Information Visualisation

Information Visualisation:
Techniques, Usability and Evaluation

Edited by

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PREFACE

Visualization is defined as the process of forming a mental image. It is a process as old as history itself, in which one individual stimulates another's senses of sight, hearing, touch, or taste to communicate information. Today, visualization is a field in its own right that capitalizes on the processing capabilities of computers to transform complex data into visual imagery for comprehension, communication, and decision and policy making.

The field of visualization has evolved dramatically over the past four decades. In the late 1980s, the National Science Foundation commissioned a report entitled "Visualization in Scientific Computing"[1] that proposed a framework defining visualization as a discipline and scientific field. Since that report appeared, visualization has sorted itself into the subfields of scientific, information, and knowledge visualization: fields that may be further differentiated into theme-specific areas such as geo(information) visualization, bio-medical visualization, software visualization, and digital humanities visualization, to name but a few. From molecules to galaxies, visualization tools and techniques have enabled researchers to "see" their complex physical data, and have become essential components of scientific discovery and communication processes. That is where the vast body of visualization successes resides.

The future impact of visualization will be from the continued development of methods that impart visual form to information and knowledge, that, unlike molecules or planets, are abstract entities and ideas possessing neither intrinsic physical nor spatial attributes. The nature of information and knowledge is often revealed as part of a storytelling aspect in which images are placed within the wider context of knowledge transfer: characterized by a sense of story that is often remembered long after it has been told. This degree of engagement remains a challenge to contemporary visualization. Some notable examples are found in the early visualizations discussed and analysed by Frank Marchese in the chapter

1. B. H. McCormick, T.A. DeFanti, and M.D. Brown., *Computer Graphics*, vol 21, no 6, ACM SIGGRAPH, 1987.

"Tables and Early Information Visualization."[2] A current prospective on this is given by Robert Kosara and Jock Mackinlay[3] in the article "Storytelling: The Next Step for Visualization."

The collection of essays in this volume represents current concepts and research directions in information visualization. It is divided into two sections, the first focusing on techniques, the second on usability and evaluation. The techniques section concentrates on the nature of data, algorithms, and models. Techniques may be characterized by their simplicity, efficiency, applicability, and generality, without restriction to their application within any problem domain or data requirements. A technique's usability is determined by how well it may be applied to different application domains.

Essays concerned with evaluation present user perspectives of techniques. Its aim is to provide a conceptual and empirical framework to research and study from the user perspective. In all, this book reports on the work of some twenty-eight researchers encompassing these topics.

The history of visualization has just begun to be written. In "The Beginnings of Medieval Information Visualization," Frank Marchese explores how early visualization techniques began to appear and evolved as part of a knowledge transfer process linked to medieval education. This historical research sheds light on the invention of visualizations by revealing imagery found in manuscripts from the Carolingian Renaissance. By examining works of early medieval scholars such as Macrobius, Boëthius, Isidore of Seville, and others, he offers insight into their techniques' invention and application.

Richard Brath and Peter MacMurchy explore how to escape the tyranny of two dimensional visualization by employing spheres as visualization primitives to support all manner of representations. Their chapter, "Information Visualization on Spheres," is reminiscent of Edwin Abbott's *Flatland: A Romance of Many Dimensions* (1884), in which these authors reveal to the inhabitants of contemporary visualization flatland how image collections, pie charts, trees, graphs, Euler diagrams, and more may be visualized by expanding into the third dimension. The true tests of these representations, as the authors observe, are based on our ability to perceive complex layers of information mapped onto spheres, and the ability of user interfaces to make the information easily accessible.

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2. F.T. Marchese, E. Banissi (eds.), *Knowledge Visualization Currents*, ISBN978-1-4471-4303-1_3 Springer, London 2013

3. Robert Kosara and Jock Mackinlay,
http://kosara.net/papers/2013/Kosara_Computer_2013.pdf

Shapes and their attributes are archetypal elements of visualization. Richard Brath examines how "The Multiple Visual Attributes of Shapes" may be exploited to encode data for information visualizations in Chapter 3. Prior art from many fields and experiments suggest there are more than half a dozen different attributes of shape that can potentially be used effectively to represent categorical, qualitative, and quantitative data. Wide ranging examples are presented, as well as novel visualizations of text and sentences employing simple shape attributes.

In today's information rich society the term data is applied more broadly than just a few decades ago because it is created continuously today, and encompasses everything we do. Data time-stamps may be employed in a variety of applications to analyse patterns of data activity. *ChronoView*, a visualization technique presented by Satoko Shiroi, Kazuo Misue, and Jiro Tanaka in Chapter 4, contains features that enable users to visualize behaviour patterns in information dense domains such as social media and networking, where the causal relationships related to an event may originate from many sources.

