METRIC SYSTEM. (*See Tables, pp. 218-19*).

The Metre is 1/10-millionth of the Equator to Pole surface-distance; the **gram**, a cube centimetre (millilitre); the **litre**, a cube decimetre, or 1000 cube cm., or 1 kilogram, of water at 39° F. The **are** is a sq. decametre; the **stere**, a cube metre, or kilolitre, or 1 million grams (tonne) of [water.

Latin prefixes, deci-, centi-, milli-, denote sub-divisions.
Greek prefixes, deka-, hecto-, kilo-, myria-, denote multiples.
*, †, ‡, §, show square and cube of length-measure with same sign.

Lineal:— *metres*		*Brit. equivt.*
1 millimetre	$\frac{1}{1000}$	0·039 ins.
1 centimetre ‡	$\frac{1}{100}$	0·394 ,,
1 decimetre †	$\frac{1}{10}$	3·937 ,,
Metre* ..	**1**	**39·370 ins.**
1 decametre §	10	32·808 feet
1 hectometre	100	328·084 ,,
1 kilometre	1000	1093·61 yds.
1 do.(abt. ⅝m.)		**0·621 mile**

Square:—*ares*		*Brit. equiv't.*
1 milliare	$\frac{1}{1000}$	1·076 sq. ft.
1 centiare*	$\frac{1}{100}$	10·764 ,,
1 deciare	$\frac{1}{10}$	107·639 ,,
Are § ..	**1**	**119·599 sq. yds.**
1 decare ..	10	0·247 acre
1 hectare	100	2·4711 acres

Cube:—**1 Stere*** (cub. metre) = 35·31 cub. feet (metric ton water); millistere† (·001 stere) = 61·02 c. in.

Troy:—1 gram = ·03215 Troy oz.

Weight: *grams*		*Brit. Equiv't*
1 milligram	$\frac{1}{1000}$	0·015 grains
1 centigram	$\frac{1}{100}$	0·154 ,,
1 decigram	$\frac{1}{10}$	1·543 ,,
Gram ‡ ..	**1**	**15·432 grains**
1 decagram	10	5 drms. 18 grs
1 hectogram	100	3½ oz. 12 grs
1 kilogram †	1000	2 lb 3¼ oz 10 grs.
1 myriagram	10,000	22 lb 0¾ oz.
1 Quintal	100,000	220·46 lbs.
1 **Tonne** or millier		**0·984 ton**, or 2204·622 lb. or 1·102 short tons.

Capacity: *litres*		*Brit. equiv't.*
1 millilitre ‡	$\frac{1}{1000}$	16·9 minims
1 centilitre	$\frac{1}{100}$	0·35 fluid oz
1 decilitre	$\frac{1}{10}$	3·52 ,,
Litre† (1000 cc)	**1**	**1·7598 pints**
1 decalitre	10	2 gall. 1½ pts.
1 hectolitre	100	2¾ bush. (22 gls)
1 kilolitre (cb. metre)		220·00 galls.

Weights of Materials. D, Density or Specific Gravity, compared with water taken as 1. **Weight** in lbs. (gases, ozs.):—of a cube inch, **In.** · of a cube foot, **Ft.** Different samples vary greatly, especially wood

Material	**D.**	**In.**	**Material**	**D.**	**In.**	**Material**	**D.**	**Ft.**	**In.**
Alumin'm	2·7	·10	Lead ..	11·4	·41	Ash, Oak, Teak	·84	45-58	·028
Brass ..	8·5	·31	Mercury	13·6	·49	Beech, Birch	·72	43-58	·027
Brick, abt	1·8	·07	Nickel ..	8·7	·31	Cork ..	·24	15	·009
Celluloid	1·4	·05	Platinum	21·5	·78	Elm, Mahog'y	·64	35-45	·023
Coal (*solid*)	1·3	·05	Sand ..	1·6	·06	Pine, Larch	·56	31-35	·020
Copper ..	8·9	·32	Silver ..	10·6	·38	,, Yellow	·50	28-33	·018
Ebonite	1·2	·04	Slate ..	2·9	·10	Walnut ..	·67	30-50	·024
Glass ..	2·7	·10	Steel ..	7·9	·28	Benzol ..	·80	50	·029
Gold ..	19·3	·69	Stone, abt	2·5	·09	Meth. Spirit	·82	51	·029
Ice	0·93	·03	Tin ..	7·4	·27	Paraffin oil	·80	50	·029
India r'br.	0·9	·03	Water (*pure*)	1·0	·036	Petrol (Avn ·68)	·74	46	·027
Iron (*cast*)	7·2	·26	,, (*sea*)	1·03	·037				
,, (*wrt*)	7·7	·28	Zinc ..	7·2	·26				

Gases: Ft. Acetylene, 1·10 oz; Air, 1·22; Carb. Acid, 1·86; Coal Gas, 0·61; Hyd'gn, 0·08; Oxygen, 1·35.

