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Exploring the Origins of Tables for Information Visualization

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***Abstract*— This paper considers the deep history of tables as visualization modalities. It covers four kinds of tables that have appeared between 1900 BCE and 1300 CE: Sumerian accounting tables, chronicles, canon tables, and medieval calendars as representations of some of the earliest milestones in information visualization. Analysis of these tables demonstrates 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.**

Keywords - information visualization, tables, computus, calendars, medieval art.

I. Introduction

This paper considers the deep history of tables as visualization media. 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, organizing 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.

Recently, 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. This paper proceeds in the same way, but steps back in time to focus on the early history of tables and their uses for the organization of information. It is concerned with exposing the visualization community to the kinds of tabular visualizations that appeared between 1900 BCE and 1300 CE. People throughout time have needed to extract, reorganize, and reconnect information, not only for documentation and communication, but also for usability. As such, the problems faced were computational in nature, requiring invention of algorithms and visual representations as interfaces to their information.

This paper will discuss four kinds of tables from history: Sumerian accounting tables, chronicles, canon tables, and medieval calendars. 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 little attention to tables in general as a mode of information communication [12], mostly focusing on the history of the periodic table [13]. But, like the periodic table, the tables covered herein have transformed the way information has been communicated and used.

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

II. 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 an 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 Ptolmey 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 centuration, which, according to David Turnbull, turned “all Europe into one vast sheet of graph paper” [17]. The ancients

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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.

The gridding of space creates containers – locations that may hold a variety of information. The contents of elemental positions within the periodic table and spreadsheet 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 came the need 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 who traded agricultural and animal products for metals and luxury goods with geographically distant kingdoms. Documentary evidence for these accounting practices is found in over five thousand 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.

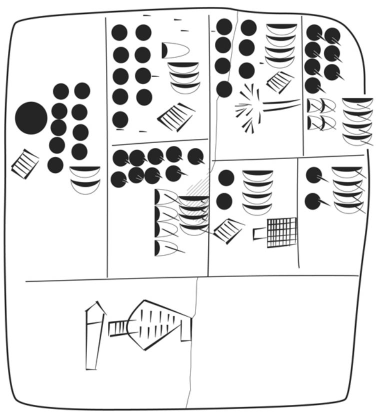

Figure 1: Uruk III Tablet, (MSVO 3, 51, Louvre Museum, Paris, France). Drawing courtesy of R. Englund.

Figure 1 shows a drawing of a tablet from the Uruk III period (ca. 3200-3000 BCE) containing an accounting of deliveries of barley and malt from two individuals for the production of beer. The bottom row bears the name of the official in charge. The table 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 [19]. 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].

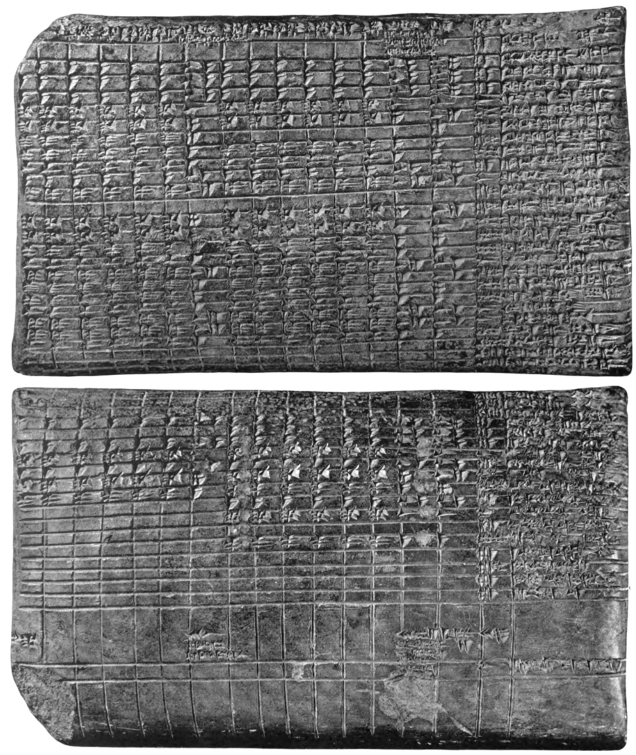

Figure 2: Cuneiform tablet, temple of Enlil at Nippur, (CBS 3323, University of Pennsylvania). Reproduced from [22].

