Chapter 3
Tables and Early Information Visualization

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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

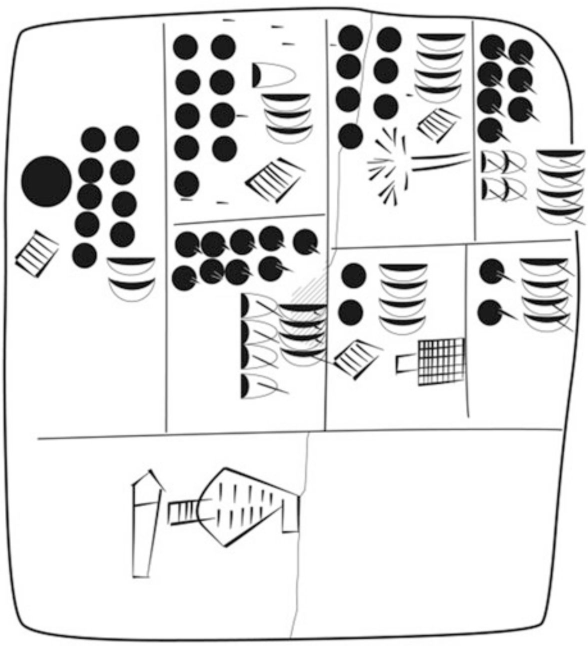

Fig. 3.1 Uruk III tablet (MSVO 3, 51, Louvre Museum, Paris, France). (Drawing courtesy of Englund [18])

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

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

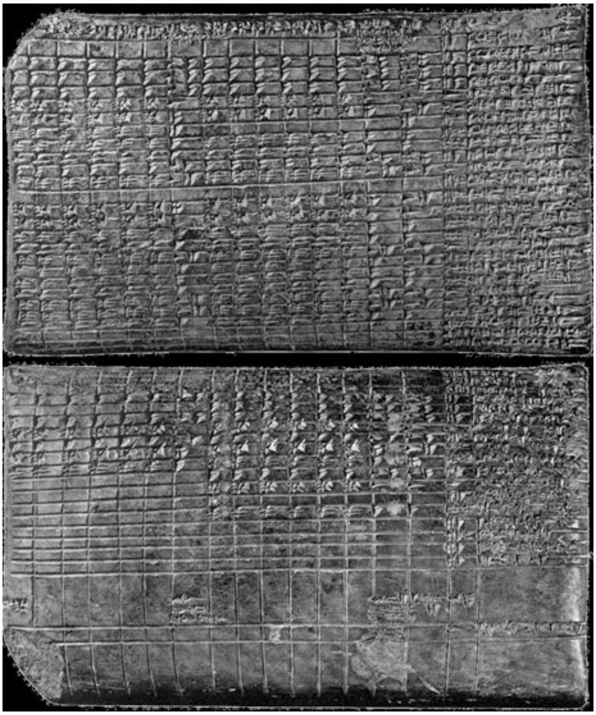

Fig. 3.2 Cuneiform tablet, temple of Enlil at Nippur (CBS 3323, University of Pennsylvania). (Reproduced from [23])