Imperial Coinage. Diameter in ins.; weights in grains, &c.

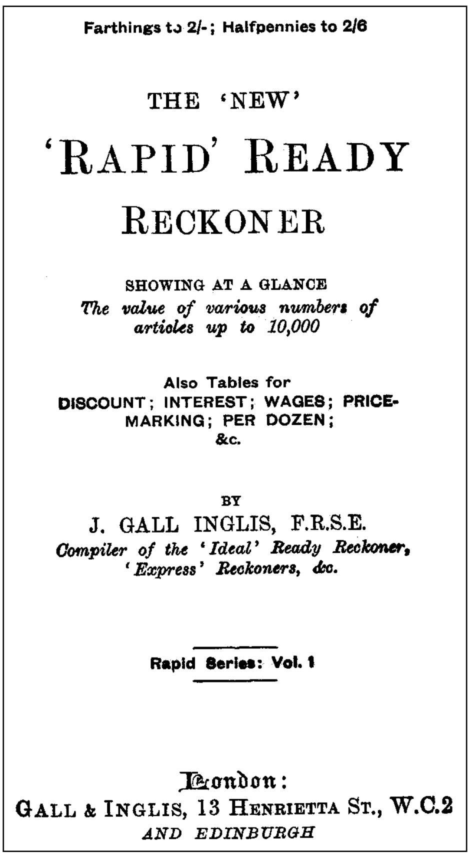
Gold:—	**Ins.**	**Grs.**	**Silver** *cnt'd*	**Ins.**	**Grs.**	**Copper:**	**Ins.**	**Oz.**
Sovereign	0·86	123·2	Florin	1·12	174·5	Penny	1·21	⅓ oz
Half-Sov.	0·75	61·6	Shilling	0·92	87·2	Halfp'ny	1·00	⅕ oz
Silver:—			Sixpence	0·76	43·6	Farthing	0·80	$\frac{1}{10}$
Half-cr'n	1·27	218·1	Threep'ny	0·64	21·8			

Money lying at undrawn Interest. When it doubles itself:—

Interest	**2½%**	**3%**	**3½%**	**4%**	**4½%**	**5%**	**5½%**	**6%**
Simple	40 yrs.	33⅓ yrs.	28·57 y.	25 yrs.	22·22 y.	20 yrs.	18·18 y.	16⅔ yrs.
Comp'd	28·07 y.	23·45 y.	20·15 y.	17·67 y.	15·75 y.	14·21 y.	12·95 y.	11·89 y.

Introduction

Tables have been with us for some 4500 years. For at least the last two millennia they have been the main calculation aid, and in dynamic form remain important today. Their importance as a central component and generator of scientific advance over that period can be underestimated by sheer familiarity. Like other apparently simple technological or conceptual advances (such as writing, numerals, or money) their influence on history is very deep. The history of tables now deserves, and is ready, to be brought forward from the narrow floodlights of particular special studies into the open sunlight.



Farthings to 2/-; Halfpennies to 2/6

THE 'NEW'

'RAPID' READY

RECKONER

SHOWING AT A GLANCE
The value of various numbers of articles up to 10,000

Also Tables for
DISCOUNT; INTEREST; WAGES; PRICE-MARKING; PER DOZEN;
&c.

BY
J. GALL INGLIS, F.R.S.E.
Compiler of the 'Ideal' Ready Reckoner, 'Express' Reckoners, &c.

Rapid Series: Vol. 1

London:
GALL & INGLIS, 13 HENRIETTA ST., W.C.2
AND EDINBURGH

Fig. 0.0(a)(b) A page from J. Gall Ingliss's, *The 'new' 'Rapid' ready reckoner*, published in London in the early twentieth century. Ready reckoners were pocket- or handbag-sized books of tables, designed to aid everyday calculations, especially in multi-base Imperial systems of weights, measures, and coinage, in the days before electronic computing devices. This page shows four different kinds of table: (i) The Metric System (empirical data for use as a calculation aid); (ii) Weights of Materials (presentation of theoretical data); (iii) Imperial Coinage (presentation of empirical data); (iv) Money drawn at interest (theoretical data for use as a calculation aid).