Structuring information hierarchically as a tree is natural to many disciplines from biology to computer science. As trees increase significantly in size, the branching of nodes obscures the data within. The Treemap is a display alternative. It is a space-filling visualization designed for the presentation of hierarchical structures in which each node is represented as a rectangle. The area of the rectangle is proportional to the dimension of the data it contains. The Treemap is tiled with smaller rectangles representing sub-branches of the tree.

Chapters 5 and 6 present two approaches to creating Treemaps. In "Angular Treemaps," Jie Liang, Quang Vinh Nguyen, Simeon Simoff, and Mao Lin Huang discuss how Treemap visualization may be enhanced using an algorithm inspired by "Tangram," an ancient Chinese puzzle game in which seven different pieces cut from a square are rearranged to construct a shape that matches a given outline (Slocum and Jerry 2001).[4]

This concept is adopted using a polygon-based enclosure to interactively partition the display space into several sub-polygons as in the Tangram. The variation created by this angular partitioning algorithm may help users identify specific areas of interest or to fit large data into smaller display areas. In "Edge-Equalized Treemaps," Aimi Kobayashi, Kazuo Misue and Jiro Tanaka discuss embedding various graphs, such as bar charts, within leaf node rectangles. This representation equalizes the horizontal widths of each chart, enabling comparisons of charts by visual inspection.

4. Slocum, J. 2001, *The Tao of Tangram*, Barnes & Noble.

Visualizing the structural and behavioural characteristics of evolving software to support its maintainability and reuse remains a challenge because of its complexity. In Chapter 7, Ugo Erra and Giuseppe Scanniello present a visualization approach to understanding evolving object-oriented software systems based on a forest metaphor. The approach takes advantage of familiar concepts such as forests, trees, trunks, branches, leaves, and leaf colour to display attributes of each software release. A software version is viewed as a forest, allowing software maintainers to navigate, to interact, and to understand the evolutionary nature of changes in code.

It has been said that things happen for a reason. But events often have multilayer interpretations dependent upon one's perspective, thus making them difficult to visualize because the relationships between events is nonlinear, or intertwined, meaning that they cannot be partitioned easily into a simple collection of independent parts. Such visualizations play an important role in discovering cause and effect relationships, and testing of hypotheses within social, historical, and evolutionary contexts. A case study of visualization that fits well within historical analytical events is explored by Masahiko Itoh and Mina Akaishi in Chapter 8, "Visualization for Changes in Relationships between Historical Figures in Chronicles." It demonstrates how a massive number of digitized historical documents can be used to analyse historical events and retell those events with more substantive scientific and analytic underpinnings.

Exploring time-varying data, such as weather or financial and social behaviour, to understand their underlying causative or correlated factors, remains an interesting research problem. Traditionally, Polyline charts are used to represent time-varying datasets. Many examples may be found in newspapers and on the Web, designed to show changes in quantities such as stock prices, sports performance, the weather, and alike. But these charts do not display associated or correlated data. Sayaka Yagi, Yumiko Uchida and Takayuki Itoh present in Chapter 9 an interactive technique for polyline-based visualization and level-of-detail control of tagged time-varying data that tags each time-step with correlated information so that each polyline may be sorted by a tag's attribute. They then provide a method for filtering out unwanted polylines for better visual perception.

Rules of thumb, educated guesses, or common sense are all approaches to problem solving that fall under the general concept of heuristics – experience-based problem solving techniques that afford reasonable solutions to problems when rigorous approaches are impractical. Heuristic approaches to evaluating user interfaces, known as heuristic evaluation, have produced fruitful results. In Chapter 10, Camilla Forsell reviews the

Heuristic evaluation method and recommends how it may be applied to evaluate information visualization tools, concepts, and methodologies. Heuristic evaluation in information visualization remains an open problem that the author addresses by discussing the kinds of methods available, their need for further grounding, and the research challenges that must be met to improve current methodologies.

Understanding the relationship between the perceptual senses and how they affect one another is not only of scientific interest, but also of interest in the fields of marketing and healthcare. In Chapter 11, Arto Lehtiniemi and Jukka Holm report how animated mood pictures may be used to select music. The results of their prototype experiment indicate that mood pictures are a promising way to access music collections and to explore new music. In their evaluation study, the authors show that the majority of the participants expressed the desire to use this kind of application as a complement to other music player applications.

In many situations advanced 3D visualization and interaction techniques have been shown to support user performance of complex spatial tasks more efficiently than 2D visualization. In Chapter 12, Stefan Seipel reports on experiments that shed light on the myth that three dimensions are more effective for visualization than two by comparing 2D and 3D visualizations for the assessment of quantitative information in geographical visualizations.