III. Sumerian Accounting Tables

The first systematically structured tables (see e.g. Figure 2) originated in Mesopotamia about 1850 BCE [21]. 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, Eleanor Robson has found striking similarities with contemporary counterparts [21]. These similarities may be seen in Figure 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 forty-six temple personnel by its bursar Ḫunabi for the year 1295 BCE [22]. 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 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” [21].

IV. 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) [23]. 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 [24]. 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 [25]. 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 [26]. 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 chronographical 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 (A.D./B.C.) 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 multi-column 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 and 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 *Chronicle* 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 – 379 CE; publishing his *Chronicon* in 380 CE [31]. Figure 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.

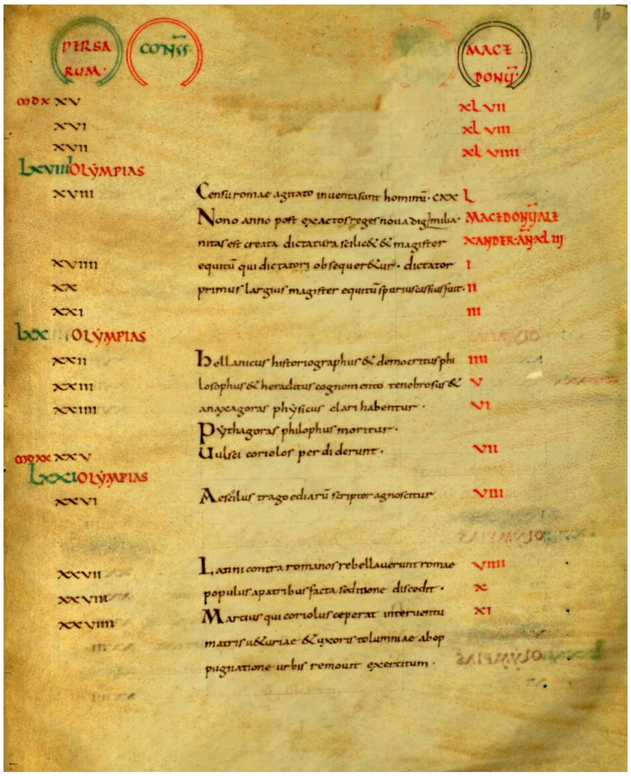

Figure 3: Jerome's *Chronicon,* (Merton MS 315, fol. 96r). Reproduced by permission of the Warden and Fellows of Merton College, Oxford.

V. 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 1165 self-contained passages distributed across Matthew (355), Mark (235), Luke (343), and John (232) [32]. The challenge faced by a student of the 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 cross-correlated 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 is exhibited in Figure 4 (MS. Egerton 608, fol. 11, British Library). It is drawn from a gospel book that originated at the Monastery of St Willibrord, Echternach, Germany; produced during the 2nd or 3rd quarter of the 11th century. This is Canon Table IV, 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 this canon table 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's 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 IV, 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 fifty 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].