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

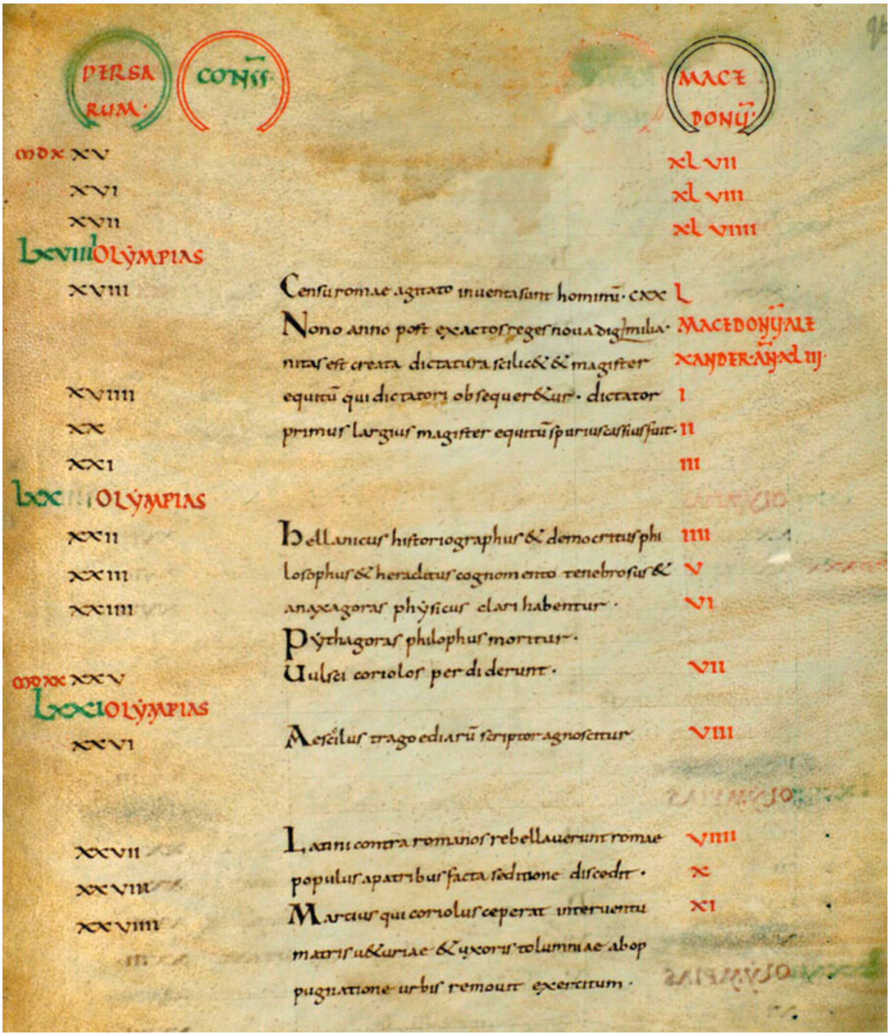

Fig. 3.3 Jerome's *Chronicon* (Merton MS. 315, fol. 96r). (Reproduced by permission of the Warden and Fellows of Merton College, Oxford)

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

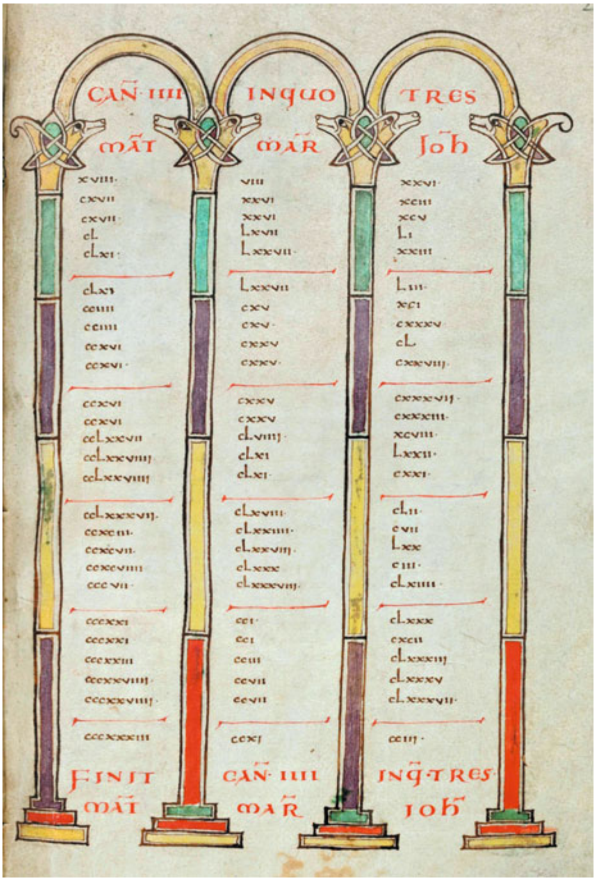

Fig. 3.4 Eusebian canon table from the *Gospels of St. Ursanne* (MS. 34, f. 21, Porrentruy, Jura Canton Library)

