco colors. Thus, all fragments should be photographed with lighting being most similar to natural church lighting. At the same time, we used ordinary scanning as another method of copying fragments. This method helps to avoid size and color distortion, that is, typical from photography. Using color and densitometer scales we can avoid color distortion; dimensional scaling helps to avoid size distortion.

Technical and technological features of paintings are especially important for restorers. Materials obtained by scanning can be enlarged and studied in detail. This study helps to bring out special features of texture and materials, direction of brushstroke and stylistic manner, to analyze the morphological characteristics of the fragments. Modern high resolution monitors provide the capability of multiple scaling. Further enlargement in graphic editing programs allows for the detection of almost invisible elements, which could not be recognized by human eye.

Fig. 8.3 Monochrome image of the wall with extant fragments

8.4.5 *Making a Single-Tone Image Based on Archival Photographs*

The next stage of the process is to create a single image of the wall, based on archival documents. First, we need to produce a monochrome image of the wall with extant frescos—it illustrates the current state of the wall surface and is a basis for the whole further reconstruction. This image consists of obtained photographs of the church which is adjusted according to the drawings produced on the stage of measurements (Fig. 8.3). Then we start to complete this image with fragments obtained from archival photographs. All of them are carefully adjusted to extant frescos.

Efficiency during this stage depends on the number of fragments remaining on the wall (reference points). In practice, it turned out that the majority of black-and-white photographs taken before 1941 were not frontal, and had distortions that made the work more difficult. The monochrome image, completed with fragments from photographs is the documentary basis for further reconstruction of color and pattern of lost parts (Fig. 8.4).

8.4.6 *Creation of Scheme to Estimate an Author's Drawing*

From this monochrome image, we can acquire outlines of an author's drawing. Outlines are drawn in monochrome (Fig. 8.5), and then the underlying image is removed to reveal an outline image of estimated author's drawing as shown in Fig. 8.6. This image provides us with the exact data about the width of strokes, pleats on clothes, boundaries of light and dark areas, and boundaries of lost fragments.

Fig. 8.4 Monochrome image of the wall completed with pictures from archival photographs

Fig. 8.5 Estimated author's drawing put on monochrome image of the wall

8.4.7 Making Sweeps of Walls with Extant Fresco Fragments Obtained from Museum's Collections

The next task was to place fragments of the extant frescos on the estimated author's drawing. It is important to find the exact location of each fragment on the wall. Signs which aid in the recognition of each fragment's location are:

Fig. 8.6 Estimated author's drawing

- Obvious morphological signs (proper for large fragments)
- Color of composition
- Obvious coincidence of fragments outlines.

Obvious morphological signs are coincidence of:

- Fragments of the holy faces
- Fragments of pleats
- Specific ornaments and patterns
- Architectural elements, fragments of landscape and greenery
- All graphical elements, which could be easily recognized.

Actually, most of the fragments do not have obvious morphological signs; for example, parts of the background, self-colored clothes, or parts that had been damaged when they were photographed. Location of such fragments can be defined according to the direction and texture of brushstroke (this method is very efficient for parts of fresco background, where the texture is well defined). Sometimes, but quite rarely, compilation of fragments can be provided according to an object's contour, such as parts of mosaic.

Previously prepared materials such as high-resolution photographs and quality-scanned images of fragments enabled successful compilation of fragments. Graphic-editing programs allowed enlarging fragments and recognizing direction and intensity of strokes, and tonal and color peculiarities. Sometimes the smallest detail, which seem to be not considerable, such as a part of a pleat or contour of a figure, helps to define the location of the fragment.

A deep study of the background fragments even helped in the recognition of specific traces of brush bristles. The artist's strokes differ in strength, amount of paint, and direction. Adding these parameters to fresco fragment descriptions increases the probability that a more accurate location of the fragment would be found.

Color variance within fresco fragments is another important aspect of compilation. The physical state of fragments may be different. They may have been stored in museum halls or in cellars and warehouses. Two fragments of the same fresco may vary in color because of different storage conditions. Moreover, Nereditsa paintings exhibit complex color variations, exhibiting many shades. Even within a single fresco fragment the colors may vary from warm to cold shades. Fresco backgrounds or image regions representing the earth, water, and other singly colored objects that occupy large areas of the painting may vary in shade from warm to cold inside a single component. Such extensive transformations in color may be seen in a blue background that represents the sky, which can vary in shade from warm to cold across the composition.

This method provides an iterative approach. Searching for the most suitable fragment and its substitution can take place at any stage of work. The process of fragment compilation requires participation of experts such as artists and restorers, who have broad experience in working with a particular church. Free access to all materials provides efficiency in the compilation process. Digital copies of fresco fragments make the entire job significantly easier and help to reduce the time required in searching for the proper fragment. In fact, in a graphic-editing program, all fragments are arranged on different transparent layers and their locations are defined by moving them according to a specific author's drawing and searching for coincidence of all the parameters. It should be understood that if a fragment is installed in the church wall improperly, in real life its dismantling would lead to further destruction of fragment. However, working with a digital copy cannot bring any harm to existing fresco parts.

The result at this stage is an image on which surviving fragments of frescos are assembled on an approximated author's drawing (Fig. 8.7). For restorers, this image functions as a map of the entire fresco composition. Along with a black-and-white sweep of the wall made from archival photographs, it becomes a basis for further artistic reconstruction. The materials created here may help restorers to project the image on the wall and draw the contour of the lost mural so that it would be a basis for collecting separated fragments of frescoes. It is necessary to emphasize that at this stage there is no artistic intervention. From this moment on, all activities can be called analog reconstruction.

8.4.8 Production of a Coloristic Painting Map

The next important stage in this process is the production of a technological coloristic map for the murals. We can obtain coloristic data from:

Fig. 8.7 Extant fragments of fresco from the museum's collections put on estimated author's drawing

- The existing fragments of paintings from the walls of the church and from museum collections.
- The historical descriptions of frescos colors.
- The chemical research of pigments.
- The historical artistic copies of the church interior.

We can take information about color from an iconographic canon as well. Traditionally, symbolism of painting is transfused by canon signs. Conventional color is typical for monumental painting, and canonical color is typical for icons. Thus, using these prescriptions we can define color of clothes, the background, and separate elements with significant authenticity.

Color is a very specific characteristic of painting. Even if a fresco was entirely preserved, over the years its color certainly must have changed. Discoloration is caused by chemical modification of paint. This process affects the whole picture, making the color of ancient fresco different from the original. Color also changes because of different storage conditions. For example, after Nereditsa's destruction, the fragments that were left on the walls underwent climate impact; others were left within earthen cellars of the church. According to the restoration documents of the Nereditsa Church : "During winter and spring 1970/71 drying of fragments, gluing of freshly destructed fragments, and boxing were completed. . . . Paint was covered with a thick soil layer. The commission from the Novgorod Museum estimated 90 % destruction of the paint layer. Fragments of holy faces were not found."

Reasons for discoloration include:

- Actual destruction of bottom stucco layer—foundation for painting
- Chemical modification of pigments
- Lightning impact
- Technical and physical impact (splits, scratches, graffiti, etc.)
- Dust and micro particles from the air
- Storage conditions: temperature and humidity variance; inappropriate monument ventilation
- Latest restorations
- Destruction or thinning of separate painting layers (top ceruse layers, thin glazing layers).

A very important question is whether the authors should restore the estimated original colors (till the year 1199), the colors before destruction (in 1941), or the colors as it would have looked if painting had not been destroyed. Finally, it was decided to restore the mural colors as it would have looked today.

Chemical analysis showed that ancient painters used a wide variety of pigments. Only natural ingredients were available and even in original versions colors could be very different. Mixing of paint pigments creates a greater diversity of colors. It means that color variation was provided not only by visual effect of complex shades relations, but also by using rich palette.

The authors have studied all characteristics of the fresco color system and have produced a palette for painting the fresco as it would have looked today, if the church had not been destroyed (Fig. 8.8). This palette became a basis for further artistic works.

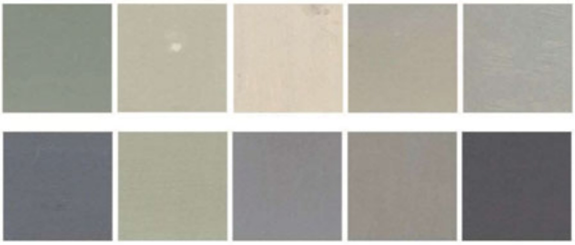
After finishing reconstruction, the colors of obtained images could be edited in a graphics program. So it is possible to show gradual color modification from 1199 to today. This virtual reconstruction provides an opportunity to show the painting in a defined time period as well as to show all changes of whole coloristic system of the fresco. This is a big advantage of virtual method because several versions of painting, related to different time periods need not be drawn manually.

8.4.9 Producing Linear Patterns at a 1:1 Scale (Performed Only in Artistic Reconstruction, as the Basis for Paintings)

An analog reconstruction of frescos was begun at this stage, which is actually the process of painting all lost fragments based on the archive materials and analogues. We created several templates with outlines produced at a 1:1 scale. These templates repeat the expected author's drawing, produced during the six stages of reconstruction.

Yellow (yellow ochre)

Red (brown-red iron-containing), dark-red (iron-containing)



Black (black fusain and pure carbon black)

Fig. 8.8 Coloristic painting map of murals

8.4.10 *Creation of Artistically Colored Cardboards the Same Size as Real Frescos or Smaller (Working Models)*

Restoration documentation indicated that no preparative drawings for the Nereditsa frescoes had been made. Therefore, these ancient painters must have worked in a natural, free, and unschooled manner; creating images with energetic uniqueness. When a painting is created spontaneously, an artist puts his feelings and emotions into the picture, even into the precise painting of fine details. At the same time, these fine details are integral to the composition of the work as a whole, conveying a strong overall impression that cannot be conveyed easily by a digital copy. Other examples include images that have been edited in graphics programs. Although this method is theoretically possible, the digital copy usually loses artistic uniqueness and a sense of the original. It is impossible to simulate manual drawing mechanically without loss of perception and deep understanding.

There is limited experience in these kinds of reconstructions. Most works are painted sketches, produced against an original. These images give only general information about the composition, iconography, and color of the fresco. Color is approximate in such works. The question we needed to answer was which particular paint should be used to capture these artists' acts of invention. The composition of modern polyvinyl-acetate and tempera differ significantly from the ancient paints used for Nereditsa frescos. The pigments of that time consisted of natural ingredients that were composed of minerals and clay, produced in the region around the site. Very rarely were pigments (rare blue and green colors) imported from Byzantium. In fact, our research is not an absolutely truthful reconstruction, because our

Fig. 8.9 Fragment of analog reconstruction

aim was to restore the painting style, color system, and general visual impression. Faithful copying according to ancient twelfth century technologies appeared to be inexpedient.

When the final versions of all artistic cardboards were completed (Figs. 8.9 and 8.10), they were integrated into a single image.

8.4.11 Making Sweeps of the Walls

After the fresco reconstruction we made a sweep of the western wall of the church (Fig. 8.11). Lost elements of the interior were also reconstructed (Figs. 8.11 and 8.12). The basis for the reconstruction was the result of scientific research and archival material.

8.4.12 Visualization, Production of Three-Dimensional Color Modeling

The final stage of the work was the three-dimensional color modeling (Fig. 8.12) for the forthcoming creation of static images, video, and interactive models, which would allow a user to choose the viewing angle of architecture and frescos.

Fig. 8.10 Fragment of analog reconstruction

So, step-by-step, we have accurately recreated the frescos of the Church on Nereditsa Hill, which seemed to have been lost forever. Two main methods of reconstruction were used at the same time: a technology of computer graphics and analog pictorial reconstruction. Both of them have advantages and disadvantages. The method of computer reconstruction provides maximum documentary accuracy—all manipulations with shapes and colors are made strictly in accordance with historical documents. In addition, each operation can be fixed at any stage of work. At the same time, this method cannot help us to convey the artist's style; the reproduction of the form, direction, and strength of the artist's touch; and texture of the frescos. Thus, especially when we deal with completely lost fragments of frescos, it is better to use the method of pictorial reconstruction. The main disadvantage of this method is its complexity. It is very difficult to provide exact documental accuracy and to find the appropriate author's stylistic manner at the same time. Painting has become cyclic: some fragments were redrawn several times according to the produced template until reaching expected result.

Fig. 8.11 A sweep of the western wall of the Church (analog reconstruction)

Fig. 8.12 Western wall of the Church (result of reconstruction)

Virtual reconstruction may be used as the basis for future work: for producing static images, videos, and interactive models, enabling users to choose camera and viewing angles when browsing through architecture and artistic decorations.

In contrast to the widespread practice that takes a comparative approach to documentary materials, a specific feature of this project has been to fully match the model to the actual original appearance of the monument. The documentary precision of the source materials offers the use of these results for the practical work of restoration of the object in future. Moreover, the method used in this project may open new possibilities for solving restoration problems of other fresco ensembles of the medieval Novgorod, also lost during the War.

The results of the project can be used for further practical work for the restoration of Nereditsa Church. Virtual model of the church may be used in future as a basis for producing virtual exhibition. Using modern technologies such as multiprojection systems, holograms, and augmented reality systems, information about the monument can be produced in interesting interactive forms. Such an information center can be organized in the Nereditsa Church, the Novgorod State Museum, or any other complex.

The results of the work are presented at the educational portal of St. Petersburg State University.[1]

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[1] http://sakai.spbu.ru/portal/site/169dd5df-93bd-4150-9a01-86f567045218 or http://www.nereditsa.ru in the form of educational resource Nereditsa.

Part IV
Culture

Chapter 9
Mediation of Knowledge Construction of Historic Sites: Embodied Interaction + Space

Kristine Deray and Michael Day

Abstract This chapter focuses upon the reframing of cultural heritage as a bodily experience articulated through narrative-based media. The concept of mediation is introduced and explored as a knowledge-intensive process made accessible through embodied interaction. As such, the mediation process is shaped through the reformulation of embodied experience that both customizes the interaction process and shapes resultant insights effecting information revelation and the construction of knowledge. This chapter demonstrates a mediation framework, discusses ambient design guidelines for maintaining the integrity of the mediation, and mediation strategies that enhance bodily experience of historic content. The approach is demonstrated over a scenario applied to an historic site that explores the mediation process through low-fidelity prototyping executed in an experimental manner.

9.1 Introduction

The work in this chapter references a theoretical framework drawn from discourses that seek to go beyond documenting the cultural heritage through predominantly textual modes of representation focused on the documentation of specific sites. This is a shift from a passive mode of production to one that is interactive and dynamic, that generates a different model of participation by visitors to merely providing access to information through predominantly didactic means. Such a shift is contextualized through the rapid growth in participative media, embodied in Web 2.0, and the heralded advent of Web 3.0, where the focus has shifted to creative production as a primary means of interaction that overshadows previous modes of interaction, such as, basic access with databases, archives, and search engines [1]. As such, meaning is increasingly expressed in relation to a person's experience. New ways of combining physical and virtual information as well as real time and historic content are required. For cultural archives, such as Heritage Housing, this provides issues that center on divergent representational strategies and the manner by which the

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creation and support of innovative access to archival content within heritage/historic sites can be deployed.