The issues turn out to be very interesting. From the earliest times there has been a range of different kinds of table, from the representation of mathematical functions to documents summarizing empirical values. What they have in common is an expression of complex information in a two-dimensional form. From the start, issues of design and legibility jostle with issues of abstract information processing. The structure of tables, the transition from one-dimensional to two-dimensional layout in the location of information, has a far greater significance than might naively be expected. A number of diverse roles are involved in the panorama of activities associated with tables, among them theoretician, constructor, scribe, printer, and consumer.

The insights brought to bear by recent historiography enable us to position the history of tables as a fascinating confluence of different aspects of human endeavour. In the history of information processing, for example, we can see table making in the modern era as lying at the historical junction between the factory-based production of physical goods and the office-based processing of information. The wide range of consumers of tables, whether scientific users such as astronomers, mathematicians, physicists, and medical statisticians, or professional and trade users such as engineers, actuaries, or navigators, indicates something of the challenge to historians to make sense of an extremely rich field of understanding.

The history of this extraordinary human invention falls into four periods. From around 2500 BC to 150 AD, the story is one of the invention of the table as a concept and its realization in a number of forms for different purposes. Over the next millennium and a half the second period saw some of the great achievements of the human mind, in the astronomical and trigonometric tables which lay at the heart of progress in the hard sciences leading up to the scientific revolution. The third period, from the early seventeenth to the mid-nineteenth centuries, was the heyday of work on logarithm tables which formed the basis of calculation needs for the industrial revolution. The fourth period, from the mid-nineteenth century up to the present, has seen a number of developments in the production of a range of ever more sophisticated tables for physical, mathematical, industrial, and economic purposes, as well as the development of technology to help in their calculation. The story is by no means over, as the development of spreadsheets, dynamic tables in computers, shows that there is still a lot of life in the deep idea of presenting information on a two-dimensional tabular screen.

In recent decades there has been unprecedented historical activity on each of these four periods, work of high quality which has appeared in specialist journals in different areas (such as economic history, Oriental studies, and the histories of technology, astronomy, computing, information science, mathematics, and science). It is now timely to seek to synthesize the results of these studies for a broader audience and present for the first time a historic sweep of a fascinating and unexpectedly important human invention.

These paragraphs were written by John Fauvel at the start of our planning meetings for 'Sumer to Spreadsheets: The History of Mathematical Table Making', the summer meeting of the British Society for the History of Mathematics held at Kellogg College, Oxford in September 2001, of which this book is the final outcome. John died unexpectedly in May 2001. Not wanting to dilute his voice amongst our own, we have chosen to let him have the first word, and simply to expand on three of the themes he mentioned: the different types of table; the communities of table-makers and consumers; and the production of tables.

Types of tables

Tables facilitate the selection, categorization, calculation, checking, and extraction of data—but there are as many different applications of mathematical tables as societies which used them. The twelve chapters of this book cover a bewildering variety: from Sumerian tables of squares (Chapter 1) to late twentieth-century spreadsheets (Chapter 12), from natural logarithms and other purely mathematical functions (Chapters 2, 4, 9, and 10) to astronomical ephemerides (Chapters 1, 7, and 11) and statistical data (Chapters 3 and 8). How can we begin to make sense of this enormous range?

Take, for example, the ready reckoner. These little books, often published with titles such as *The Pocket Ready Reckoner*, were small, inexpensive sets of commercial tables. They were a common calculating aid in the Western world, but particularly in Britain because of the difficulty of computing sterling amounts and quantities in imperial weights and measures (both of which were non-decimal). They were particularly common—almost essential—in retail emporia that unit-priced goods. Imagine walking into a draper's at the turn of the twentieth century and buying $13\frac{1}{2}$ yards of curtain material at 5s 9d a yard. This was not an easy calculation, even in an age when schools taught commercial arithmetic. However, the appropriate table gives the almost instant answer of £3 17s $7\frac{1}{2}$d. The ready reckoner became a commodity item during the late Victorian period, when low-cost publishing made them very affordable. They continued to be used up to about 1970, when currency decimalization (in Britain) and inexpensive electronic cash registers and calculators made them obsolete.