[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,

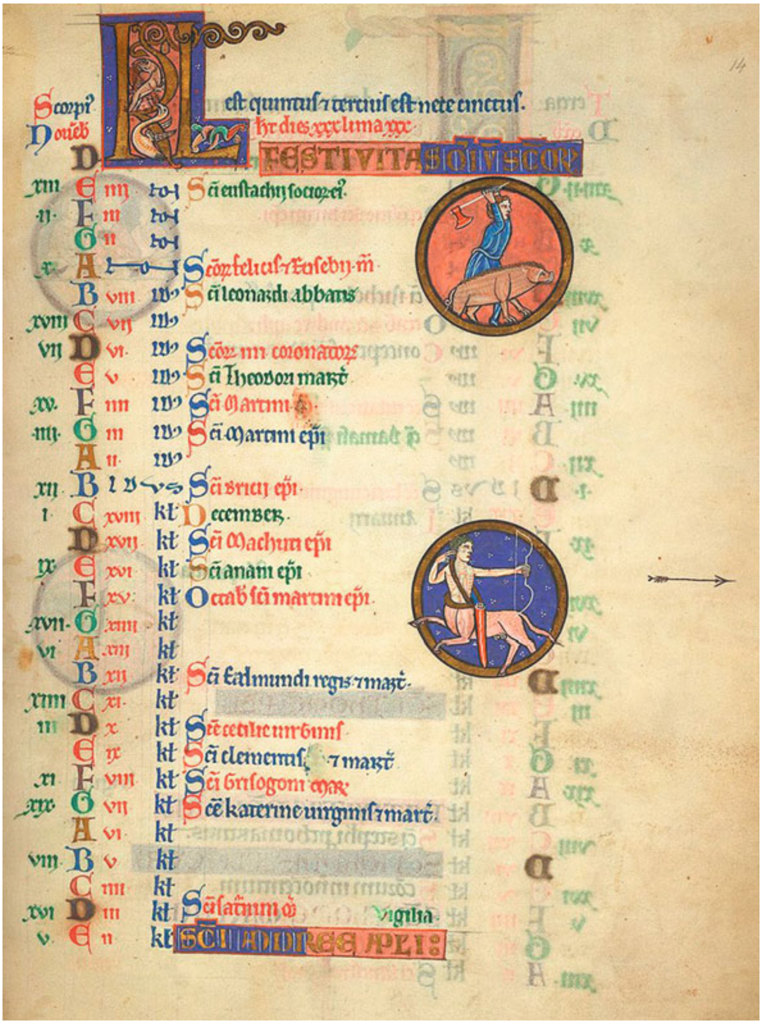

Fig. 3.6 Calendar, November, English psalter (MS. Royal 1DX, f. 14, British Library). (©British Library Board)