This chapter considers the value of mediation in the construction of interactive narrative(s) to enhance the experience for visitors of site-specific cultural content. It is proposed that the mediation process constructed through embodied interaction has advantages for the dissemination of historic content and knowledge construction of such. This is in line with the work of phenomenological archaeologists who have supported the construction of knowledge systems that reference embodied sensory experience. Importantly, such experience is situated, by which we mean interpretation of cultural archives becomes subjective and relational with accompanying personalization of content provided through each person's experience. One of the benefits of such a shift in relation to cultural heritage is the centrality of the body to create and engender dialogue based upon how the body represents the affective, corporeal, and sensuous dimensions of human knowledge [2, 3]. Cognitive psychology [4] and artificial intelligence [5] emphasize the phenomenon that the knowledge about the human body is well embedded in us, that cognition is a situated activity, and that embodied cognition exploits the manipulation and interaction with external entities [5, 6]. Hence, embodied interaction provides a cognitive approach to decode, what is often a static hierarchical geometry, the archival content of heritage sites. Rather the space, when considered somatically, becomes a space of bodily movement and sensory experience in which we reflect on our own subjectivity and its embodiment through that experience. Inherent in this reflection is the centrality of interaction as the construct upon which exchanges between humans and external entities are constructed.

This chapter is structured as follows: Section 9.2 considers the concept of mediation situated in physical space; Sect. 9.3 outlines mediation strategies inclusive of design guidelines; Sect. 9.4 reviews the mediation scenario as an example of the approach; and, Sect. 9.5 contributes concluding remarks and outlines future directions. From now on the term "visitor" will be referred to "participant," as the latter term conveys the active nature of components of the mediation process.

9.2 Mediation + Space

Means for studying the structure and content of mediation have been developed primarily for artificial intelligence, for instance, agents as mediators between disputing parties [7]; for social interaction, for example, in virtual and immersive environments avatars are used as mediators [8]; in social and political sciences, mediation has been extensively used for conflict resolutions; while in social networks mediation is now being utilized to facilitate an emotional response [9]. This chapter focuses upon mediation as a process that assists with the deconstruction of historical content in heritage/historic sites to enrich the participant's experience.

The notion of mediation is a simple one—that a third variable transmits the effect of one variable to another. Although this is a simple idea to grasp, the analysis of these variables and their behavior is a complex task. Mediation is considered as a knowledge-intensive process that involves information revelation and part of the mediation process is guiding the process of information revelation and how that occurs. A significant part of information revelation is *how* the mediation process "shapes" the transfer of information to people and *how* the information is interacted with through bodily reasoning. As mediation is a relational process, with technology placed as the intermediary the third variable, the process unfolds when there are computational representations that support, sense, and distribute the mediation process, as well as, communicate meaning related to engendering information revelation. The process of embodied interaction suggests that information artifacts construct meaning through their use—for instance components of visual display provide semantics when manipulated [6]. The use of information artifacts are always embedded in some context, albeit it social, physical, and/or cultural. These contextual factors require consideration as noted by Lui et al. [10]. It is anticipated that the mediation process focuses explicitly on the process and mechanisms of perception, highlighting the active and constructive nature of perception and subjective experience.

9.2.1 Development of Typologies of Mediation Strategies

When addressing mediation in an historic site it is important to remember that conceptions of space diverge considerably, informing differences between people. Understandings of basic spatial concepts are intrinsically linked to how we orientate and move in the physical world and the physical context. Such bodily reasoning references the experience of the structure of our bodily movement in space providing us with mental models of our actions in space. Tversky ([11] pp. 3–13) notes that peoples' conceptions of space vary as they depend upon how the space is perceived and what actions people contribute to the space. Tversky divides space up into a number of "mental spaces" based on distance from the center of the human body. There is the "space of the body," "space around the body," the "space of navigation," and the "space of graphics." As well there are "multiple spaces." For this work we consider: (1) "the space around the body;" a space that relates to the space within the reach of eye or hand conceived in three dimensions; (2) "the space of navigation" a space that is too large to be taken in by one view point and can be compared with a process akin to "cognitive collage;" and (3) "the space of graphics." We consider the space of graphics is synonymous with information visualization spaces as the space of graphics is considered as external spaces created to represent spatial and other information.

9.2.1.1 A Mediation Framework

Interaction is always situated in some context that encapsulates some problem- or goal-directed activity. Thus, it is important that these situations as noted in Sect. 9.1

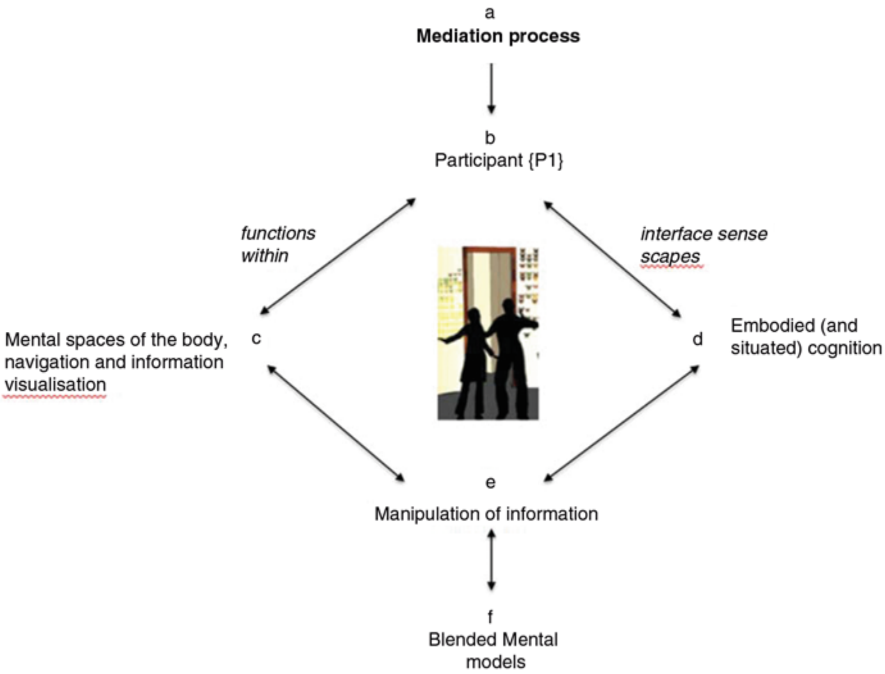

Fig. 9.1 The mediation framework

are acknowledged, as by incorporating direct support for them can improve the ability of interactive interfaces to help human's reason. The importance of manipulation of information, the experience of which provides the context that the inquiry functions within, links manipulation to insights [12]. By incorporating acts of conceptual manipulation, the mediation process assists with information revelation. In the context of historic and heritage sites, the bringing together of background contexts and current observations to enrich the experience of visitors to such sites can be facilitated by such a process.

Keeping this in mind we consider the mediation process. In Fig. 9.1, participant 1, [P1], at (b), engages with the mediation process, indicated at (a). The primary spatial perceptions of P1 can consist of a number of mental spaces at any one time, indicated at (c). As the mediation unfolds, P1 may be interacting with one mental space, or, may at any one time be engaged with the perception of multiple mental spaces. Within these spaces, P1 actively engages with the goal-directed activity through embodied cognition (of which situated cognition is considered a component [5]) at (d). This process involves P1 in the subjective and relational experience of information manipulation (e) that delivers information revelation. Through this process gained insights build blended mental models at PM^t, where PM^t denotes a participant's mental model at time t. (f). Each PM^t denotes the person's blended mental model and at specific times in the mediation. These blended models are a mixture derived from the mental models of space and from embodied interaction experienced through sense-scapes. Over time a sequence of conceptual blending may be involved in the mediation experience. The term provides semantics of participants building their knowledge of information on various views and the role of mediation assisting with which views are built and how such models guide the behavior of the participants. This knowledge is internal to the person and subjective.

Finally, mediation is considered as a delayering process, a way of deriving archaeological modeling, and a method to unpack embeddedness. Fundamentally, delayering deconstructs complexity. The process of delayering has been applied to urban design [13] as a 3D operation of uncovering cultural production in the various strata of sites as materiality constructed over time. Various techniques can be employed to unpack embeddedness noted by [13]. Rescaling techniques can be introduced to create transitions between layers of information. Another strategy is to reposition points of view both through different modes of representation.

9.3 Mediation Strategies to Enhance Interaction

It is important to provide the right tools and methods for the design and deployment of the mediation process. Information visualization needs to be embedded in a framework that provides leverage, through reasoning, to the human knowledge construction process. Yet creating well-constructed and consistent visual representations remains a challenge (see Chap. 3 in [14] for some of the issues facing designers of visual representations). The following strategies are considered supportive to the mediation process:

- *Sense-scapes*: First person methodologies, that is, to learn through the experience of the self, engender concepts that value attention to the senses. Dealing with the body, through its materiality and senses, provides meaning to experience, and generates the notion of archival content being explored through sense making. The embodied subject with its multiple concomitant ways of sensing, feeling, knowing, performing, and experiencing offer dynamic routes to different perceptions of the human relation to the material. Narrative agency supports personalized kinaesthetic and haptic experience.
- *Soft spaces*: Space is perceived as performative and experiential capable of constructing and mediating dialogue. Modeling space as performative and mutable supports engagement with space as material presence, represented as flows and interactions. Space is no longer only described through its Euclidian geometry.
- *Social collaboration*: The sharing of experience enables visitors to explore narrative content through implicit and/or explicit collaborative encounters, such as, physical proximity. Semantics can be derived from social and bodily interaction.
- *Feedback loops*: Capacity for interaction is increased by the perception of reciprocal effects. Information that generates iterative interaction can assist participants' mental models to enhance information revelation.

- *Unbiased mediation*: The mediation process has not been deployed with bias toward outcomes. An open-ended environment is preferable, that is, a space where experience and context are critical to goal-directed activity.

The benefit of such strategies is that from mediation typologies, mediation "types" can be constructed by which classification of large amounts of information can be organized.

9.3.1 Design Guidelines for Mediation of Cultural Heritage

In this section, we consider how information about the dynamics of the mediation process can be presented. For this purpose, this chapter takes in account ambient considerations of display in the design stage in order to comply with the requirements of pervasiveness, cognitive manipulation of information, and embodied interaction. Two design principles are included, namely, complexity and expandability, in the context of displays operating in spatial contexts. This chapter considers another group of additional design principles, which address the design of ambient aspects of delivery as it is considered that ambience is inherent in mediation. These are, information capacity, attention-attracting capacity, expressive power, and aesthetics (adapted from [15]):

- *Complexity*: This design principle aims at low representational complexity, so that through the visual representation the development and unfolding of interactions can be monitored in real time.
- *Expandability*: This design principle aims at visualization that can accommodate change in the representation of interaction information.

The ambient aspects of delivery of mediation include the following principles (adapted from [16]):

- *Information capacity*: This design principle relates to the trade-off between the size of the visual elements, the space for the display of the elements, and the time for presenting an information segment.
- *Attention-attracting capacity*: This design principle relates to the ability of visualization and respective media to demonstrate critical patterns in interaction, capable of rising person's alert and the need for immediate consideration during the decision making.
- *Expressive power*: This design principle relates to the semiotics [17] of the discrete elements that constitute the visualization and their combinations that constitute the mediation, i.e., how the information about cultural heritage is encoded into patterns, pictures, words, or sounds that eventually convey the information about the site. Such visual semiotics relates directly to how condensed is the information delivered by the visualization. The range is from direct presentations of low-level data for monitoring participant interaction to metaphorical reasoning based on

Fig. 9.2 **a** Elizabeth Bay House. **b** Vaucluse House

bodily knowledge and other graphical displays of complex and latent information structures (see [18] for a survey of diverse displays) that convey condensed information.

- *Aesthetics*: This design principle concerns to what extent a graphical display is considered as visually pleasing. Extraction and sense making of information about interactions relate to the ability to gain insights, hence, this design principle is closely connected with the principles of information capacity and attention-attracting capacity.

The quest for implementing these principles acts as the constraint factor in the design and deployment of the mediation process. In Sect. 9.4, these principles are referenced to discuss a mediation scenario in historic housing.

9.4 A Mediation Scenario

In line with site-specific mediation into heritage/historic housing mediation is through interaction with a previously existing or present space that can reflect traces of habituation, layers of materiality, topologies of structures, landscapes, atmospherics, and/or artifacts. A building is reconceived as a multidimensional information system open to interpretation from different views dependent upon what and how information is revealed. Participant's mental models are situated within a 3D space that informs the process of embodied inquiry and interaction that shape each person's narrative. Each perceived view frames the duration and provides a set of information, but only one in a field of relations within the whole.

The mediation scenario reviewed here is taken from an interdisciplinary lab run for university design students. The students were required to respond to the brief of framing mediation to benefit the experience of visitors. Two sites were selected, Elizabeth Bay House and Vaucluse House, shown in Fig. 9.2. Both sites are under the governance of the Historic Housing Trust (HHT) of NSW, Australia, who actively contributed to the dialogue in their role as an industry partner. HHT is a statutory authority within Communities NSW. It is "one of the largest state museums in Australia and is entrusted with the care of key historic buildings and sites in New

South Wales."[1] HHT was interested in engaging with archival material through bodily experience. A focus of the work was to heighten the experience of the visitors to historic housing through low-budget solutions that still engender creative production as a primary means of interaction. Further discussion of the project "Vestige" follows in Sect. 9.4.1.

9.4.1 Vestige: An Interpretation of "Mediation"

The project "Vestige" looked to narratives constructed around past inhabitants. It was recognized that the archival content of the historic houses commonly reflect the presence of the inhabitants through various artifacts, such as, clothing, furniture, natural collections, books, and so on, yet the lived experience of significant inhabitants is noticeably absent. Vestige, sought to explore the narrative of past inhabitants through a metaphorical framework.

The application of a metaphoric framework provides the three variables (mentioned in Sect. 9.2) in which the mediation process, the third variable, transmits the effect of the variable, the source; the (selected) historic content of the site, to the target; the participant. The notion of conceptual metaphor [19] considers a conceptual metaphor is a cognitive mechanism that derives abstract thinking from the way we function in the everyday physical world. Lakoff and Nunez [19] argue that such conceptual systems align with our body, that the conceptual system is embodied and shaped by our physical processes, and that by "being in the world." The revelation and retrieval of information deployed through various perceptual interactions reflect metaphorically the form, semantics, and function of the content of the mediation.

The metaphor employed in vestige was mapped from the letters from Frances Macleay (the daughter of John Macleay the owner of Elizabeth Bay House) to her brother William still based in England. The content pertained to her difficulty with her new home in New South Wales, as well as, her brother's lack of sincerity and concern for the family's new situation. In response to this dialogue between sister and brother, the mediation explores the concept of distortion represented through the physical unit of "echo" that visualizes and resonates to notions of unrequited dialogue. The mediation was set in the cellars of Elizabeth Bay House, a space that was enclosed, uninhabited, and dim. The materiality of the space was beneficial for the exploration of the core form, echo.