The ready reckoner was not just for calculating purchases in retail establishments, though that was certainly its dominant use. It was a compendium of tables that any citizen—from cleric to jobbing builder—might find useful to have about their person. Here are examples of some of the typical tables they contained: Perpetual calendar, Table to calculate Easter day, Metric equivalents of imperial weights and measures, Tables for commissions and discounts, Interest tables, Stamp duty, Postal rates, Wage tables, Currency conversion tables, Areal, liquid, and dry measures.

Classification and taxonomy offers one way of making sense of the universe of tables. First, we can think about what goes into tables: are they computed from empirical or theoretical data? Or to put it another way, to what extent are the contents of the table determined by social convention and/or objective mathematical formulae? Second, we can consider what tables are used for: are they aids to further calculation (such as the dreaded four-figure tables of school mathematics before the pocket calculator made them obsolete) or do they present self-contained information in a final form (for instance a railway timetable)? In short, it should be possible to make a rough and ready 'table of tables', categorizing them as to whether they are computed from empirical or theoretical data, and whether they are primarily used to calculate other things or are an end in themselves. For example, the tables from *The 'new' 'Rapid' ready reckoner* shown in the frontispiece to this Introduction might be classified like this:

	Computed from empirical data	*Computed from theoretical data*
Used as calculating aid	The Metric System	Money Lying at Undrawn Interest
Used to present data	Imperial Coinage	Weights of Materials

But categorization is not straightforward. At one end of the empirical–theoretical spectrum there is census data, as described by Edward Higgs in Chapter 8. Not only do census designers have to choose the types of information they wish to elicit from the population, but they have to then categorize the relatively free-form responses they receive into discrete categories for tabulation. However carefully designed the process is, censuses do not produce objective results but reflect the ideals and prejudices of the commissioning society, as embodied in the minds and work of the census officials. At the opposite extreme there are tables of mathematical functions, such as those manufactured by de Prony and his team in late eighteenth-century Paris (see Ivor Grattan-Guiness's description in Chapter 4). Sines, logarithms, or number theoretical series—provided they are calculated accurately—are (and have been) reproducible across time and space regardless of the language, number base, or personal belief system of the tabulator. Along the spectrum in between are myriad tables which are constructed from a mixture of empirical and theoretical data, the socially constructed and the value-free. How, for instance, should we consider astronomical ephemerides, which tabulate the predicted movement of the major heavenly bodies over the coming year(s)? They depend on a celestial coordinate system and on a mathematical model describing lunar, solar, and planetary motion, both of which are socially defined and open to constant revision and refinement, as Arthur Norberg explains in Chapter 7. But from another viewpoint an ephemeris is no more than the tabulation of a mathematical function, which makes it in some sense more objective than a census table.

On the calculation–aid/data–presentation spectrum we see a similar range of possibilities. Logarithms, of course, are the archetypical calculating aid, as Graham Jagger shows in Chapter 2. Ephemerides were calculating aids too, enabling navigators to locate their position on the Earth's surface by the night sky. On the other hand astronomers could also use them like a railway timetable, looking up the times and locations of celestial events that they wished to observe. Census tables and tables of vital statistics were, on the whole, meant to be read as final reports rather than as raw material for further calculations—although this was necessary too for instance to enable civil servants to plan a community's needs. In Chapter 3 Chris Lewin and Margaret de Valois explain how actuaries used tabulated mortality data to create and develop the concept of life assurance.

When we move on to look at dynamic tables in the form of spreadsheets (Chapter 12), we now see a form of table that can both show empirical or derived data and then manipulate that data and display the results all in one and the same 'table'. Here we see an interesting paradox: on the one hand computers have been the death of the printed table-as-calculating-aid but conversely computerized spreadsheets have given new and vigorous life to the still ubiquitous table-as-data-presentation format.

Communities of table makers and users

Table making is a community-based activity. Communities of table makers and table users are as old and diverse as tables themselves. However, three particular groups feature across many of the chapters of this book: the astronomical, mathematical, and actuarial communities.