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

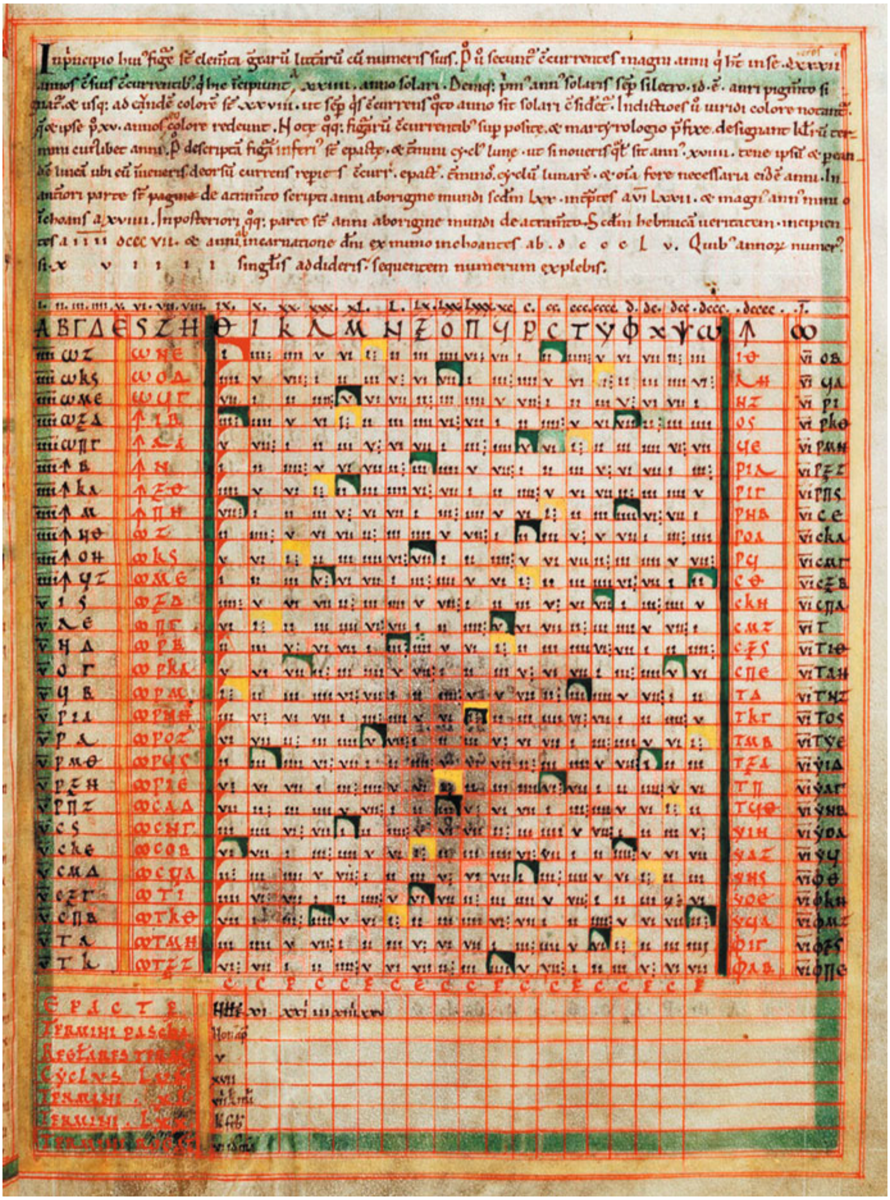

Fig. 3.7 Computus table, Dionysius Exiguus (MS. 17, f.30r, St. John's College, Oxford University). Reproduced by permission of the President and Fellows of St John's College, Oxford

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

[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

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.