The design, a view of which is illustrated in Fig. 9.3, aimed at exploiting the interplay between contextual information as a foundation for visitors to explore the narrative of past inhabitants of Elizabeth Bay House. The contextual information is derived from how the visitor(s) interact with the various bodies of information and what the information revelation produces.

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[1] http://www.hht.net.au/about.

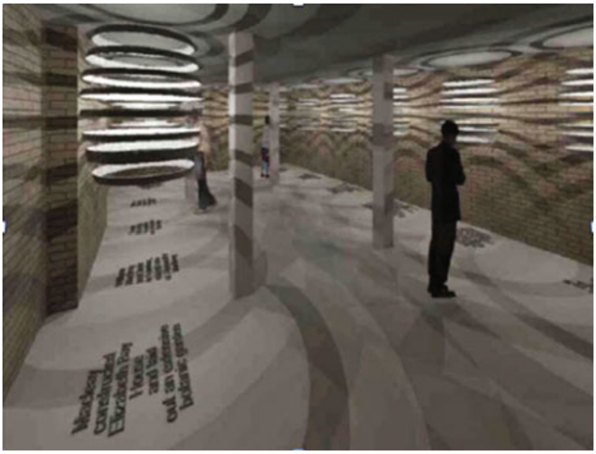

Fig. 9.3 Vestige: mediation through a metaphoric framework

9.4.2 Applying Design Guidelines

For a mediation to take place certain conditions are required: (1) The process of information revelation needs to communicate accessible semantics to participants; and (2) the mapping through metaphoric reasoning supports the attainment of (1). The implementation of design guidelines (discussed in Sect. 9.3.1) is advantageous to both these conditions. In Tables 9.1 and 9.2, the application of design guidelines to "Vestige" is summarized.

Table 9.1 Mediation strategies deployed in vestige

Mediation strategy	Deployed	Method
Sense-scapes	Yes	Experience of archival content by the participant is supported through sense making from first person methodologies
Soft spaces	Yes	Semi-immersive enhanced through choice of dim enclosed space in Elizabeth Bay House (the cellars) and controlled lighting Continuous auditory and visual input compounds sensory scape
Feedback loops	Yes	Deployed in the mediation—visual and auditory patterns predominate
Unbiased mediation	Yes	Vestige is nondidactic and open ended in its sense making supportive of personalization of content
Social collaboration	No	Not (explicitly) supported in vestige

Table 9.2 Ambient capacity as measured by the design guidelines

Design guidelines	Mediation capacity
Low representational complexity	Complexity is contained through limited and repeated motifs text (written/spoken), reflective artifacts, and atmospherics continuity
Expandability	Not explicitly supported
Information capacity	Spatial boundaries delineate the size of visual elements. Duration is layered through the feedback loops of information
Attention-attracting capacity	Critical patterns in (implicit) interaction are demonstrated over different perceptual modalities
Expressive power	Vestige contributes semantics mapped through various modalities—visual/auditory perceptions are supported while kinesthetic associations are embedded through movement patterns
Aesthetics	Consistent aesthetics is achieved through limiting the set of visual representations. This limitation can enhance information capacity and attention-attracting capacity through the use of repetition

9.5 Conclusions

This chapter has presented the initial work on building a mediation framework engaged with a knowledge-intensive process that is experienced through embodied interaction. The framework was applied into heritage/historic housing to facilitate the deconstruction of archival content. The potential of mediation, as a process to augment the experience of cultural heritage, bears further investigation. This is timely given the emerging area of research to source interface metaphors that provide consistency for people in differing situations and environments. As noted ([12] p. 287), new tools that use familiar metaphors can be more easily adopted. Future directions will entail combining earlier work developed in relation to kinesthetic and/or multimodal interaction and semantic visualization [20] with the mediation framework. The bodily basis of meaning embedded in the mediation process provides impetus for research into interaction analytics as within a person's experience in the world interaction is always embedded. The mediation framework builds on this premise.

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Chapter 10
Memory, Difference, and Information: Generative Architectures Latent to Material and Perceptual Plasticity

Andrew P. Lucia, Jenny E. Sabin and Peter Lloyd Jones

Abstract Stemming from ongoing research between architecture and the biological sciences, this chapter explores dynamic organization of matter in both a multidimensional microscopic scale human cellular system and a human-scaled perceptual environment from an information theoretical framework. This research examines latent virtual diagrams residing within real dynamic material systems whose generative potential emerges from *difference*, history, and ultimately the *structural information* content of spatiotemporal data arrays. Through the development of a design tool, we offer a method for visualizing the underlying formal structures of these data arrays. Currently within LabStudio, a hybrid research and design network, this method is being developed and deployed in the biomedical sciences as a means of analyzing dynamic biological data sets for purposes of determining unique spatiotemporal behavioral signatures in different cell types within unique cellular environments. From a design standpoint, a parallel aim of this research deploys these same *information* theoretical principles as an analytic technique, specifically in areas of generative design, materiality, and affect as they pertain to organizations of data arrays generated from objects within their environments with and without perceiving subjects, or what we call relative observers.

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10.1 Introduction to LabStudio

LabStudio, co-founded by Jenny E. Sabin and Peter Lloyd Jones in 2006, is a hybrid research and design network with active members based at Cornell University, the University of Pennsylvania, and Stanford University. Within LabStudio, architects, cell biologists, mathematicians, and materials scientists are actively collaborating to develop, analyze, and abstract dynamic biological systems through the generation and design of new tools. These new approaches for modeling complexity and visualizing large datasets are subsequently applied to both architectural and biomedical research and design. The real and virtual world that LabStudio occupies has already offered radical new insights into generative and ecological design within architecture, and it is providing new ways of seeing and measuring how dynamic living systems are formed and operate during development and in disease. Overall, the mission of LabStudio is to produce new modes of thinking, working, and creating in design and biomedicine through the modeling of dynamic, multidimensional systems with experiments in biology, applied mathematics, fabrication, and material construction.

As stated, one intent of LabStudio is to derive new approaches for the analysis of large biological datasets that are unapproachable using existing means. Employing both intuition and logic as guiding devices, computational approaches are developed to filter and output datasets into comprehendible forms that can be understood using multiple senses including touch, sight, and sound. For example, in the biological portions of the project outlined in this chapter, we are creating individual signatures that describe behavioral motility patterns inherent to unique cell cultures. In the studies presented, recognizable qualitative and quantitative differences in cell movement were noted between two experimental conditions being examined. This project has already resulted in a more complex understanding of a dynamic cellular structure that negotiates and integrates changes in external forces with internal cellular mechanics.

Current trajectories in the *motility* project examine notions of movement abstractly, and are concerned not only with movement itself but also in the translation of resulting data into alternative media in order to reveal previously unseen underlying structure. Already, this dynamic data has been translated into visual and sonic mediums in order to discern underlying pattern and structure not inherent within traditional means of visualization. Presented herein, parallel modes of investigation examine data in terms of its underlying *information* content and structure, for the ordering of systems.[1] Using these approaches, initial data sets are understood abstractly in a scale-free environment allowing for the analysis of data generated by any dynamic system, be it biological, or understood spatially at the human scale. Amongst several trajectories explored in LabStudio, here we present methods that are rooted in a field-based approach to data rather than an object-based approach. These studies explore the organization of light-based temporal artifacts inherent to data arrays generated within dynamic organizations of matter. Seen here, we have

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[1] For the purposes of this text, the term "information" should be taken in the sense of information and communication theory, based on the pioneering 1948 work of Claude Shannon and Warren Weaver [1].

applied this method to systems such as our own immediate perceptual environments, as well as to dynamic data sets concerned with the plasticity of populations of cellular morphologies as they interact in specific microenvironments.

10.2 Introduction

The work presented herein stems from an inquiry rooted in architecture and design. The questions posed are raised in relation to how we conceive of and construct the world about ourselves. Furthermore, the research and design described was conducted through a systemic approach to material systems of which we are a part, thereby allowing its application to extend to other pertinent areas of inquiry. The biological sciences are explored here, through the examination of cellular motility in relation to its surrounding architecture or extracellular matrix environment.

Education, technology, and traditions of the trade, frequently predispose architects and designers to approach the world via descriptive and projective geometric principles. There are, however, alternate formal mathematical abstractions and representations to investigate under the topics of materiality and affect. In setting aside these geometric predispositions, how else might we approach these issues from a design standpoint? We ask:

1. Can a dynamic material system's characteristics be understood in terms of spatiotemporal order, *difference,* and *information* rather than through descriptive or projective geometric terms?
2. To what extent do humans identify with an object's curvature or rates of change (or environmental curvatures), over that object's morphological symbolism? In this regard, what are the underlying formal structural diagrams residing beneath actual morphologies or perceptions of morphologies? How could these diagrams be represented and characterized in architectural design?

Taken as an architectural design inquiry, this investigation is at the root of questions pertaining to how we identify with material aggregations (i.e. their relationship to us, and our perception and sensations of them within our environments). While aspects of the initial discussion, which centers on human perception, could revolve around several human sensorial systems, we direct our focus to the visual realm, given the nature of light-based data analyzed for our case studies; the *information* that is said to arise from these examples is generated from the advent of *difference* in light intensities within multidimensional dynamic data arrays.

This chapter explores the roles of *difference*, history, and framing upon the *information* content inherent in data arrays generated within dynamic micro cellular and macro material systems; here, *information* is defined as a function of temporal *difference* within a particular signal, or set of signals, within a specific spatial neighborhood. Considered from an *information* theoretical standpoint, this work ultimately underscores a fundamental shift away from an explanation of environments in descriptive and projective geometric terms to one based on spatiotemporal order and disorder, and ultimately the *structural information* content. Here, environmental perception is a generative function of the variant or invariant elements of a given data set which gives rise to the perception of material plasticity. Simply put, if one is to perceive, there must be *information* generated between an observer and the surrounding environment. Furthermore, this current research offers a new method for characterizing the underlying formal structure of these multidimensional data arrays and the objects and material environments of which they are borne, be it through analyzing the pure *difference* or *information* generated within.

This way of "seeing" *difference* suggests a fundamental shift in the way we relate to objects within our spatial environments. The detection or study of objects is not undertaken in this research. Rather, our work posits that all objects or entities arising out of dynamic processes generate a continuum of constantly fluctuating *potential information* arrays. These *information* arrays, or *events of interest,* are field-based and favored over object-based analyses of systems. For example, when moving through space, the term "parallax" is frequently used to describe the greater relative displacement of objects in the foreground as opposed to those in the background. This parallax depends upon a geometric understanding of the world about us. However, the work presented herein does not presuppose a Cartesian three-dimensional world. In other words, we do not constrain the "geometry" of objects or environments by limiting them through a description of their breadth, width, and depth. Rather, we focus upon the *difference* between and within the objects and material in a given environment, which gives rise to multidimensional observational data about that specific environment. These data would have greater or lesser associated rates of change within particular spatially structured neighborhoods. Thus, as it would still hold true, that the matter nearer to a person in motion would generate a *differenced* data array with a corresponding rate of change higher than matter farther away; this suggests the *information* generated between an observer and the environment is not a geometric problem, but rather is one of *structural information* which is therefore capable of being understood solely in terms of spatiotemporal order and disorder.

Of primary importance to the research presented here is the *difference* arising within dynamic datasets. While the merits of examining pure *difference* within data are worthy in and of themselves, we have extended this inquiry to probabilities of *difference* in the form of *information* calculations for two reasons: (1) By involving the probability of change (*information*) within a dataset, we are able to weight the likelihood of temporal events for visualization and classification purposes, as is the case in the biological data presented here, and (2) Psychologists and neuroscientists have demonstrated that human perception arises ultimately through the generation of *information,* not merely the *difference*, inherent in perceptual datasets. As such, designers of environments and perceptual phenomena might take into consideration the instantaneous causal relationships inherent to the generation of affects, and furthermore examine the potential loci of their productions within environments and material systems.[2]

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[2] For a broad discussion surrounding theories present in contemporary visual perceptual theory, please see *Theories of Visual Perception, Third Edition*, by Ian E. Gordon [2].

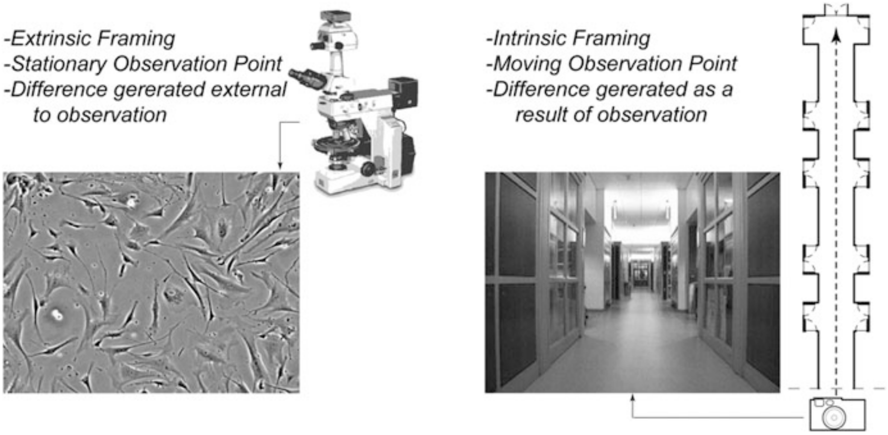

Fig. 10.1 Extrinsic Framing (Case study 1, *left*) and Intrinsic Framing (Case study 2, *right*) for data acquisition (Cellular images courtesy of Peter Lloyd Jones Lab, University of Pennsylvania). Copyright © 2011, IEEE

While the chapter initially centers around two distinct visually-based data mapping case studies relating to: (1) Behavioral signatures of biological systems, and (2) The human perceptions of moving through space; our extended studies broach more fundamental questions about the loci of *information* production within systems and our relationship to them. We ask, "What are the implications of *information* generated: (1) Extrinsically to a system [produced internally within a system and observed autonomously], or (2) Intrinsically within a system?" Here, the ramifications of dynamic material interactions upon a system's *information* content are considered from the standpoint of digital mechanisms, though two conceptually different framing references: (1) From a scientifically "objective" standpoint of cellular behavior within a specific microenvironment under a microscope, and (2) A camera tracked through a hallway, essentially mimicking/recording how a human being moves through a specific space or environment (Fig. 10.1).

Following our studies of the acquisition of biological and perceptual data generated within these dynamic systems in Sect. 10.4 and 10.5, we introduce a method for visualizing the distribution of spatial intensities inherent to both the pure *difference* and *information* generated from these dynamic datasets and others (i.e. images of paintings and an autonomous object) for comparison and proof of principle in Sect. 10.6 and 10.7. By further examining neighborhoods surrounding discreet locations within a given dataset, spatial intensities may be extracted from their metric neighborhoods and remapped to a vector space devoid of their "real" spatial distributions/representations. First, we present this method in context of the perceptual datasets from our initial case studies (Sect. 10.6), and further extend these concepts to autonomous objects and environments, thereby establishing intensity distribution signatures based upon the rates of curvature intrinsic to the objects/environments in question (Sect. 10.7). These diagrams may then be further characterized in terms of their organization or disorganization.