A Voronoi diagram, named after the Russian mathematician Georgy Voronoi, is a means of partitioning a plane into distinct regions. Beginning with a set of reference sites (e.g. cities on a map), regions are demarcated so they surround these sites in such a way as to contain all the positions in the plane that are nearest to one site than any other. The result of this partitioning is a set of convex polygons enveloping each reference point with which nearest neighbour sites share polygon edges. In Chapter 13, Adam Russell, Karen Daniels, and Georges Grinstein use Voronoi diagrams to assess the quality of visualizations based on radial plots (RadViz), in which each radial axis corresponds to a data dimension. RadViz plots are created by normalizing data for each axis and plotting them within a unit circle. Implementations have been used as data exploration tools for high dimensional data sets, often making it possible to view thousands of dimensions with insightful outcomes. The challenges facing designers of these kinds of plots include which dimensions to use and where to place each dimension optimally around the circumference of the circle that encapsulates all data points. Too many dimensions produce noise, while improperly positioned dimensions may lead to perceptions of data correlations that do not exist. The authors demonstrate that their Voronoi diagram analysis of RadViz visualizations exposes a link between visualization quality, and selection and arrangement of dimensions. It holds promise for improving these visualizations in the future.

Target Audience

The intended audience for this collection includes researchers from industry and academia whose backgrounds reflect a diverse range of ideas, applications, and insights from the information and knowledge visualization communities. This volume provides them with unique examples of applied information visualization in areas of scholarship traditionally less associated with visualization, such as history, management, and the humanities. Finally, it reveals the evolving features of visualization, with examples of early visualization that enable us to understand cultural aspects of information and knowledge visualization.

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PART I

INFORMATION VISUALIZATION - TECHNIQUES

CHAPTER ONE

THE BEGINNINGS OF MEDIEVAL INFORMATION VISUALIZATION

FRANCIS T. MARCHESE

Abstract

This chapter considers the origins of the earliest designs for medieval information visualizations documented in manuscripts from the Carolingian Renaissance (c. 780–c. 900). Works by Macrobius, Boëthius, and Isidore of Seville are examined. These works are placed within the timeline of information visualization, and suggestions are made as to their antecedents.

Introduction

The Middle Ages (c. 450–1450) was a time of transition and upheaval. After the fall of the Roman Empire in the West, monastic communities arose as preservers and disseminators of ancient knowledge, and sources of proto-scientific research. Early scholars grappled with sacred and profane information and invented charts and diagrams to confer visual form to abstract concepts from classical, religious, and secular texts. Begun as a few incidental charts created to help communicate concepts within their manuscripts, these graphical representations would evolve by the twelfth century into routine formats for rendering scientific, philosophical, and theological truths.

Some of the earliest examples of medieval information visualization are preserved and replicated in manuscripts from the Carolingian Renaissance (c. 780–c. 900) onward [1][2]. These manuscripts disseminated visualizations that were devised to either clarify texts of early authors, or were created by early authors as parallel depictions of information contained within their texts. Imagery is reviewed that has been addressed in the histories of art, religion, and science, reconsidering it from the perspective of the history of information visualization. Beginning with a review of the historical context underlying early medieval scholarship, the chapter focuses on texts available for study during the Carolingian Renaissance. This is the earliest period with manuscripts containing the visualizations discussed here. Subsequent sections describe contributions to information visualization by the early medieval authors Macrobius, Boëthius, and Isidore of Seville. A final discussion concerning the origins of these visualizations closes the chapter.

Background

The decline of the Roman Empire throughout Western Europe and its disintegration in the fifth century engendered a loss of classical knowledge linked to the long tradition of Hellenistic scholarship communicated through the ancient Greek language. Although Greece had been under Roman rule as early as 146 BCE, and formally annexed by Augustus in 27 BCE, Greek remained the recognized language of the Eastern Mediterranean and the language of Roman erudition. A nearly complete disengagement with Greece meant that by about 450 CE the majority of classical texts available to scholars were either written in the original Latin or translated from the Greek into Latin. In the latter case, few translations existed from classical Rome largely because the educated Roman elite were trained to read Greek, and saw little reason to translate these works [3, chap. 7].

The available Roman manuscripts with the greatest impact on early medieval authors and scholars were written by Pliny the Elder (23–79 CE), historian, naturalist, natural philosopher, and author of *Natural History*, a comprehensive encyclopedia of the natural world; Marcus Vitruvius Pollio (d. 15 BCE), architect and engineer, who wrote *De Architectura* (On Architecture); Martianus Capella (c. 410–439 CE), writer of *On the Marriage of Philology and Mercury*, an encyclopaedic work posed as an allegory that encompassed the seven liberal arts (grammar, logic, rhetoric, arithmetic, geometry, astronomy, and music), that became a major influence on Medieval education; and finally Macrobius Ambrosius Theodosius (c. 395–423 CE), commonly called Macrobius, writer of *Commentary on the Dream of Scipio* (*Commentarii in Somnium Scipionis*), which laid out a comprehensive philosophy of nature covering arithmetic, astronomy, and cosmology.