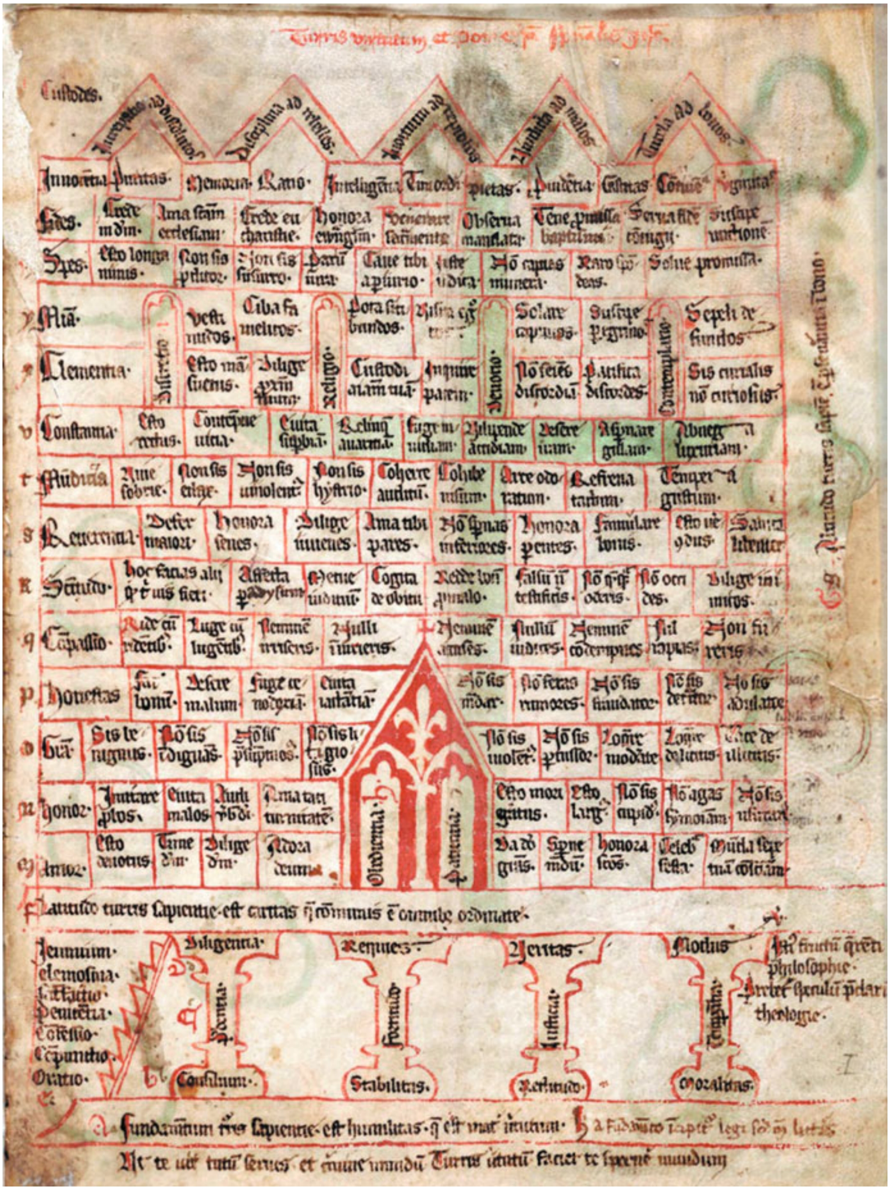

Fig. 3.10 Tower of Wisdom (Beinecke MS. 416, Beinecke Rare Book and Manuscript Library, Yale University)

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

[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].

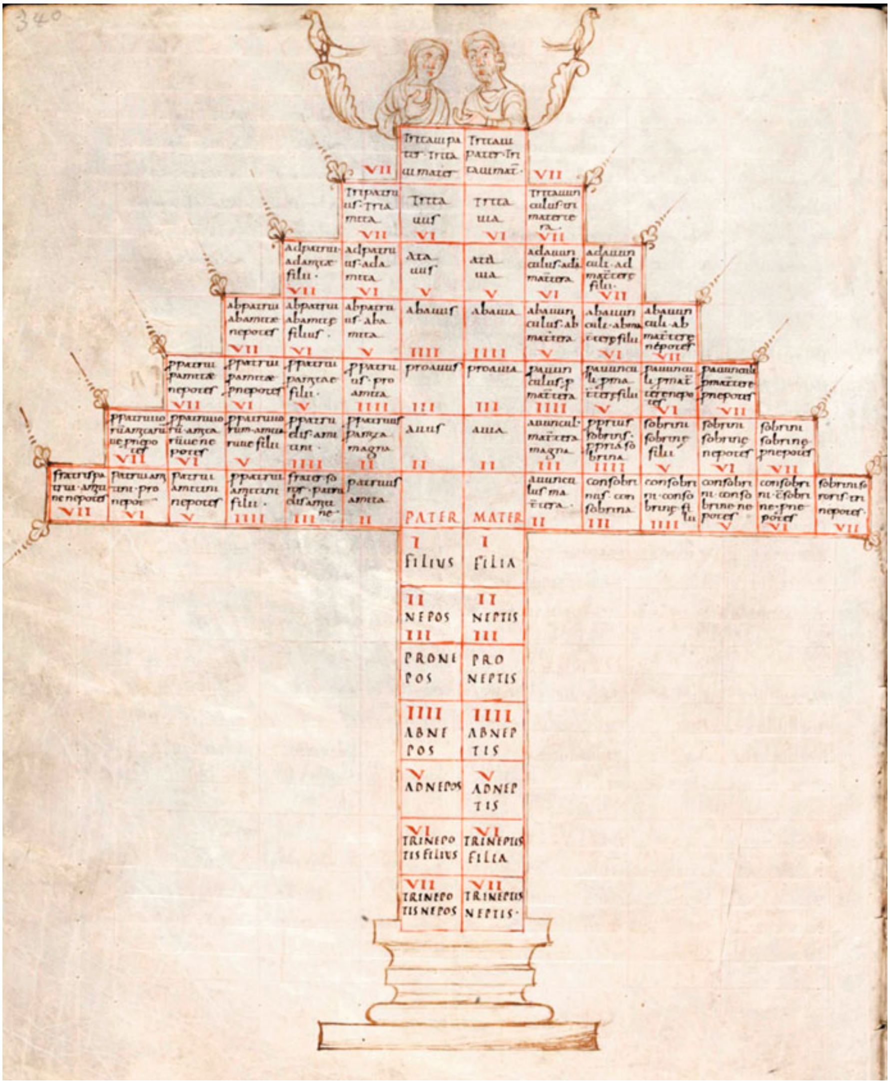

Fig. 3.11 Consanguinity table (Cod. Sang. 231, p. 340, St. Gallen, Stiftsbibliothek)