10.3 Background

10.3.1 Information Theory

Within our transdisciplinary research, which spans biological science and architectural design, *information* is taken as a measure of nonlinguistic content or the communicative artifact of dynamic material systems. In these terms, *information* is the medium of communicative exchange for relative observing bodies, be they organic or inorganic. These bodies are said to be relative in that each distinct observer possesses a unique memory or history that has an impact on the instantaneous perception about its environment. Often termed "*information entropy*," this approach to the measurement of *information* quantifies the likeliness of events within a signal. More specifically, this measurement is a function of the probability of those unique events. As stated by neuroscientist, Kenneth Norwich:

> *Information theory* provides a way of quantifying the initial uncertainty and, therefore, quantifying the information received. The uncertainty preceding the occurrence of an event is usually termed entropy, so that the quantity of information received is equal to the reduction in *entropy*. [3]

Here, the more unlikely an event is to occur, the more information is said to be associated with that event's actual occurrence.

10.3.2 Spatial Perception, Art, and Information

As proposed by Norwich, amongst others, human perception ultimately arises through the production of *information,* not merely the *difference*, inherent in perceptual datasets. Given that architects and designers are interested in the roles of materiality in the production of perceptual phenomena, it is increasingly important to revisit this discussion in the context of contemporary advancements in digital architectural design and computation, permitting us to consider the possibility and importance of the roles of *information* and *difference* upon the perception of environments and material systems. The following section provides an introductory overview of a sampling of the nuanced ideas surrounding *information's* role in perception and its usefulness in artistic debate (for a more complete discussion, readers are strongly encouraged to see the sources cited below). Of course, *information's* role in these arenas is not new nor are the references cited herein. Therefore, this research should be viewed as a revision of these ideas, which certainly deserves consideration, given advances in computational design and an evolving architectural discourse which questions the role of symbolic metaphor in favor of one that has the capacity to position issues of memory and material phenomena in a nonrhetorical manner.

Additionally, Norwich suggests, if one is to perceive, *information* must be present with respect to an observer. This sounds simple enough, but a *signal* and *information* should not be confused, for uncertainty is a necessary requisite for there to be *information* present within a signal. Put another way, there must be *difference* within a signal in order for it to contain *information*. From an entropy-based approach to perception, Norwich states "when our uncertainty vanishes. . . so do our perceptions" [4]. This ultimately suggests that even in the presence of a signal, the perception of the data within that signal is only available through differentiation, either in the signal itself or in the relation of an observer to that signal.

Compared to Norwich's entropy-based theory of perception, which is rooted in uncertainty and *difference* within perceptual channels, psychologist James J. Gibson developed a novel theory of perception based upon *ambient information* arrays, specifically visual arrays of disparity, which must have structure in order to be perceived. Ultimately it is both Gibson's and Norwich's insistence upon *difference* as a requisite factor of *information* which merits discussion within this chapter. As Gibson states:

> Only insofar as ambient light has *structure* does it specify the environment. I mean by this that the light at the point of observation has to be different in different directions (or there have to be *differences* in different directions) in order for it to contain any information. The differences are principally differences of intensity. [5]

In order to be perceived, these arrays must be heterogeneous, or contain *difference*. Specifically, Gibson focuses on what aspects of these *information* arrays remain variant or invariant under transformation with respect to an observer [6]. It should be noted, however, that Gibson strongly distinguishes his idea of "information" from its use in *information theory*. Gibson's *Ecological Approach to Visual Perception* posits an understanding whereby the world is "specified" by *information*, and opposed an approach to *information* as it existed in signal processing and communication theory, because he believed "the environment does not communicate with the observers who inhabit it. . . The concept of stimuli as signals to be interpreted implies some such nonsense as a world-soul trying to get through to us" [7]. More importantly, Gibson's "direct perception " of the external environment favors a view that is not mediated through higher order man-made constructs, such as symbols. If we set aside the notion of a transcendental communicating world, however, there are complementary ideas put forth by Norwich and Gibson which suggests that perception can be approached as a function of *differenced* arrays (signals) of data present to our person.

Last but not least, our research also addresses another issue surrounding the artistic merits of *information theory* questioned by psychologist Rudolf Arnheim. Also taking issue with signal processing and communication theory in the essay *Entropy and Art: an Essay on Order and Disorder*, Arnheim confronted the field of *information theory* for its ambivalence toward spatial structure [8]. Our research, however, posits that such concern for metric spatial structure can be accounted for if one takes into consideration (and holds true) the spatial aspects of data within an array of *potential information*. Arnheim may be correct in originally considering this neglect from a communication theoretic approach, but only because he critiqued an approach which utilizes single sources of data transfer (i.e. singular data arrays through communication systems), which do not inherently possess multidimensional spatial attributes. Essentially, Arnheim and Gibson failed to, or chose not to, take into consideration the actual possibility of multiple, discrete, spatially structured data arrays from an *information theoretical* standpoint. Taken as our starting point, we have generated and developed unique digital design tools for the analysis of spatiotemporal *information* arrays comprised of discrete signals that possess a unique spatial structure.

10.4 Methods for Establishing *Difference* and the Generation of *Information*

10.4.1 Difference

Dynamic processes are governed and marked by *difference*, i.e. fluxes of matter and energy which are the essential driving mechanisms governing the emergence of events within physical systems. As an outcome or byproduct of emergent events, *potential information* is also generated as an artifact of the dynamic processes in consideration. These emergent events create potential perceptual stimuli possessing an uncertainty and which we suggest are comparable to Gibson's *ambient information arrays*. Norwich has "termed an absolute entropy or an uncertainty as the *potential* of the perceiving system to acquire information. *Potential information is transformed gradually into information as the perceptual act proceeds*" [9]. At its inception, this *information* is generated through *difference* within dynamic spatiotemporal data arrays. Within the case studies presented here, *difference* in pixel brightness (intensity) is considered to be generated in two ways: (1) External to an observing mechanism (video microscopy), and (2) As a function of an interacting observing mechanism and its environment (i.e. video camera moving through a hallway).

Case study 1 is an account of observation by a stationary mechanism (video microscopy) examining distinct dynamic extracellular environments (Fig. 10.1). *Difference* in this system's associated data array is generated solely within the dynamic cellular environment, and captured externally by an observing mechanism (video camera); *difference* is determined between discrete pixel intensities across all time states within a video (Fig. 10.2).

However, when one turns the data-capturing mechanism away from a scientifically "objective" scenario to one in which an observer operates, a new set of issues arise as to the "objectivity" or "subjectivity" of the data being captured. Our second case study relies on the relative *difference* generated between a nonstationary observer and the environment within which the observer moves; here, *difference* is neither solely a product of external or internal references but exists simultaneously between the two. In this example, the observing mechanism (video camera) is tracked through a hallway in order to generate *difference* in intensities for pixel arrays between time frames (Figs. 10.1 and 10.3).

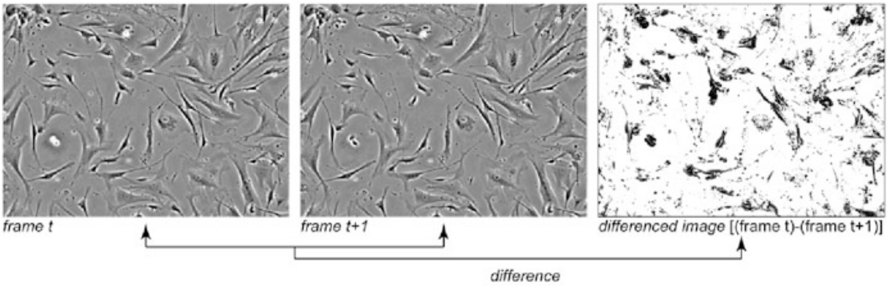

Fig. 10.2 Case study 2-Extrinsic framing. Difference in pixel contrast (*right*) between consecutive cell images (*left* and *middle*) under microscope (captured with video microscopy). (Cellular images courtesy of Peter Lloyd Jones Lab, University of Pennsylvania). Copyright © 2011, IEEE

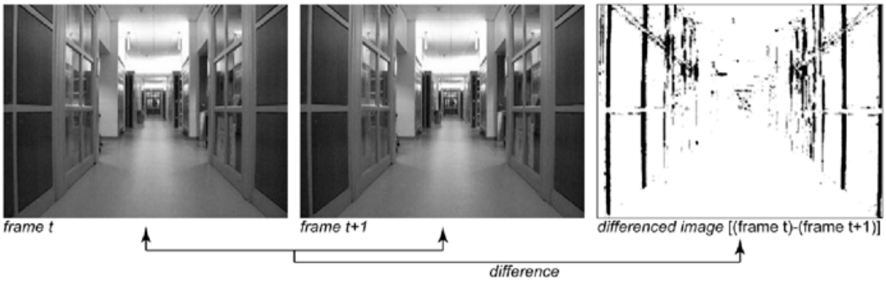

Fig. 10.3 Case study 2-Intrinsic framing. Difference in pixel contrast (*right*) between consecutive images (*left* and *middle*) while moving through hallway (captured with video camera). Copyright © 2011, IEEE

10.4.2 History/Memory

Thus far, *difference* has been understood in terms of change within a system and an observer to/within that system. As an example, we have implicated this change to arise out of: (1) Plastic morphologies between a population of dynamic cells within a physically associated and extremely plastic extracellular environment at a micro-scale, and (2) From the acquisition of data about the surface variation within a hallway by means of movement through that environment at a macro-scale. Both approaches rely upon a particular framing (extrinsic or intrinsic) for *differences* to arise.

Until now, only *differences* within each system have been considered. The production of *information*, however, relies upon the history or memory of change that is internal to the systems in question. As stated above, the *information* of a system is reliant upon the uncertainty or likelihood of an event's occurrence. In our studies, we consider an event-space to be each discrete pixel within the spatial array of the viewing frame. To consider that an event has occurred, we merely ask "Has this pixel changed?" To determine a probability of occurrence, we could have chosen a fixed

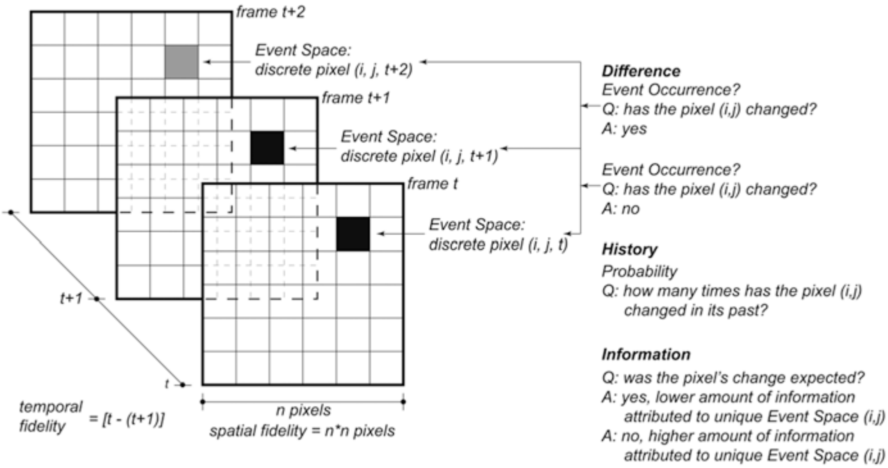

Fig. 10.4 Schematic diagram of pixel event space, difference, history, and information. Copyright © 2011, IEEE

a priori probability of change for each pixel. However, we consider our systems to be naïve, having no "knowledge" of their expected behaviors. As such, they require their own history to be queried in order to determine the probabilities of events within (Fig. 10.4).

The outcomes of these studies are represented in the form of *information* maps that do not consider short term memory and adaptation; rather they take into consideration total histories of the systems. As such, for these studies we disregard the ramifications of short-term, long-term, or floating durations of probability in the particular examples presented here.

10.5 Case Studies

10.5.1 A Note on Data Acquisition

The mappings presented in Case studies 1 and 2 represent the cumulative *information* accrued over all time states. In these mappings pixel intensities represent the moments of what we consider the "common, moderate and rare-events" within the respective systems (Figs. 10.5 and 10.7). Events occur only within each discrete pixel across a temporal array with spatial structures and coordinate positions remaining constant. Though only discrete pixels are taken into consideration temporally, the ordinal spatial structure of the pixels is considered to be absolute and unalterable, thus taking into consideration the likelihood of events within discrete signals (individual pixel states through time) and spatial structure of the overall pixel arrays on each discrete picture frame. Given this pixel-based approach, the fidelity of spatial measurement

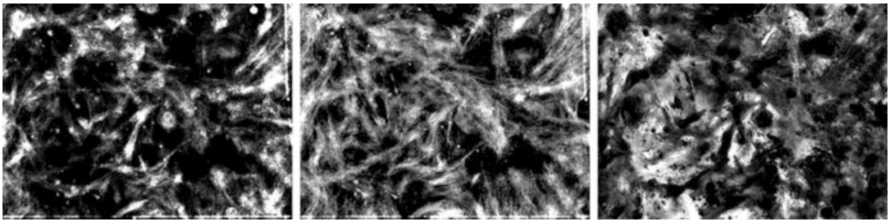

Fig. 10.5 Cumulative summation values for information maps derived from the same video that demonstrate weighted "standard" [(p)log2(p)] (*left*), "moderate" [log2(p)] (*middle*), and "rare" [(1/p)log2(p)] (*right*) event occurrence information for smooth muscle cells in the same non-native environment. Copyright © 2011, IEEE

of any array in question will be governed by the resolution of the associated pixel array, while temporal fidelity is taken to be the duration between each captured frame (Fig. 10.4).

10.5.2 Case Study I: Information Mapping of Biological Behaviors

We originally developed Case study 1 as a way of detecting and measuring subtle, yet biologically important, differences as to how identical human cell types behave within different external environments, be it a petri-dish or an artificially generated, self-assembling, extracellular protein-based network of one type or another. A major goal of this biological research was to detect distinct spatiotemporal behavioral signatures between cell types or their environments. These signatures will ultimately be used to produce noninvasive tools designed to diagnose, prognosticate, and to determine responses to new and existing therapeutics on a patient-to-patient basis. Current means of capturing and understanding differences in cell behavior involves classifying individual cells as discrete objects with each possessing a distinct boundary. These methods of object detection, however, have inherent philosophical, logical, and technical limitations. Therefore, in order to derive cell behavioral signatures, we do not rely upon object detection, but rather employ a technique which distinguishes regions of difference between two consecutive images. This technique, known as "image difference analysis," relies upon the recognition of abstract change over an entire data field, regardless of the objects contained within (Fig. 10.4).

Next, the *information* content is measured by calculating the probability of *difference* events across a data array through time. In this case, the primary parameter is contrast variation in pixel brightness values between temporally consecutive images of human vascular smooth muscle cells within different microenvironments over time (Figs. 10.4, 10.5, 10.6, and 10.7).