Works in Latin that were available included the Vulgate Bible, translated by St. Jerome in the late fourth century; Plato's *Timeus,* translated into Latin first by Cicero (106–43 BCE), and later by Calcidius (a late fourth century philosopher); Euclid's *Elements*; and Porphyry's *Introduction to Aristotle's Logic*, translated by Anicius Manlius Severinus Boëthius (480–c. 524 CE). In addition, Boëthius wrote handbooks based on Roman and Greek sources covering logic (*In Ciceronis Topica*), music (*De institutione musica*), and arithmetic (*De institutione arithmetica*). By 524, the year of Boëthius's death, it remained to be seen whether any of these works, other than the Bible, would be extensively studied [4, chap. 3].

Medieval scholarship faced manifold problems. The gradual dissolution of the Roman Empire brought degradation in education and an increase in illiteracy. Early medieval monasteries concentrated on studying the Bible, not pagan works such as those created by natural scientists and philosophers. Copying manuscripts was not a priority. Performed with little oversight, usually at the whim of a literate religious, the crude artisanal character of these works mitigated any formal effort at wide dissemination.

One important thing that needed to occur was a reorientation of thought towards the kind of knowledge that was acceptable for study within a monastic community. This conceptual change would derive from the writings of Augustine of Hippo (St. Augustine, 354–430), North African Bishop of the Christian Church, who merged the Greek philosophical tradition with the Judeo-Christian religious and scriptural traditions [5].[1] Augustine's message for early medieval scholars was that the Bible was not the only source of truth; truth could be discovered anywhere. Since the universe was God's creation, any truth would naturally stem from Him.[2] The implications for medieval scholarship were two-fold. First, history, philosophy, dialectic, and rhetoric – the core of the Hellenic scholarly tradition – were neither secular nor human, they came from God. So these works could be employed as part of monastic practice. Second, since truth was "discovered," not created [6], Augustine's philosophy endowed the search for truth with an epistemic dimension that would eventually lead to the development of proto-scientific research practice by early scholars, such as Venerable Bede (c. 672–735) [7].

Literacy was addressed during the reign of Charlemagne (c. 742–814). As the lands under his dominion continued to grow during the eighth

1. Augustine was not only a major influence on medieval philosophy, but also influenced the writings of a long line of philosophers including Martin Luther, Emanuel Kant, Martin Heidegger, Friedrich Nietzsche, and Bertrand Russell.

2. *De Doctrina Christiana*, II, cap. 17: "Quisquis bonus verusque Christianus est, Domini sui esse intelligat, bicumque inveneritv eritatem" (let every good and true Christian know that Truth is the truth of his Lord, wherever found).

century, there were insufficient literate individuals to help administer the expanding state. For the Church at that time, illiteracy meant that not all priests possessed the requisite skill to read the Vulgate Bible. Language and communication were issues as well. The decline of the Roman Empire had engendered a regionalization of Latin dialects, the future modern romance languages, which seriously impeded communication across Europe. During the last quarter of the eighth century Charlemagne executed a program of reforms that would transform the state, and become known as the Carolingian Renaissance [8]. A major part of his programme was to attract many of the leading scholars of his day to his court. With the aid of one of these scholars, the English monk Alcuin of York (c. 735–804), who arrived at his court in 782, a programme of cultural revitalization and educational transformation was undertaken to restore old schools and found new ones throughout his empire, each under the guidance of a monastery, cathedral, or noble court. A standard curriculum was developed that established the *trivium* (grammar, logic, and rhetoric), and *quadrivium* (arithmetic, geometry, music, and astronomy) as the basis for education, and textbook writing was undertaken. A standardized version of Latin was also developed that became the common language of scholarship and supported pan-European administration of the empire. Writing was standardized too. The Carolingian minuscule was introduced to increase the uniformity, clarity, and legibility of handwriting. It was used between 800 and 1200 to write codices, pagan and Christian manuscripts, and educational texts [9].

Medieval Visualization

In general, early medieval scholars were more concerned with the study and preservation of classical texts than generating new scholarship. For example, in Eastwood's discussion of Roman astronomy's impact on Carolingian science education [10], he considers the four most influential, widely disseminated classical scientific texts that can be found in the manuscripts originating during the Carolingian Renaissance [3, p. 197]: Macrobius's *Commentary on the Dream of Scipio*, Pliny's *Natural History*, Martianus Capella's *On the Marriage of Philology and Mercury*, and Calcidius's *Commentarius* (Commentaries) on Plato's *Timaeus*. The significance of these works from an information visualization perspective is that they contain diagrams explicitly created to elucidate concepts within their respective texts. In some cases the diagrams that appeared in manuscripts needed to be invented by medieval readers, because none were specified in the original source (e.g. Pliny, Capella). In other cases, diagrams in an original manuscript (e.g. Calcidius) did not survive uncorrupted into the ninth century, necessitating either their reconstitution or invention anew. Finally, there were manuscripts in which the original author (e.g. Macrobius) explicitly stated how these diagrams were to be constructed. But even precisely defined procedures were misinterpreted. As Eastwood has observed, Carolingian students and teachers alike were challenged by the process of transforming text into visualizations. Thus, given their insufficient knowledge of geometry, and their difficulty in assessing a diagram's correctness, the design, construction, validation, standardization, and integration of these diagrams into pedagogical practice would need to evolve over time.