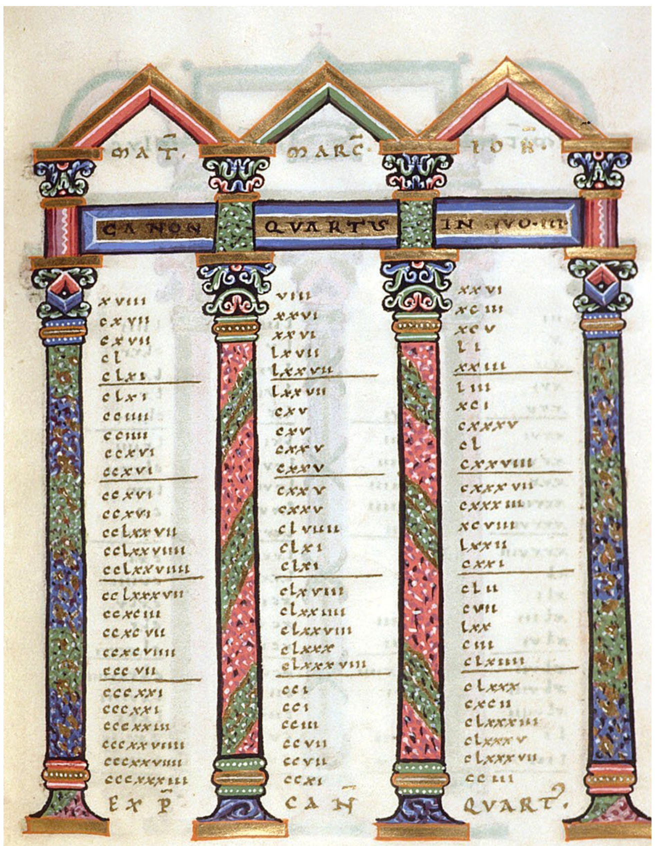

Figure 4: Eusebian canon table for Matthew, Mark, and John, © British Library Board (MS. Egerton 608, fol. 11, British Library).

VI. Medieval Calendars

Keeping track of time was important to 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 5 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, 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) [24].

Figure 5: Calendar, November, English Psalter, © British Library Board (MS. Royal 1DX, fol. 14, British Library).

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 3rd 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 calender because in some years the Jewish calender placed Easter's date either before the vernal equinox or not on Sunday. The First Council of Nicaea in 325 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 6 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 12th 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 x 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 boarders) of Figure 6. Color flags designate cells marking the beginning of solar cycles (yellow), and cells which signal the beginning of *indictions* (green) [38]. Indictions is 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 envelope 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 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 calenders 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 Figure 5). By employing only the first two columns of the table in Figure 5, 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) by the Limbourg Brothers.

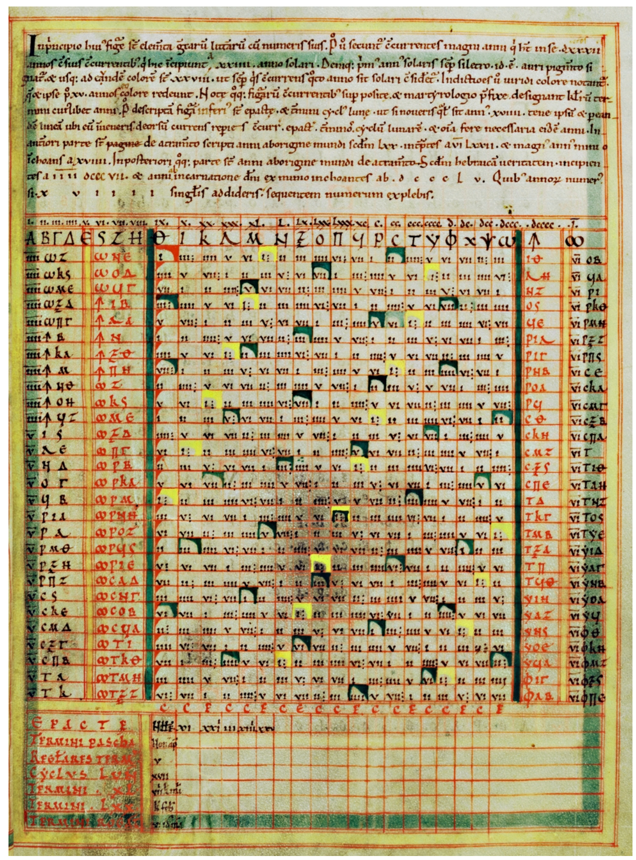

Figure 6: Computus Table, (MS. 17, fol. 30r, St. John's College, Oxford). Reproduced by permission of the President and Fellows of St John's College, Oxford.

VII. Analysis

Wainer has set forth rationales for table usage and design: exploration, communication, storage, and illustration [14][15]. 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 the canon table's structure logically organizes the gospel texts.

If longevity is an effective measure of the communication capability of these tables, then they are all highly effective. The 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. In addition, the structure of each table supports the creation of narratives. The temporal structure of Eusebius's *Chronicles* and 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 (Figure 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 [40]. 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 Figure 6 explains a color coding scheme attributed to Abbo of Fleury (c. 945 – 1004) [38]. Table cells associated with solar and bureaucratic cycles were highlighted with yellow and green respectively, in order to highlight their temporal patterns for ease of visualization. And the specification of important medieval calendar dates in red, which became known as red letter days, is traceable as far back as the Romans.

VIII. Conclusion

The five tables investigated here appeared between 1300 BCE and 1300 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 4000 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.

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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