Consequently, upon the advent of change within a pixel array between two time points, the spatiotemporal sequence of events (i.e. pixel brightness change)

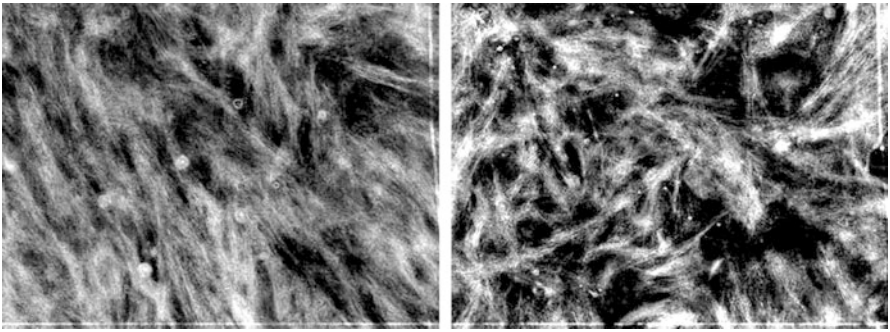

Fig. 10.6 "Moderate" information maps for smooth muscle cells in two unique environments, native (*left*) and non-native (*right*). Copyright © 2011, IEEE

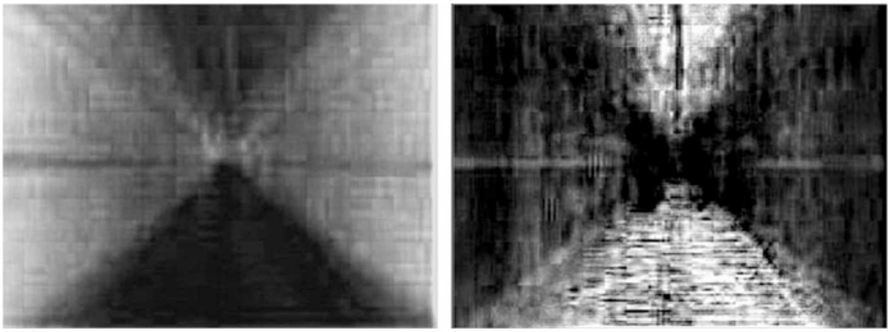

Fig. 10.7 Cumulative summation values for information maps derived from a video as a camera is tracked down a corridor that demonstrate weighted "moderate" [log2(p)] (*left*) and "rare" [(1/p)log2(p)] (*right*) event information for an observer traversing a hallway. Copyright © 2011, IEEE

is catalogued for further analysis. Already, as a measure of total change through time, our preliminary studies have succeeded in providing a means to distinguish statistically significant differences in smooth muscle cell motility within the different interacting extracellular microenvironments. Similarly, the *information* mappings of these same studies have further revealed distinct spatiotemporal patterns of event probabilities arising from these different and physiologically relevant microenvironments (Fig. 10.6).

10.5.3 Case Study II: Information Mapping and Spatial Perception

Using the same techniques and tools outlined in Case study 1, the Case study 2 begins to speculate upon a *difference* based approach to environmental sensorial data acquisition, whereby *difference* is generated not solely as a function of objects and environments external to an observer but rather as a function of the intrinsic *difference* between an observer and their environment.

Presented as end-state total *information* mappings, the visualizations presented in Fig. 10.7 do not mark a 1:1 correspondence between their production and our actual perception of the selected environments. Nonetheless, these mappings reveal insights to those data (*potential information*) present in our environments that are capable of giving rise to perceptions and sensations about that environment. Such *information* maps and our comprehension of the surroundings in which we exist and interact are ultimately generated by the same concepts of *difference* and history/memory. This dependence also suggests uniqueness to an observer's understanding of a system (of which they are a part) based upon their memory of and history within that system. In other words, *information* generated from two distinct observers traversing an identical environment will bear similar, though different information signatures because the generation of *information* is linked to the probability of events that have occurred in the history of a system.

10.6 Method for Developing Gradient Intensity Distribution Signatures of Perceptual Data

10.6.1 Overview

So far, we have considered a basis for establishing the *difference* and ultimately the generation of *information* inherent within dynamic multi-dimensional data arrays. How would/could one further visualize the underlying formal structures of these arrays removed from their original metric neighborhoods or "real" representations? We posit that production of such a diagram would enable designers to study the affectual attributes associated with a particular aggregation of matter (i.e. environment or object) devoid of the burden associated with their actual appearances, resemblances, or symbolic legacies.

The qualities of interest inherent in these *information* mappings do contain an overall ordered structure, namely in the form of adjacent intensities, or gradients. Given a large enough field of these adjacencies, a macro pattern begins to emerge. At the time that Arnheim presented his critique on *information theory* and perception, the ability to take these macro patterns and structures into consideration was absent or lacking. By using a rigorous local and global approach to the data acquisition and *information* calculations, however, we have adequately addressed Arnheim's critiques, which were likely limited due to technological constraints during his time [10]. Given this, a method for the extraction of the structural qualities from their metric space of representation is presented—a transform that allows better understanding of the relational qualities underlying the formal diagrams of these data arrays.

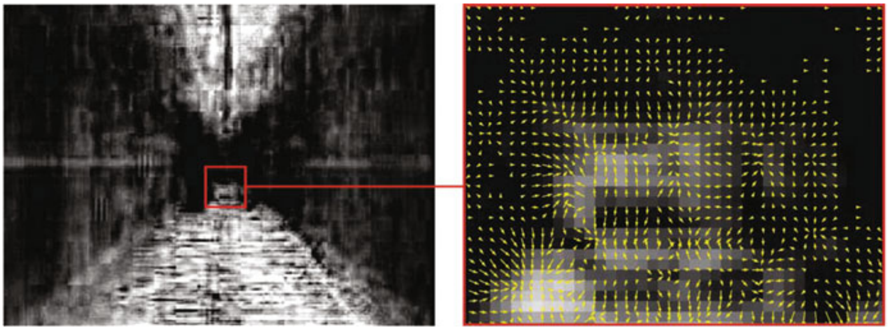

Fig. 10.8 Information content displayed as an array of pixel *brightness* (*left*). Close-up of vector field (shown in *yellow*) derived from intensity and direction of information present in the original pixel array (*right*). Copyright © 2011, IEEE

10.6.2 Method of Gradient Extraction and Mapping

In order to visualize the *structural information* distribution signatures thus far generated, pixel intensity is again considered to be the main parameter of interest. While a histogram generating approach could have been used to characterize the distributions of each pixel intensity value throughout the image, such a limited analysis would ultimately provide no useful knowledge with respect to the spatial structures of the intensity distribution in relationship to the given image as a whole (dataset). Therefore, a method was developed whereby the intensity at each discrete pixel is compared against its nearest neighbors. This method does not inherently measure *information* content per se, but rather the spatial distribution of intensities (gradient) across any given image. Therefore, this method may be used to determine any gradient of brightness intensity within an image, be it an *information* mapping, or the *difference* in pixel intensities across an actual image as are the cases presented in Fig. 10.10.

First, the intensity of each pixel (i, j) within an image is compared to each of its surrounding neighbors. The difference of each of these 8 values is scaled and assigned a vector. Next, each of these 8 vectors is summed and this sum is again normalized in order to determine a single resultant vector representing the intensity difference of each pixel (i, j) with its surrounding neighbors (Fig. 10.9). This new resultant vector describes how much and in what dominant spatial direction pixel (i, j) is different from its neighbors (Fig. 10.9).

Next, each resultant vector within a given image's pixel space (Fig. 10.8) is plotted to a unit polar coordinate grid comprised of 360 radial divisions and 256 concentric divisions (one for each possible pixel value given a 256 value working pixel space; Fig. 10.9). For visualization and quantification purposes, each resultant vector is assigned to its corresponding location in one of these 360×256 (direction and magnitude) divisions, defined as a "bin," within the polar coordinate grid. The number of resultant vectors falling within each of these polar bins is summed. This sum is then assigned a pixel brightness value between 1 and 256.

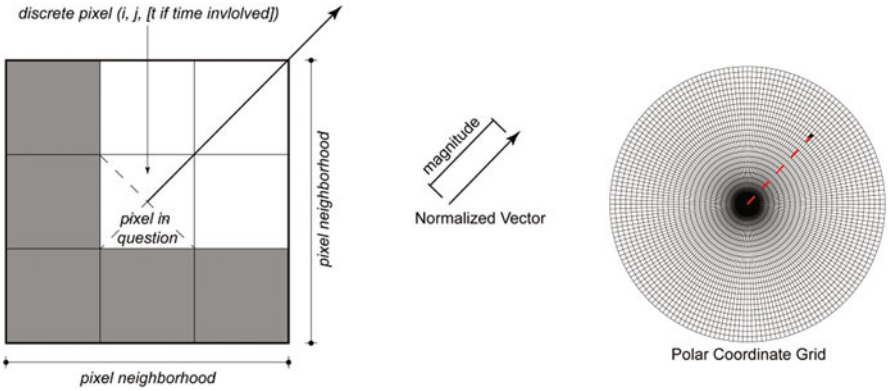

Fig. 10.9 Gradient distribution development. Schematic diagram depicting overall comparative difference in brightness between each pixel (*i, j*) and its nearest neighbors (*left*). Each pixel is assigned an intensity vector, normalized, and mapped to a polar coordinate system using the resultant vector's intensity and direction (*right*). Copyright © 2011, IEEE

Fig. 10.10 Gradient distribution signatures mapped to a polar coordinate system for the analysis of three paintings; Jackson Pollock's Number 1, (Lavender Mist) (*left*); Piet Mondrian's Composition A, 1923 (*middle*); and Sol Lewitt's Arcs from Four Corners (*right*). Copyright © 2011, IEEE

A demonstration of this method's visualization potential in Fig. 10.10 illustrates the distribution mappings of nearest neighbor difference vectors calculated for three paintings using the above method: Jackson Pollock's *Number 1,* (*Lavender Mist*); Piet Mondrian's *Compostition A, 1923*; and Sol Lewitt's *Arcs from Four Corners*.

10.7 Method for Developing Curvature Intensity Distribution Signatures for Autonomous Objects and Environments

10.7.1 Overview

In the previous sections, *information* was a function of the *difference* in data arrays arising from variant or invariant data structures borne between an observer and their

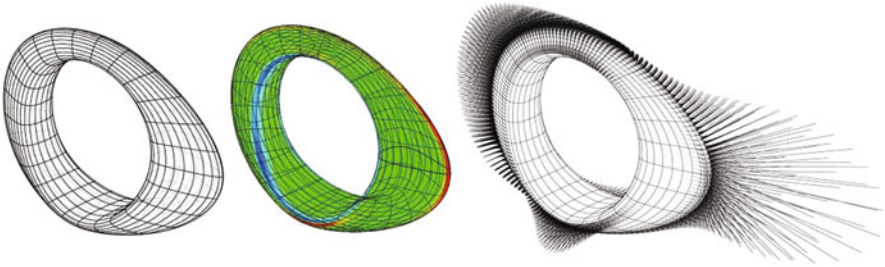

Fig. 10.11 Deformed torus; original object/environment under analysis (*left*). Gaussian curvature analysis (*middle*). Curvature intensities translated to vectors using Gaussian values as magnitude and surface normal as direction (*right*). Copyright © 2011, IEEE

environment. Complementary to that inquiry, this methodology is extended to objects and environments whose *difference* or change is internal to their makeup; this method relies solely on autonomous internal rates of change to local neighborhoods regardless of an implied observational mechanism. Similar to the former method of visualizing gradient intensity distributions, the underlying formal structure of objects and environments is examined by way of extracting the rates of change (curvatures) associated within local neighborhoods. This is not, however, a description of that entity's *information* content, rather a classification of its underlying formal attributes (i.e. how similar or dissimilar is the object/environment to itself?). Whereas the method presented in Sect. 10.5 is not a method for calculating *information* but rather a method to visualize spatial intensities in perceptual data, the method presented here is similarly not a determinant of *information* but rather a method for visualizing spatial intensities intrinsic to objects and environments. Similar to the study in Sect. 10.6, this method would also produce a diagram that would enable designers the ability to study the characteristic curvatures inherent to morphologies devoid of the burden associated with their appearance, shape and, all too often, symbolic legacy. Once extracted, this type of abstract formal diagram of material organization may subsequently be used as a productive device enabling designers the ability to generate new, yet familiar, objects and environments without necessarily working through projective geometric means as a description of shape.

10.7.2 Method of Curvature Intensity Mapping

Much like the previous studies, whereby the amount of change surrounding a discrete pixel is taken in its local neighborhood, here the Gaussian curvature values are taken at each (u, v) parameter upon a given surface. By taking the Gaussian curvature values, external observations are not inherently presumed nor is determination of curvature projected upon the object or environment in question. For the Gaussian value at each (u, v) point in question, a vector is assigned whose magnitude and direction are taken to be the Gaussian curvature value and normal to the surface at

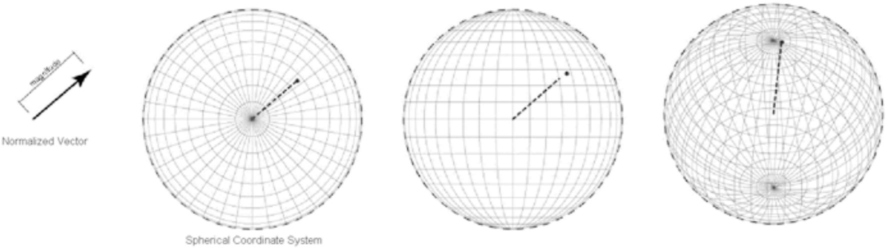

Fig. 10.12 Each curvature vector is normalized and mapped to a spherical coordinate system using the curvature vector's intensity and direction. Copyright © 2011, IEEE

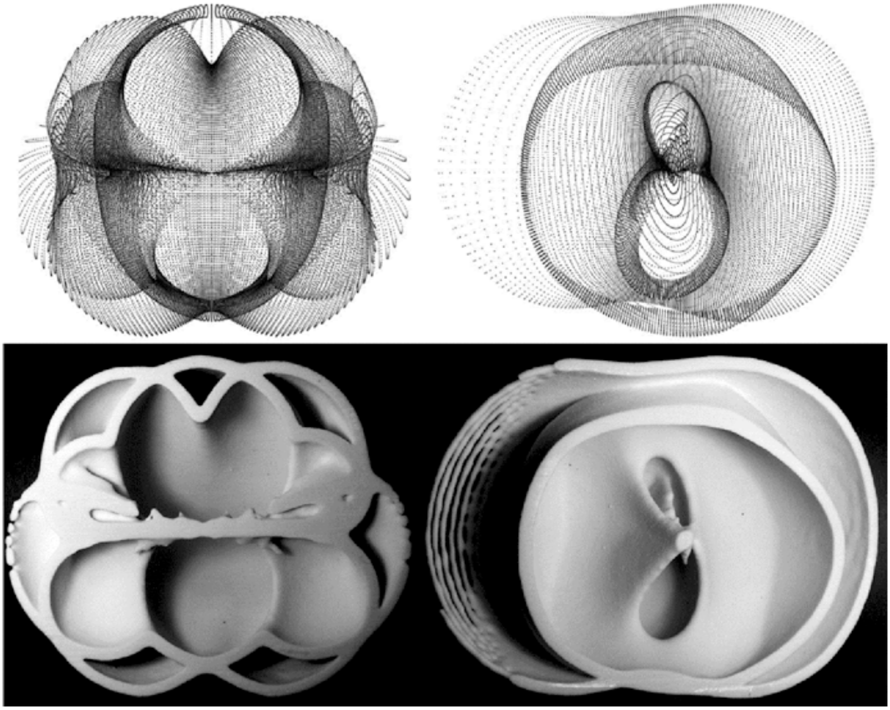

Fig. 10.13 Vector data derived from a deformed torus and mapped to a spherical coordinate system (*above*). Rapid prototyped (*printed*) sectional model of an approximated surface from vector data (*below*). Copyright © 2011

that point respectively (Fig. 10.11; Note: the vector magnitudes in Fig. 10.11 are amplified for visualization purposes).