Most examples of information visualization are found in Carolingian manuscripts associated with the quadrivium, the segment of Carolingian education focused on arithmetic, geometry, music, and astronomy, with the great preponderance of charts and diagrams being astronomical or cosmological in nature (c.f. Eastwood [10] for a complete discussion). Works by three seminal authors will be considered herein: Macrobius's *Commentary on the Dream of Scipio* (*Commentarii in Somnium Scipionis*), Boëthius's *De institutione arithmetica* and *De institutione musica*, and Isidore of Seville's (c. 560–636) *Etymologiae* (*Etymologies*) and *De natura rerum*. These three scholars created manuscripts that were a significant influence on medieval thought and produced writings containing diagrams that delineated the origins of medieval information visualization.

Macrobius

Little is known precisely about Macrobius Ambrosius Theodosius [11]. He was a Roman who prospered during the early fifth century, perhaps born in North Africa. He mastered Greek, but with less facility than his native Latin. He is chiefly known for a few major writings: *Saturnalia* [12], a compendium of ancient Roman religious and antiquarian lore; the *Commentarii in Somnium Scipionis* (*Commentary on the Dream of Scipio*), which was an important source of Platonism in the Latin West during the Middle Ages; and *De differentiis et societatibus graecilatini queverbi* (*On the differences and similarities of the Greek and Latin verb*), which is now lost.

Macrobius's *Commentary on the Dream of Scipio* [13] is an explanation and amplification of text from the final section of Cicero's *De re publica*, a treatise on the state of the Roman republic. The *Dream of Scipio* appears in the sixth and last book of Cicero's work [14], in which he employs a Socratic dialogue to communicate a cosmic vision experienced by Scipio Aemilianus, Roman military tribune and future consul, to elucidate Rome's relation to the cosmos. In effect, *Scipio's dream* is a cosmological treatise transformed by Macrobius's *Commentary* into an early medieval astronomical primer.

Macrobius relied substantially on visualization to convey Cicero's ideas. He believed the visual channel was a far faster means of communicating concepts than speech or text [15]. Five diagrams are integrated into his *Commentary*, with instructions for drawing four of them offered as part of its narrative stream [15]. Fig. 1.1 depicts a map of the Earth divided into frigid, temperate, and torrid zones taken from a manuscript created around the year 820 in northern France, based on Macrobius's c. 430 text (MS Lat. 6370, fol. 81r, Paris, Bibliothèque Nationale de France) [16]. The letters along the circle's periphery refer to their respective narrative texts in *Commentary* and are intended to enhance the reader's understanding of Macrobius' explanation of zonal theory.

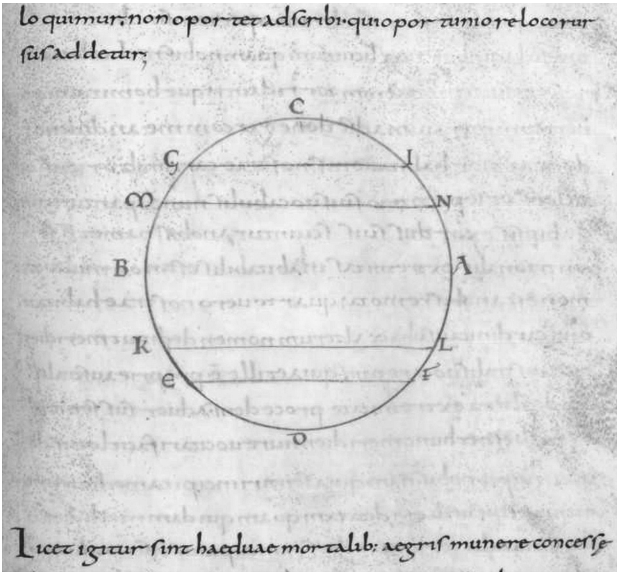

Fig. 1.1 Zonal map of the Earth from Macrobius's *Commentary on the Dream of Scipio* (MS Lat. 6370, fol. 81r, Paris, Bibliothèque Nationale de France).

Macrobius's zonal map organized the spherical world into five climate zones: the northern and southern frigid zones, northern and southern temperate zones, and an equatorial tropical zone. Only two of these zones were believed to be inhabitable, with the known world populating the northern temperate zone's Eastern Hemisphere. Because most surviving zonal maps are traceable to illustrations in Macrobius's *Commentary*, this map is also known as a "Macrobian" map.