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

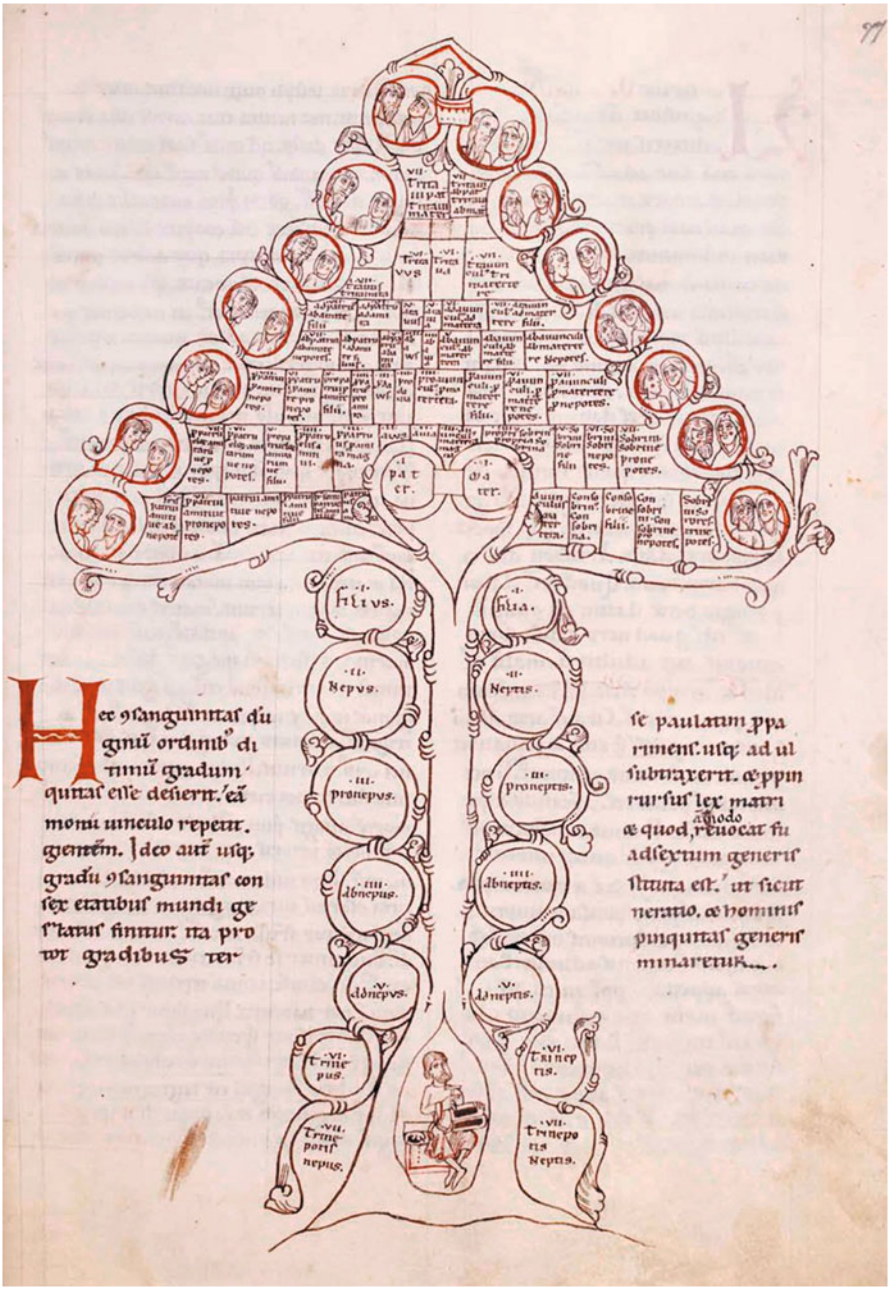

Fig. 3.12 Consanguinity table (MS. Harley 3099, f. 77, British Library) (©British Library Board)

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.

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