Similar to the previous studies, where distributions are made about a polar coordinate system, here each new resultant vector characterizing the intensity and direction of curvature at each *u, v* point about an actual surface is mapped to a spherical coordinate system accordingly (Fig. 10.12). The point cloud represented in two views in Fig. 10.13 corresponds to the distribution of vectors extracted from the (u, v) space about the deformed torus shown in Fig. 10.11. As the measured (u, v) density of the actual environment in question approaches infinity, so too does the density of the point data mapped to spherical space, ultimately approximating a surface (Fig. 10.13).

10.8 Conclusion and Discussion

The studies and ideas presented in this research extend beyond disciplinary boundaries by way of scrutinizing underlying field-based dynamic data present in material systems, be they biological or architectural. It is precisely this transdisciplinary approach to design and research fostered in LabStudio that has firstly—enabled this inquiry, and secondly—allowed for the projective application of these speculative methods to find relevance beyond purely theoretical grounds and within seemingly disparate disciplines. Concerning the work presented here, the openness to abstract speculation present in LabStudio has enabled the following to be asked:

Should designers and architects limit themselves to being merely actors in a world of objects external to their persons, or is it possible to expand this perspective towards a continuum of fluctuating entities (persistent and nonpersistent) whose identities are a product of our relational difference with them? If we accept the latter, this would suggest a fundamental shift in how we conceive of and approach designing objects, environments, and affects. The studies presented, rooted in *difference* and *information*, serve to demonstrate a shift in thinking from the construction and production of objects and environments in solely descriptive and projective geometric terms to one which places emphasis upon thinking organizationally though time about the aggregation of material systems and their phenomenal affects. While descriptive and projective geometric principles continue to serve the architecture community, they are burdened by the remnants of an idealized geometric world. Furthermore, these geometric principles and abstractions also offer an ex post facto description and simplification of the world about us which also requires a qualitative description to be ascribed to the entities within that world. As an alternative, an approach rooted in *information* production inherently suggests an instantaneous perceptual construction of the world through which we traverse. This latter direction also takes into account the affectual attributes of the material organizations with which we interact as participating agents. While various approaches have been rhetorically discussed within architectural design, this chapter provides a framework and rigorous methodology in support of a discourse by which we may approach a set of design problems surrounding actual material phenomena removed from their symbolic inheritance. Furthermore, the methods presented offer a means by which we may study latent formal diagrams underlying the identity of metric morphologies and affects of actual entities. Not only could these diagrams be harnessed as productive devices for the production of new (yet familiar) material organizations, they also offer an approach to discuss the underlying similarities and *differences* inherent to the formal make-up of such spatiotemporal material aggregates while allowing the potential for a dialogue beyond morphological symbolism. This approach necessitates considering the actual parameters at play in the production of material organizations and affects by examining the much larger implications of *difference*, history, and *information* upon our perception of systemic environments as we shift away from an object biased approach to the analysis, comprehension, and construction of the world in which we are actively a part.

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Chapter 11
Cultural Data Sculpting: Omnidirectional Visualization for Cultural Datasets

Sarah Kenderdine, Jeffrey Shaw and Tobias Gremmler

Abstract This chapter presents five research projects currently underway to develop new omnispatial, omnidirectional visualization strategies for the collaborative interrogation of large-scale heterogeneous cultural datasets using the world's' first 360°-degree stereoscopic visualization environment (Advanced Visualization and Interaction Environment – AVIE). The AVIE system enables visualization modalities through full body immersion, stereoscopy, spatialized sound and camera-based tracking. The research integrates work by a group of international investigators in virtual environment design, immersive interactivity, information visualization, museology, archaeology, visual analytics and computational linguistics. The work is being implemented at the newly established research facility, City University's Applied Laboratory for Interactive Visualization and Embodiment – ALIVE) in association with partners Europeana, Museum Victoria (Melbourne), iCinema Centre, UNSW (Sydney), UC Merced (USA), the Dunhuang Academy, and UC Berkeley (USA). The applications are intended for museum visitors and for humanities researchers. They are: (1) *Data Sculpture Museum*, (2) *ECloud*, (3) *Blue Dots 360* (Tripitaka Koreana), (4) *Rhizome of the Western Han, and* (5) *Pure Land: Inside the Mogao Grottoes at Dunhuang*.

11.1 Introduction

Research into new modalities of visualizing data is essential for the world producing and consuming digital data at unprecedented rates [23, 27, 44]. Existing techniques for interaction design in visual analytics rely upon visual metaphors developed more than a decade ago [28] such as dynamic graphs, charts, maps, and plots. Currently, the interactive, immersive, and collaborative techniques to explore

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large-scale datasets lack adequate experimental development essential for the construction of knowledge in analytic discourse [51]. Recent visualization research remains largely constrained to 2D small-screen based analysis and advances in interactive techniques of "clicking", "dragging," and "rotating" [27, 52]. Furthermore, the number of pixels available to the user remains a critical limiting factor in human cognition of data visualizations [26]. The increasing trend toward research requiring 'unlimited' screen resolution has resulted in the recent growth of gigapixel displays. Visualization systems for large-scale data sets are increasingly focused on effectively representing their many levels of complexity. These include tiled displays such as HIPerSpace at Calit2 [22], and next generation immersive virtual reality systems such as StarCAVE at UC San Diego [10] and Allosphere at UC Santa Barbara [2].

However, in general, the opportunities offered by interactive and 3D technologies for enhanced cognitive exploration and interrogation of high dimensional data still need to be realized within the domain of visual analytics for digital humanities [29]. The five projects described in this chapter take on these core challenges of visual analytics inside the Advanced Visualization and Interaction Environment (AVIE) [1, 45] to provide powerful modalities for an omnispatial/omnidirectional (3D, 360°) exploration of heterogeneous datasets responding to the need for embodied interaction, knowledge-based interfaces, collaboration, cognition, and perception [50]. The projects are developed by the Applied Laboratory for Interactive Visualization and Embodiment (ALiVE), City University, Hong Kong [3]. A framework for 'enhanced human higher cognition' [18] is being developed that extends familiar perceptual models common in visual analytics to facilitate the flow of human reasoning. Immersion in three-dimensionality representing infinite data space is recognized as a pre-requisite for higher consciousness, autopoesis [43]; and promotes nonvertical and lateral thinking [47]. Thus, a combination of algorithmic and human mixed-initiative interaction in an omnispatial environment lies at the core of the collaborative knowledge creation model proposed.

The five projects discussed also leverage the potential inherent in a combination of 'unlimited screen real-estate', ultra-high stereoscopic resolution, and 360° immersion to resolve problems of data occlusion and distribution of large-scale data analysis in networked sequences in order to reveal patterns, hierarchies, and interconnectedness. The omnidirectional interface prioritizes 'users in the loop' in an egocentric model [26]. These projects also expose what it means to have embodied spherical (allocentric) relations to the respective datasets. These hybrid approaches to data representation also allow for the development of sonification strategies to help augment the interpretation of the results. The tactility of data is enhanced in 3D and embodied spaces by attaching audio to its abstract visual elements, and has been well defined by researchers since Chion et al. [7]. Sonification reinforces spatial and temporal relationships between data (e.g. an object's location in 360°/infinite 3D space, and its interactive behavior (for example, see [60]). The multichannel spatial array of the AVIE platform offers opportunities for creating a real-time sonic engine designed specifically to enhance cognitive and perceptual interaction, and immersion in 3D. It also can play a significant role in narrative coherence across the network of relationships evidenced in the datasets.

11.1.1 Advanced Visualization and Interaction Environment

Applied Visualization Interaction Environment (AVIE) is the UNSW iCinema Research Centre's landmark 360° stereoscopic interactive visualization environment space. The updated active stereo projection system together with camera tracking is installed at ALiVE. The base configuration is a cylindrical projection screen 4 m high and 10 m in diameter, a 12-channel stereoscopic projection system and a 14.2 surround sound audio system. AVIE's immersive mixed reality capability articulates an embodied interactive relationship between the viewers and the projected information spaces [1, 45].

11.2 Experimental Projects

The five experimental projects included in this chapter draw upon disciplines such as multimedia analysis, visual analytics, interaction design, embodied cognition, stereographics and immersive display systems, computer graphics, semantics and intelligent search, and computational linguistics. The research also investigates media histories, recombinatory narrative, new media aesthetics, socialization, and presence in situated virtual environments, and the potential for new psychogeography of data terrains. Each work takes place in AVIE system. The datasets used in these five works are:

- *Data Sculpture Museum*: Over 100,000 multimedia-rich heterogeneous museological collections covering arts and sciences derived from the collections of Museum Victoria, Melbourne, and ZKM Centre for Art and Media, Karlsruhe, for general public use in museum contexts.
- *ECloud:* Approx 10,000 objects derived from an internet archive of First World War data.
- *Blue Dots 360*: Chinese Buddhist Canon, Koryo version (Tripitaka Koreana) in classical Chinese, the largest single corpus with 52 million glyphs carved on 83,000 printing blocks in thirteenth century Korea. The digitized Canon contains metadata that links to geospatial positions, contextual images of locations referenced in the text, and to the original rubbings of the wooden blocks. Each character has been abstracted to a 'blue dot' to enable rapid search and pattern visualization ; for scholarly use and interrogation.
- *Rhizome of the Western Han*: Laser-scan archaeological datasets from two tombs, and archeological collections of the Western Han, Xian, China culminating in a metabrowser and interpretive cybermap; for general public use in a museum context.
- *Pure Land*: Laser-scan archaeological dataset and ultra-high resolution photography of CAVE 220, Dunhuang Caves, Gansu Province, China, including 2D and 3D animations, redrawn and recolored cutouts (based on archaeological research) and high resolution magnification; for general public use in a museum context.

11.3 Techniques for Cultural Visualization

11.3.1 Cultural Databases and Visualization

The intersection of key disciplines related to the first three projects in this chapter includes multimedia analysis, visual analytics, and text visualization. An excellent review of the state of the art multimedia analysis and visual analytics appeared in *IEEE Computer Graphics and Applications* [6]. The research projects also respond to core challenges and potentials identified in Visual Analytics [28, 55] and to key emerging technologies for the coming years such as Visual Data Analysis and Gesture Based Computing [25]. Visual Analytics includes the associated fields of Human Perception and Cognition, where 3D technologies and immersive and interactive techniques hold significant potential for enhanced research applications [26]. Computational linguistics is providing many of the analytics tools required for the mining of digital texts (e.g. [37, 52, 54]). The first international workshop for intelligent interfaces to text visualization only recently took place in Hong Kong, 2010 [39]. Most previous work in text visualization has focused on one of two areas: visualizing repetitions and visualizing collocations. The former shows how frequently, and where, particular words are repeated; and the latter describes the characteristics of the linguistic "neighborhood" in which these words occur. Word clouds are a popular visualization technique whereby words are shown in font sizes corresponding to their frequencies in the document. They can also show changes in frequencies of words through time [23], in different organizations [8], and emotions in different geographical locations [19, 21]. The significance of a word also lies in the location at which it occurs. Tools such as *TextArc* [48], *Blue Dots* [5, 33–36], and *Arc Diagrams* [59] visualize these "word clusters," but are constrained by the window size of a desktop monitor. In the digital humanities, words and text strings are the typical mode of representation of mass corpora. However, new modes of lexical visualization such as *Visnomad* [57] are emerging as dynamic visualization tools for comparing one text with another. In another example, the *Visualization of the Bible* by Chris Harrison, each of the 63,779 cross references found in the Bible are depicted by a single arc whose color corresponds to the distance between the two chapters [20].

Websites such as Visual Complexity [58], and mainstream projects such as Many Eyes [42] attest to the increasing interest in information visualization. Visual Analytics is closely related to HCI and the development of gesture based computing for data retrieval [25]. Microsoft's *Project Natal* and Pranav Mistry (MIT) *Six Sense* are examples of increasing use of intuitive devices that promote kinesthetic embodied relationships with data.

In the analytics domain of the humanities, the *Cultural Analytics* as developed by UC San Diego offers us visionary trends in large screen immersive system visualization. *Cultural Analytics* researches visualization of large-scale heterogeneous data in immersive system displays. It uses computer-based techniques from quantitative analysis and interactive visualization employed in sciences to analyze massive multi-modal cultural data sets on gigapixels screens [41]. This project draws upon

Fig. 11.1 *T_Visionarium* I in EVE © UNSW iCinema Research Centre

cutting-edge cyberinfrastructure and visualization research at Calit2 (including the aforementioned new generation CAVE and Powerwall).

Previous embodied and interactive visualization systems created by researchers collaborating on projects reported in this chapter include *T_Visionarium I & II* [53]. *T_Visionarium I* was developed by iCinema Centre, UNSW in 2003. It takes place in Jeffrey Shaw's EVE, an inflatable (12 × 9 m) dome that includes a motorized pan-tilt projection system affixed to a tripod, and a head-mounted position-tracking device. EVE's database comprises a week-long recording of 80 satellite television channels across Europe. Each channel plays simultaneously across the dome; however, the user directs or reveals any particular channel at any given time. The matrix of 'feeds' is tagged with different parameters—keywords such as phrases, colour, pattern, and ambience. Using a remote control, the viewer selects options from a recombinatory search matrix. Upon parameter selection, the matrix extracts and distributes all the corresponding broadcast items related to that parameter over the entire projection surface of the dome. For example, by selecting the keyword "dialogue", all the broadcast data is reassembled according to this descriptor. The viewer head movement controls the position the projected image, and shifts from one channel's embodiment of the selected parameter to the next. In this way, the viewer experiences a revealing synchronicity between all the channels linked through the occurrence of keyword tagged images. All these options become the recombinatory tableau in which the original data is given new and emergent fields of meaning (Fig. 11.1). *T_Visionarium II* in AVIE (produced as part of the ARC Discovery, 'Interactive Narrative as a Form of Recombinatory Search in the Cinematic Transcription of Televisual Information' [53]) uses 24 h of free to air broadcast TV footage from seven Australian channels as its source material. This footage was analyzed by software for changes of camera angle, and at every change in a particular movie (whether it be a dramatic film or a sitcom), a cut was made resulting is a database of 24,000 clips of approximately 4 s each. Four researchers were employed to hand tag each 4 s clip with somewhat idiosyncratic metadata related to the images shown, including: emotion, expression, physicality, and scene structure; with metatags that include speed, gender, colour,

Fig. 11.2 *T_Visionarium* II in AVIE © UNSW iCinema Research Centre

Fig. 11.3 Datasphere, *T_Visionarium* II in AVIE © UNSW iCinema Research Centre

and so on. The result is 500 simultaneous video streams each looping 4 s, responsive to a user's search (Figs. 11.2 and 11.3).