The significance of the visualizations in Macrobius's *Commentary* is not that they are early visual representations of information, which they are, but rather that they represent the results of a formalized process for visualizing information which Macrobius explicitly states as part of his narrative. Here is part of his procedure for generating Fig. 1.1 taken from Hiatt's translation from the Latin [15]:

> …let there be [drawn] a circle of earth on which the letters ABCD are inscribed; and around A, let N and L be written; around B, the letters M and K; and around C, G and I; and around D, E and F…

Macrobius goes further to clarify the meaning of the relationships among the parallel lines:

> …the two spaces thus opposite each other, that is the one from C up to the line which is drawn from I, the other from D up to the line which is drawn from F, should be understood to be 'frozen with perpetual winter', for the upper one is the furthest northern zone, the lower the furthest southern.

The difference between "learning something" and "learning to do something" clearly was important to Macrobius, otherwise he could have easily omitted the procedural details for diagram creation. The ultimate result is that his *Commentary* is transformed, at least in part, from an informational treatise to a handbook along the lines of Vitruvius's *De Architectura*, in which information sets the context for a formal discussion of architectural and engineering practice.

Boëthius

Anicius Manlius Severinus Boëthius (c. 475–7 CE–c. 524? CE) was born into an elite Roman family, lost his father at an early age, and was subsequently adopted by Quintus Aurelius Memmius Symmachus (d. 526), a Roman aristocrat and historian of the sixth century, who belonged to the Symmachi, one of the richest and most influential senatorial families in Rome. Under the tutelage of his adopted father, Boëthius rapidly grew intellectually – learning Greek, studying ancient Greek scholars, and developing an ambitious agenda of translating all the works of Aristotle and Plato into Latin, in order to make them available as part of the quadrivium, the term he created to define the collection of the four-fold path of learning in the mathematical sciences: arithmetic, music, geometry and astronomy. He also followed in Symmachus's footsteps entering public office to become the highest ranking official in the court of the Ostrogothic king Theodoric the Great (c. 454–526), ruler of post-Roman Italy, the man who would ultimately condemn him to death for the act of treason [17].

Boëthius, along with Augustine and Aristotle, is considered to be a fundamental philosophical author of late antiquity. His most famous work *De consolatione philosophiae* was written during his imprisonment in Pavia before his execution there in 524 [18]. His treatises on arithmetic, geometry, and music were not only essential contributions to the quadrivium, but also contain a wealth of visualizations. The sources for his works on arithmetic, *De institutione arithmetica* [19], and music, *De institutione musica*, are believed to have been Pythagoras, Plato, Aristotle, and, in particular, his direct translations from the Greek of Nicomachus of Gerasa's (c. 60–c. 120) works, *Introduction to Arithmetic* [20] and *Manual of Harmonics* [21].

Boëthius believed as Macrobius did that visual representation of information was an important pedagogical tool for clarifying concepts. As a result, his works on arithmetic and music are filled with illustrations. Fig. 1.2 shows a diagram from Book 1 of *De institutione arithmetica* taken from a mid-ninth century manuscript created in the region around Laon, France (MS Cod. Sang. 248, fol. 10a, St. Gallen, Stiftsbibliothek) [22], which he uses as part of a discussion of "the nature of the odd times the even." At the core of this diagram is a 4 x 4 square array consisting of even numbers that are related through multiplication. Boethius takes a cartographic approach to the table's design,[3] employing the terms "latitude" and "longitude" to designate rows and columns, respectively, and connecting these with arcs, each of which is labelled with a number that is the product of two numbers anchoring each arc. For example, the multiplication of the far left number 12 by the far right number 96 of the top row produces 1152 (īcLii), the number viewed along the apical arc.

3. It is reasonable to assume that Boëthius's use of latitude and longitude was influenced by his reading and translation of Ptolemy's works. Ptolemy (Claudius Ptolemaeus, c. 90–c. 168 CE) has been credited with the invention of these terms, and was the first individual to place a grid on a map [23, p. 3].

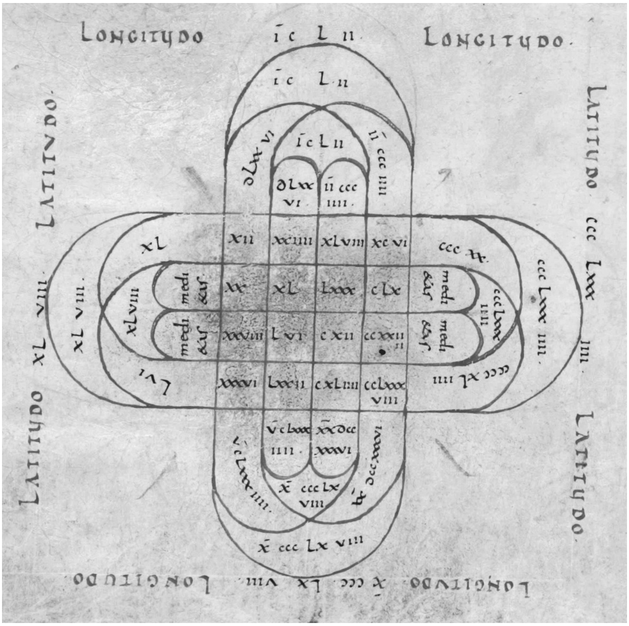

Fig. 1.2 Arithmetic diagram from Boëthius's *De Arithmetica* (MS Cod. Sang. 248, fol. 10a, St. Gallen, Stiftsbibliothek).

Arcs are an important part of Boëthius's graphical schema. He uses them in his discussions of arithmetic and geometric ratios, and they are integral to his treatise on music, which has its foundation in ancient Greek musical theory. Fig. 1.3 displays an arc diagram taken from a twelfth century version of Boëthius's *De institutione musica* (MS VadSlg. 296, fol. 53r, St. Gallen, Kantonsbibliothek, Vadianische Sammlung) [24]. It shows the ratios: 4:2 (*dupla*) that yields the octave (*diapason*); 6:2 (*tripla*), that represents the twelfth (*diapason ac diapente*); and 6:4, a ratio that governs the fifth (*diapente*).

In Fig. 1.4 [24] Boëthius goes beyond this simple arc diagram by charting three tetrachord genera for the monochord. The monochord is a single stringed musical instrument invented by Pythagoras to study ratios that eventually became an integral part of medieval music education. A tetrachord is a four note series having a specific pattern of whole and half steps that served as a basis for Greek and Medieval melodic construction. Here, the three monochord genera are plotted from top to bottom: the diatonic genus (e.g. whole, whole, half steps), chromatic genus, and enharmonic

Fig. 1.3 Musical arc diagram from Boëthius's *De institutione musica* (MS VadSlg 296, fol. 53r, St. Gallen, Kantonsbibliothek, Vadianische Sammlung).

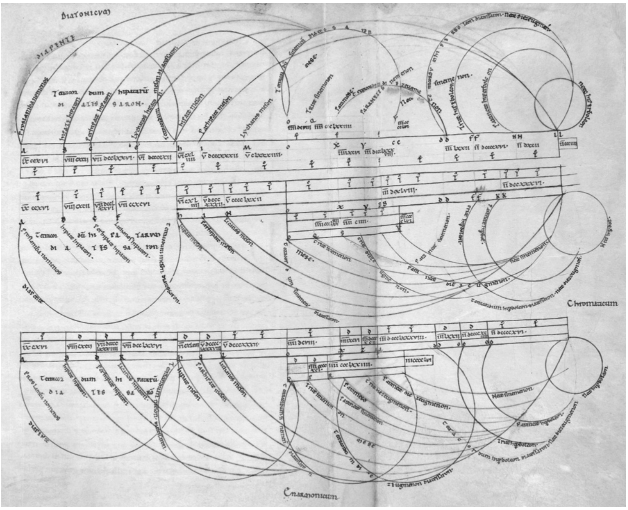

Fig. 1.4 Musical arc diagrams for the monochord from Boëthius's *De institutione musica* (MS VadSlg 296, fol. 96r, St. Gallen, Kantonsbibliothek, Vadianische Sammlung).

genus. What is immediately noticeable from this image is its overall complexity. It is probably the most complex visualization of early medieval times, and concomitantly the most difficult to craft and understand, even with direct reference to the associated text. Yet, this visualization, and nearly all other illustrations in Boëthius's manuscript were copied and disseminated throughout the Middle Ages, making *De institutione musica* the standard musical textbook for over 400 years.

Clearly, these illustrations were an important part of musical pedagogy that justified the investment of significant skill and effort required for their reproduction.

Isidore of Seville

Born in Cartagena, Spain, around 560 CE, Isidore of Seville is considered one of the greatest scholars of late antiquity, best known as the first encyclopedist of the Middle Ages [25]. His *Etymologiae* (*Etymologies*) is a wide-ranging work in twenty books that quotes over 154 classical authors encompassing grammar, religion, law, agriculture, medicine, and more [26]. *Etymologiae* was the textbook most in use throughout the Middle Ages, regarded so highly as a repository of classical learning that, in great measure, it superseded the use of the individual works of the classics themselves, full texts that were no longer copied and thus were lost. *Etymologiae* and *De natura rerum* [27] are two of his works that are of interest to the history of information visualization, because they contain diagrams he considered useful for the communication of ideas. In particular, *De natura rerum* contains seven figures, six of which are circular diagrams called *rotae*, that Isidore employs for conveying a variety of concepts including cartography, computus, the elements, and the relation of man to the cosmos. Two kinds of *rotae* will be considered here.