An antecedent of the *T_Visionarium* projects can be found in Aby Warburg's Mnemosyne, a visual cultural atlas. It is a means for studying the internal dynamics of imagery at the level of its medium rather than its content, performing image analysis through montage and recombination. *T_Visionarium* can be framed by the concept of aesthetic transcription, that is, the way new meaning can be produced is based on how content moves from one expressive medium to another. The digital format allows the transcription of televisual data, decontextualising the original, and reconstituting it within a new artifact. As the archiving abilities of the digital format allow data to be changed from its original conception, new narrative relationships are generated between the multitudes of clips, and meaningful narrative events emerge because of viewer interaction in a transnarrative experience where gesture is all defining. The segmentation of the video reveals something about the predominance of close-ups, the lack of panoramic shots, and the heavy reliance on dialogue in TV footage. These aesthetic features come strikingly to the fore in this hybrid environment. The spatial contiguity gives rise to new ways of seeing and of reconceptualising in a spatial montage [4]. In *T_Visionarium*, the material screen no longer exists. The boundary of the cinematic frame has been violated, hinting at the endless permutations that exist for the user. The user does not enter a seamless unified space, but rather is confronted with the spectacle of hundreds of individual streams.

11.3.2 Phenomenology and Visualization

At the nexus of the work for the projects *Rhizome of the Western Han* and *Pure Land* is the embodiment of the user in 360° 3D space. In both cases, the 'cave' sites used in the visualizations are shown at one-to-one scale with ultra-high resolution imagery and 3D effects providing powerful immersive experiences. There is ample discourse to situate the body at the forefront of interpretive archaeology research as a space of phenomenological encounter. Post-processual frameworks for interpretive archaeology advance a phenomenological understanding of the experience of landscape. In his book, *Body and Image: Explorations in Landscape Phenomenology*, archaeologist Christopher Tilley, for example, usefully contrasts iconographic approaches to the study of representation with those of kinaesthetic enquiry [56]. Tilley's line of reasoning provides grounding for the research into narrative agency in large-scale, immersive and sensorial, cognitively provocative environments [29, 30]. The project examines a philosophical discussion of what it means to inhabit archaeological data 'at scale' (1:1). It also re-situates the theatre of archaeology in a fully immersive display system [49]. Further discussion on these topics has been published by the researchers [30].

11.4 Project Descriptions

11.4.1 Data Sculpture Museum[1]

The aim of this research is to investigate recombinatory search, transcriptive narrative, and multimodal analytics for heterogeneous datasets through their visualization in a 360° stereoscopic space [11]. Specifically, to explore cultural data as a cultural artifact so as to expose a multiplicity of narratives that may be arranged and projected instantaneously [11] atop the data archive architecture and its metadata [12]. This project builds upon the exploration and gains made in the development of *T_Visionarium I and II*.

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[1] This project is being developed as part of the Australian Research Council Linkage Grant (2011–2014) "The narrative reformulation of multiple forms of databases using a recombinatory model of cinematic interactivity" (UNSW iCinema Research Centre [1], Museum Victoria [46], ALiVE City University [3], ZKM Centre for Built Media) [62].

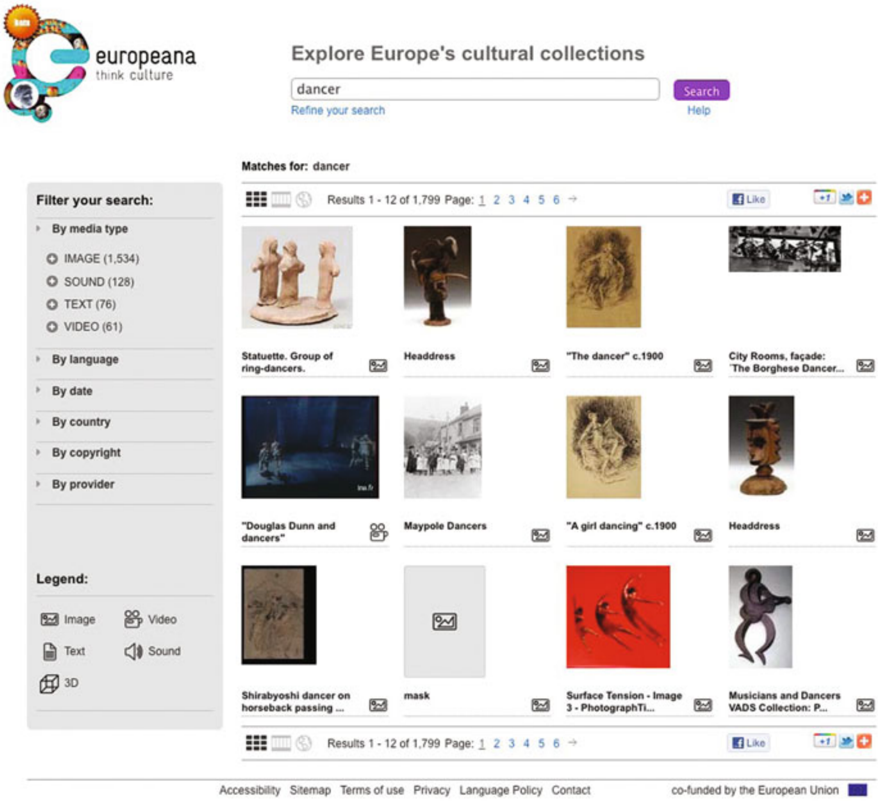
The datasets used contain over 100,000 multimedia rich records (including audio files, video files, high resolution monoscopic and stereoscopic images, panoramic images/movies, and text files) from Museum Victoria, and the media art history database of the ZKM that itself encompasses diverse subject areas from the arts and sciences collections. Data are collated from collection management systems, web-based and exhibition-based projects. Additional metadata and multimedia analysis is used to allow for intelligent searching across datasets. Annotation tools provide users with the ability to make their own pathways through the data terrain, a psychogeography of the museum collections. Gesture-based interaction allows users to combine searches, using both image-based and text input methods. Search parameters include:

- Explicit (keyword search based on collections data with additional metadata tags accessible through word clouds).
- Multimedia (e.g. show me all faces like this face; show me all videos on Australia, show me everything pink!).
- Dynamic (e.g. show me the most popular search items; join my search to another co-user; record my search for others to see; add tags).
- Abstract (auto generated flow of content based on search input which results from an algorithm running through the data and returning abstract results).

This project seeks to understand the development of media aesthetics. Problems of meaningful use of information are related to the way users integrate the outcomes of their navigational process into coherent narrative forms. In contrast to the interactive screen based approaches conventionally used by museums, this study examines the exploratory strategies enacted by users in making sense of large-scale databases when experienced immersively in a manner similar to that experienced in real displays [38, 40]. In particular, evaluation studies ask: (i) How do museum users interact with an immersive 360° data browser that enables navigational and editorial choice in the re-composition of multi-layered digital information? (ii) Do the outcomes of choices that underpin editorial re-composition of data call upon aesthetic as well as conceptual processes and in what form are they expressed? [10]

Large-scale immersive systems can significantly alter the way information can be archived, accessed, and sorted. There is significant difference between museum 2D displays that bring pre-recorded static data into the presence of the user, and immersive systems that enable museum visitors to actively explore dynamic data in real-time. This experimental study into the meaningful use of data involves the development of an experimental browser capable of engaging users by enveloping them in an immersive setting that delivers information in a way that can be sorted, integrated and represented interactively. Specifications of the experimental data browser include:

- immersive 360° presentation of multi-layered, heterogeneous data
- the re-organization and authoring of data
- scalable navigation incorporating Internet functionality
- collaborative exploration of data in a shared immersive space
- intelligent, interactive system able to analyze and respond to user's transactions.



dancer

Matches for: dancer

Results 1 - 12 of 1,799

Fig. 11.4 Europeana online portal—search return. http://www.europeana.eu/portal/search.html?query=dancer. © Europeana

11.4.2 ECloud

Another prototype project under development at ALiVE is focused on providing a multi-user interactive visualization of the online cultural collection portal Europeana [15]. Around 1,500 institutions have contributed to Europeana, assembling collections of over 14 million records in multiple languages (Fig. 11.4). The recently released future directions report for Europeana [16] emphasized the need to look for innovations in delivery of content. Our prototype uses up to 10,000 objects coming from recent collections of First World War data (Fig. 11.5), distributed in 3D space across a 9 m screen employing a touch screen interface (Figs. 11.6, 11.7). We are using the limited five-field metadata that is the basis for Europeana portal for this visualization.

Fig. 11.5 Europeana online portal—WW1. http://remix.europeana.eu/. © Europeana

Fig. 11.6 Satirical maps of Europe and image clouds, *ECloud*. © ALiVE, City

Fig. 11.7 iPad interface, *ECloud*. © ALiVE, CityU

This project builds on Europeana research into new ways of searching and/or browsing. *ECloud* will take advantage of Europeana APIs and high-resolution content existing in Europeana partner repositories. The *ECloud* prototype is designed for museums and cultural organizations as a situated showcase for engaging and inspiring visitors with the vast wealth of cultural data available at Europeana. The research proposed by *ECloud* will be at the forefront of the growth of visual analytics, cultural visualization, and information aesthetics. These methodologies are essential for a world with increasingly large data streams. The project also answers the challenge presented by the increasing desirability of large screen interactive experiences that can re-invigorate public spaces. *ECloud*'s unique design offers visitors an unparalleled opportunity for creative association and discovery through enhanced cognitive enquiry. *ECloud* will extend current interaction paradigms with audio–visual materials. New schemes will be implemented to respect the sensible nature of the Europeana's First World War sets.

Europeana's work on the First World War sets out to discover untold stories, to share them across borders, and to invite responses from around Europe. This project has collected over 24,000 records already and more are planned as the project moves throughout Europe. *ECloud* will incorporate this data giving audiences a situated experience of this crowdsourced collection providing a powerful graphic world based on individual recollections and family archives on this highly emotional subject. Based on comparative and analytic approaches to data mining, this work transforms the archive into palpable universe of emotion, with significant cognitive impact.

11.4.3 Blue Dots 360

This project integrates the Chinese Buddhist Canon, Koryo version Tripitaka Koreana into the AVIE system (a project between ALiVE, CityU Hong Kong, and UC Berkeley). This version of the Buddhist Cannon is inscribed as UNESCO World

Fig. 11.8 Tripitaka Koreana. Image © Caroline Knox (Wikipedia commons, http://en.wikipedia.org/wiki/File:Korea-Haeinsa-Tripitaka_Koreana-04.jpg)

Heritage enshrined in Haeinsa, Korea. The 166,000 pages of rubbings from the wooden printing blocks constitute the oldest complete set of the corpus in print format (Fig. 11.8). Divided into 1,514 individual texts, the version has a complexity that is challenging since the texts represent translations from Indic languages into Chinese over a 1,000-year period (second–eleventh century). This is the world's largest single corpus containing over 50 million glyphs and it was digitized and encoded by Prof Lew Lancaster and his team in a project that started in the 1970s [33–36].

Amount of content

- 1,504 texts
- 160,465 pages
- 52,000,000 glyphs
- 1 text includes 107 pages (34,674 glyphs)
- 1 page includes 324 glyphs arranged in 23 rows and 14 columns.

Contextual information

- 1,504 colophons with titles, translators, dates, places, and other information
- 202 people names (translators, authors, compilers)
- 98 monastery names.

The *Blue Dots* [5] project undertaken at Berkeley as part of the Electronic Cultural Atlas Initiative (ECAI; [14]) which abstracted each glyph from the Canon into a blue dot, and gave metadata to each of these *Blue Dots* allowing vast searches to take place in minutes which would have taken scholars years. In the search function, each blue dot also references an original plate photograph for verification. The shape of these wooden plates gives the blue dot array its form (Fig. 11.9).

As a searchable database, it exists in a prototype form on the Internet. Results are displayed in a dimensional array where users can view and navigate within the image. The image uses both the abstracted form of a "dot" as well as color to inform the

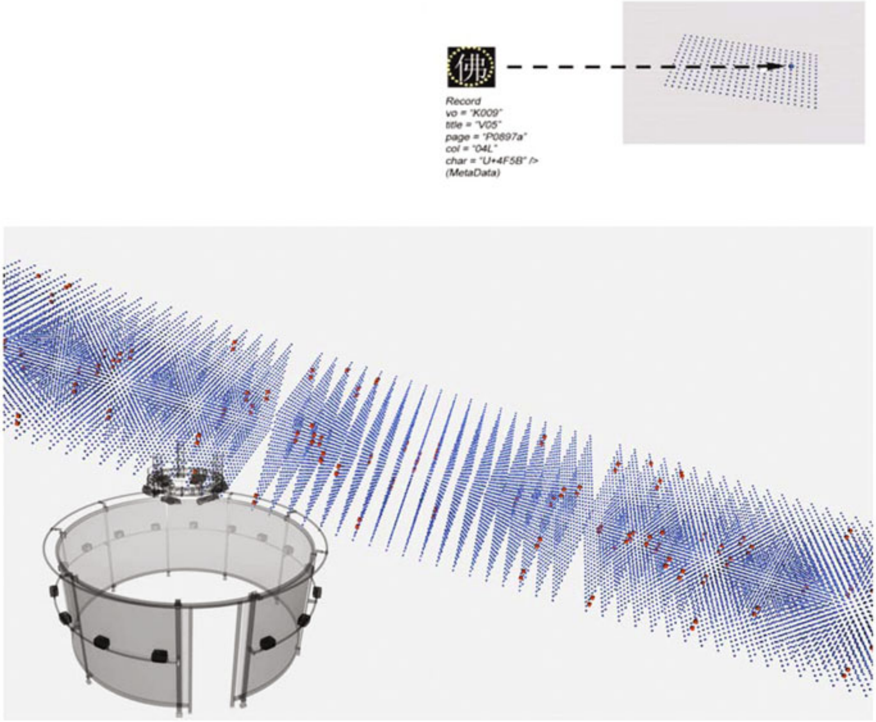


Fig. 11.9 *Blue Dots*: abstraction of characters to dots and pattern arrays © ECAI, Berkeley

user about the information being retrieved. Each blue dot represents one glyph of the dataset. Alternate colors indicate position of search results. The use of colour, form, and dimension to quickly communicate understanding of the information is essential for large data sets where thousands of occurrences of a target word/phrase may be seen. Analysis across this vast text retrieves visual representations of word strings, clustering of terms, automatic analysis of ring construction, viewing results by time, creator, and place. The *Blue Dots* method of visualization is a breakthrough for corpora visualization and lies at the basis of the visualization strategies of abstraction undertaken in this project. The application of an omnispatial distribution of these texts solves problems of data occlusion and enhances network analysis techniques to reveal patterns, hierarchies and interconnectedness (Figs. 11.10 and 11.11). Using a hybrid approach to data representation, audification strategies will be incorporated to augment interaction coherence and interpretation. The data browser is designed to function in two modes: the Corpus Analytics mode for text only and the Cultural Atlas mode that incorporates original text, contextual images, and geospatial data. Search results can be saved and annotated.