Figs 1.5 and 1.6 display respectively two examples of *rotae* that appear in copies of *De natura rerum*, the first diagram produced in the women's cloister of Chelles on the Marne east of Paris in about the year 800 (MS Cod. Sang. 240, fol. 124, St. Gallen, Stiftsbibliothek) [28], and the second created between the years 760 and 780 at St. Gall (MS Cod. Sang. 238, fol. 325, St. Gallen, Stiftsbibliothek) [29].This schema was designed to communicate the concordance between the Roman (Julian) and Egyptian calendars [30]. Egyptian calendars were composed of twelve 30 day months, with five days remaining at the end of the year. Each *rota* serves to convey the number of days that the start of each Egyptian month precedes the onset of each Roman month by. Beginning at five o'clock on the *rota* in Fig. 1.5, the labels of the outer ring are read clockwise as the months January through to December, for the twelve radial divisions of the circle. The second ring inward contains Roman numerals followed by the letters *KL*, which specify the number of days that the beginning of the Egyptian month precedes the *kalends* (*KL*), the first day of the Roman month. The three inner rings may be read from the centre outward in the following way to give the number of days in each month in the Egyptian calendar: *Roman numerals – diebus (days) – month name*.

The contents of Fig. 1.6 differ in a number of ways from Fig. 1.5. January begins at approximately nine o'clock on the *rota*, rather than five. Its inner ring displays the number of days per month according to the Julian calendar, rather than the Egyptian. And the *rota*'s centre contains an illustration instead of being blank. Although *rotae* centres are typically blank, as in Fig. 1.5, many contain text or illustrations. For example, a *rota* in a St. Gall manuscript from the second third of the ninth century (MS Cod. Pa 32, fol. 59r, Zofingen, Stadtbibliothek) [31] displays at its centre the word "menses" – Latin for month. The letters are arranged in the form of a cross, with a single letter "e" at its centre. It is then read top-to-bottom, and left-to-right. The central medallion of Fig.1.6 portrays an individual flanked by two birds. It has been suggested that this represents Christ as a young man, but it may as easily represent the document's author, or perhaps the scribe's abbot, or scriptorium director. Lending credence to the former proposition is that if these birds represent raptors, perhaps eagles,[4] they symbolize someone of rank or authority.

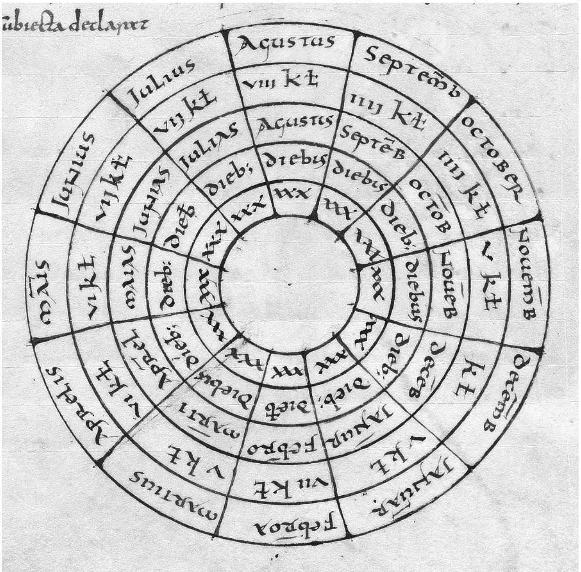

Fig. 1.5 Calendar, *De natura rerum*, Isidore of Seville, c. 800 **(**MS Cod. Sang. 240, fol. 124, St. Gallen, Stiftsbibliothek).

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4. Here the birds are reminiscent of a Visigothic design. See, for example, a pair of sixth century eagle fibula from southwest Spain in the collection of the Walker Art Museum (54.421, 54.422) [32].

A sufficient number of images of a young Christ were created during early Christendom to support this ascription.[5] One notable example is found within the apse mosaic of Ravenna's Basilica of San Vitale, created between 526 and 547, which displays a youthful Christ Redeemer sitting on the sphere of the world. Finally, *De natura rerum* embodies Isidore's understanding of the physical universe, arranged into a narrative format that follows the Bible's order of creation. It should be remembered that Isidore was a Church Bishop, whose charge was to spread Christian teaching and address paganism, so an image of Christ at the centre of "time" makes conceptual sense.

Fig. 1.6 Calendar, *De natura rerum*, Isidore of Seville, c. 760–780 (MS Cod. Sang. 238, fol. 325, St. Gallen, Stiftsbibliothek).

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5. Chavannes-Mazel [33] discusses the history behind the dual renderings of Jesus in early Christian art: the Hellenistic Jesus, eternally youthful; and the classical Christ, the bearded wise God among us. Although the latter rendering of Christ was codified in the East in the late sixth century, the West did not standardize on this scheme until the late twelfth century, thus reinforcing the argument for Christ at the centre of Isidore's calendar from this late eighth century manuscript.