The current search functionality ranges from visualizing word distribution and frequency to other structural patterns such as the chiastic structure and ring compositions. In the *Blue Dots AVIE* version, the text is also visualized as a matrix of

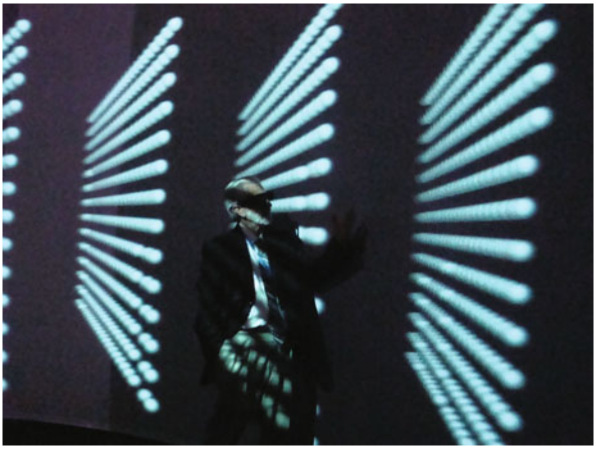


Fig. 11.10 Prof Lew Lancaster interrogates the Prototype of *Blue Dots 360* © ALiVE, CityU. Image: Howie Lan

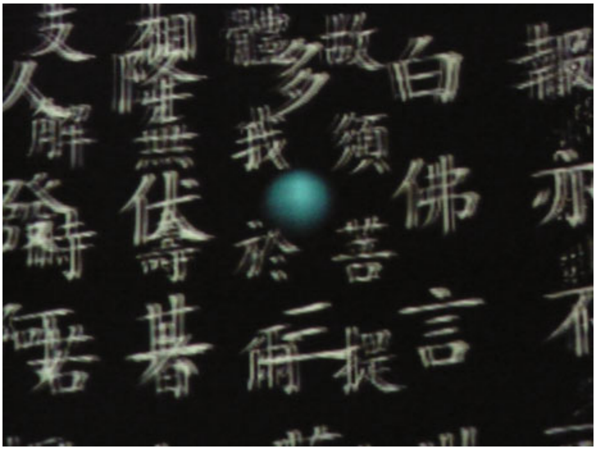


Fig. 11.11 Close up of *blue dots* and corresponding texts, Prototype of *Blue Dots 360* © ALiVE, CityU. Image: Howie Lan

simplified graphic elements representing each of the words. This will enable users to identify new linguistic patterns and relationships within the matrix, as well as access the words themselves and related contextual materials. The search queries will be applied across classical Chinese and eventually English, accessed collaboratively by researchers, extracted and saved for later re-analysis.

The data provides an excellent resource for the study of dissemination of documents over geographic and temporal spheres. It includes additional metadata such as present day images of the monasteries where the translation took place, which will be included in the data array. The project will design new omnidirectional metaphors for interrogation and the graphical representation of complex relationships between these textual datasets to solve the significant challenges of visualizing both abstract forms and close-up readings of this rich data (Figs. 11.12 and 11.13). In this way, we hope to set benchmarks in visual analytics, scholarly analysis in the digital humanities, and the interpretation of classical texts.

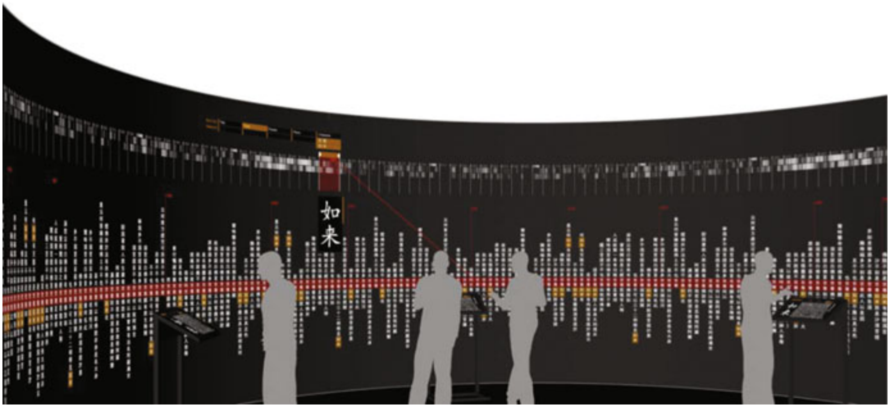


Fig. 11.12 Visualization of *Blue Dots 360*. Image: Tobias Gremmler © ALiVE, CityU

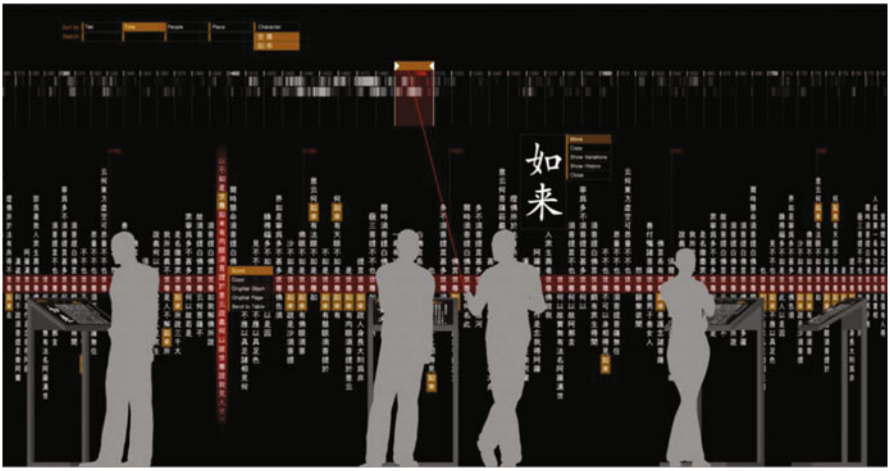


Fig. 11.13 Visualization of *Blue Dots 360*. Image: Tobias Gremmler © ALiVE, CityU

11.4.4 Rhizome of the Western Han

This project investigates the integration of high-resolution archaeological laser scan and GIS data inside AVIE. This project represents a process of archaeological re-contextualization, bringing together in a spatial context remote sensing data from two tombs (M27 and The Bamboo Garden) with laser scans of funerary objects. This prototype builds an interactive narrative based on spatial dynamics, and cultural aesthetics and philosophies embedded in the archaeological remains. The study of the Han Dynasties' (206 BC–220 AD) imperial tombs has always been an important field of Chinese archaeology. However, only a few tombs of the West Han Dynasty have been scientifically surveyed and reconstructed. Further, the project investigates

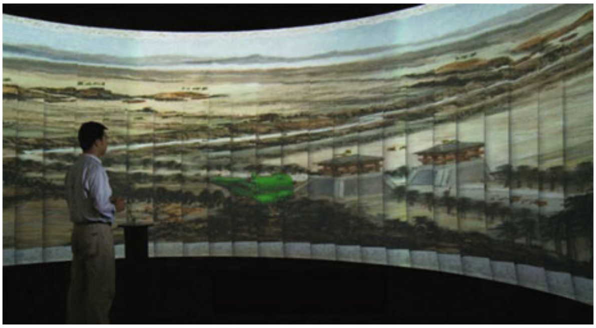


Fig. 11.14 *Rhizome of the Western Han*: inhabiting the tombs at 1:1 scale © ALiVE, CityU

Fig. 11.15 *Rhizome of the Western Han*: inhabiting the tombs at 1:1 scale © ALiVE, CityU

a reformulation of narrative based on the application of cyber-mapping principles in archaeology [17, 28, 32].

The application engine has been developed in order to be completely dynamic and not dependent on the application data. Every environment, information, models and behaviors are specified and loaded from a configuration file. When the application starts, the user is surrounded by an introductory 3D level. This scenario allows the user to select between various real 3D archaeological reconstruction scenarios through intuitive iconic representations. This Scene Browser is dynamically created according to the total amount of models available for the application (in the Western Han case of study it is possible to select between two different tomb reconstructions and a 3D objects browser). The engine is able to generate two types of scenarios with different behaviors and user experiences (Figs. 11.14, 11.15 and 11.16).

The second type of environment (the Object Viewer) displays multiple virtual reconstructions of objects around the user in a circular manner. The user can browse, magnify, and manipulate every object independently. The object browser experience is also improved thanks to the visualization of a facultative cloud of points in which the objects float.

This prototype has led to the construction of an interactive installation (*Pure Land*) using laser scan data from the UNESCO World Heritage site of the Dunhuang Caves (Magao Grottoes), Gobi Desert, China.

Fig. 11.16 *Rhizome of the Western Han*: object browser © ALiVE, CityU

11.4.5 Pure Land

Pure Land: Inside the Mogao Grottoes at Dunhuang immerses visitors in the quintessential heritage of hundreds of Buddhist grotto temples, an art treasury abounding with murals, statues, and architectural monuments. Filled with paradisiacal frescos and hand-molded clay sculptures of savior-gods and saints, they are, in size and historical breadth, like nothing else in the Chinese Buddhist world [24]. This UNESCO World Heritage site, also known as the *Caves of the Thousand Buddhas* or the *Peerless Caves,* is located at Dunhuang, a small town in northwestern China, an oasis amid the Gobi desert. It was a gateway to and from China on the ancient Silk Road, which carried trade between China, western Asia and India from the 2nd century BC until the 14th century AD.

Pure Land is an interactive 3D exhibition that takes place in the world's first 360° stereoscopic panoramic enclosure AVIE. *Pure Land* is significant because it provides a new paradigm of interpretation for the rich and intricate narratives rendered on the cave walls, in high fidelity, at 1:1 scale and in 3D. The Magao Grottoes have been subject to extensive digital imaging for conservation, preservation, and education undertaken by the custodians of the site, the Dunhuang Academy [13]. The photographic projects at Dunhuang, unparalleled in scale when compared to any other World Heritage site, is a race to 'capture' and preserve the caves before any more degradation can occur. *Pure Land* makes use of this high-resolution photography and laser scanning data to tell stories about the extraordinary wealth of paintings found in the caves at Dunhuang.

The site includes 492 caves that still contain rich murals and sculptures (there are over 700 in total). With increasing number of caves at Dunhuang closed to the public (approximately 10–29 are viewable out of 100), it is considered likely that, at some point in the future, all these caves will be closed to ensure their extended preservation. As such, the visitors may only use weak torchlight to examine the cave walls.

> And Mogaoku is in trouble. Thrown open to visitors in recent decades, the site has been swamped by tourists in the past few years. The caves now suffer from high levels of carbon dioxide and humidity, which are severely undermining conservation efforts. The short-term solution has been to limit the number of caves that can be visited and to admit people only on timed tours, but the deterioration continues. . . Plans are under way to recast the entire

Fig. 11.17 *Pure Land* visualization. Image: Tobias Gremmler © ALiVE, CityU/Dunhuang Academy

> Dunhuang experience in a way that will both intensify and distance it. Digital technology will give visitors a kind of total immersion encounter with the caves impossible before now. . . [9]

Closing important and unique world heritage caves to ensure preservation is an increasing worldwide trend. France's Lascaux closed in 1963. Lascaux II, a replica of two of the cave halls—the Great Hall of the Bulls and the Painted Gallery—was opened in 1983, 200 m. from the original. Reproductions of other Lascaux artwork can be seen at the Centre of Prehistoric Art at Le Thot, France. Spain's famous Altamira Cave has been frequently closed and is currently closed due to fungus infestations). *Pure Land* represents an innovation in providing not only a truly representative virtual facsimile, an extensive range of tools for its exploration, analysis and understanding, but also an embodied experience of this wondrous place.

Inside *Pure Land*, the visitors enter a panoramic laser scan image of the escarpment at Dunhuang to encounter a constellation of iconography from a myriad of caves. Visitors can enter inside Cave 220. Using both a torch and magnifying glass interface, the intricate iconography can be brought to life in great detail. Each wall of the Cave is resplendent with narrative and *Pure Land* employs a range of 2D and 3D animations and 3D videos to bring the paintings to life. For example, the *Bhaisajyaguru Sutra* recorded the rituals of subsisting the seven Medicine Buddhas. The painting reveals how human pray to keep away from sufferings and illness. The *Western Pure Land Sutra* or the sutra of *Infinite Life* tells about the Amitabha Buddha who sits among the solemn and beautiful scenes depicted. Here, believers are no longer afraid of death and long for rebirth in the 'other' world. Rich with interactive features, *Pure Land* transports visitors to these other realms.

Pure Land is a forerunner in the use of advanced technologies for cultural heritage interpretation of digital preservation, and new museography (Figs. 11.17, 11.18, 11.19 and 11.20). A full technical description of this work, developed in an extended Virtools framework is forthcoming.

Fig. 11.18 Close-up detail of North Wall Cave 220 with magnifying glasses effect, *Pure Land.* Image: Sarah Kenderdine © ALiVE, CityU/Dunhuang Academy

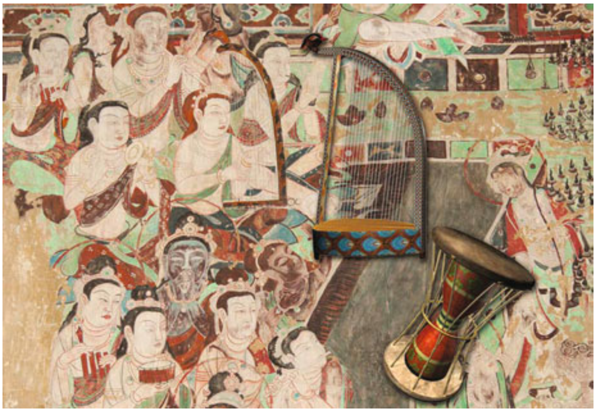


Fig. 11.19 Interactive 3D instrument inside CAVE 220, *Pure Land*. Image: Jonathan Chan © ALiVE, CityU/Dunhuang Academy

Fig. 11.20 Stereographic video capture of Beijing Academy Dancers, *Pure Land.* Image: Digital Magic © ALiVE, CityU/Dunhuang Academy

11.5 Conclusion

The five projects described begin take on core challenges of visual analytics, multimedia analysis, text analysis, and visualization inside AVIE to provide powerful modalities for an omnidirectional exploration of museum collections, archaeological laser scan data, and multiple textual datasets. This research responds to the need for embodied interaction and knowledge-based interfaces that enhance collaboration, cognition, perception, and narrative coherence. For instance, through AVIE, museum users and scholars are investigating the quality of narrative coherence of abstract and multimedia data through interactive navigation and re-organization of information in 360° 3D space. There will be ongoing reporting related to the *Data Sculpture Museum*, which has recently commenced as part of a three-year project, and the *Blue Dots 360*. The upcoming work on the interactive installation *Inside Dunhuang* will also be the subject of separate reports.

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