Astronomers have proved to be the most enduring community of mathematical table makers and table users as generation after generation has built upon the work, and tables, of its predecessors. Claudius Ptolemy (*c.*85–165 CE), working in the famous library at Alexandria in Egypt, was author of the 13-volume astronomical work *Syntaxis* or *Almagest* which revolutionized astronomical thought.[1] He selected the most useful of the astronomical tables from the *Almagest*, edited and republished them with instructions on their use as the *Handy Tables*. They were translated from Greek into Latin, Arabic, Persian, and Sanskrit and had a circulation larger even than the *Almagest*. The *Handy Tables* were originally copied by hand in manuscript form but editions in print form continued to be published in Western Europe for centuries. Their longevity, wide distribution and influence among astronomers worldwide mean that Ptolemy's *Handy Tables* can justifiably claim to be the first mass produced mathematical table.

Another famous table maker who was the product of a scholarly institution was al-Khwarizmi (*c.*780–850), of the royal House of Wisdom in Baghdad. While he is best known as the father of modern algebra and algorithms, al-Khwarizmi's collection of astronomical tables and accompanying instructions, or *zîj*, is the earliest surviving astronomical treatise in Arabic. It had a long life: Adelard of Bath, for instance, translated it into Latin in the early twelfth century—and it was still used in the Jewish Geniza in Cairo in the nineteenth century![2]

In the second half of the eleventh century, an important group of astronomers gathered in Toledo in Muslim Andalusia (southern Spain) to produce the *Toledan Tables*—some parts of which derived from the work of Arab astronomers such as al-Battani and al-Khwarizmi and other parts from Ptolemy. The *Toledan Tables* became highly popular throughout Europe until the fourteenth century.[3] Another collaborative medieval table-making effort was the *Alfonsine Tables*, assembled between 1263 and 1272 by a group of 15 astronomers at the instigation of Alfonso X of Leon and Castile. The *Alfonsine Tables* gained popularity in Paris in the 1320s, were further developed in England, and had a major influence on European astronomy in the following centuries.

The Renaissance saw huge advances in both theoretical and observational astronomy in which the invention of the telescope and the gradual adoption of the Copernican view of the solar system played a fundamental part. The international nature of the astronomical community allowed for astronomers across Europe to learn from one another and to build upon each others work. The work of Brahe, Kepler, Newton, Mayer, and others led to increasingly accurate tables for predicting the positions of the Sun, Moon, planets, and stars. The interplay between changing astronomical theory and the generation of new astronomical tables is well described by Norberg in Chapter 7.

Ephemerides, or tables of predicted positions, were highly collaborative works. They were constructed from the best available astronomical tables, often by a team of computers who were sometimes part of the astronomical research community and sometimes simply hired hands. It is here that we begin to see the division between those who actually computed the tables and the editors in whose name the tables were published. International collaboration in the construction of national ephemerides was common. For example Nevil Maskelyne, editor of the *Nautical Almanac* 1767–1811, not only checked the *Nautical Almanac* tables against those of the French *Connaisssance des Temps* but also kept up a vigorous astronomical correspondence with his French counterpart Jerome Lalande throughout the intermittent Anglo-French wars of the period.[4] By the 1930s national ephemeris publishers throughout Europe had divided up the necessary table-making work between the various international offices in order to reduce the workload and avoid duplication of effort. Even today international cooperation is common and, as George Wilkins explains in Chapter 11, the British and US almanacs are now jointly computed and published.

While astronomers have been the predominant makers and users of mathematical tables over the last four millennia, another important, and often linked, group is the mathematical community. In Chapter 2 Jagger describes Napier's invention of logarithms and the subsequent publication of logarithm tables by Briggs, Gunter, and others. Jagger's narrative demonstrates how, following Napier's initial work, the mathematical community worked to develop the use of logarithms as a calculating aid and to prepare the necessary tables.

Mathematical tables of the higher functions began to appear at the beginning of the eighteenth century and the increasing importance of higher mathematical functions to mathematical physics throughout the nineteenth century led to a rapid increase in the number of tables published. Mathematicians began to be concerned by the lack of coordination and unwitting duplication of table-making effort within the mathematical and mathematical physicist communities. In response the British Association for the Advancement of Science set up a Mathematical Tables Committee in 1871 to produce a survey of existing mathematical tables and to coordinate the creation of new ones. As described by Mary Croarken in Chapter 9, over the next ninety years the British Association Mathematical Tables Committee became a central focus for mathematical table making in Britain. At its inception the Mathematical Tables Committee was highly representative of the communities it served; later on in its history we see a growing gulf between the mathematical table maker and the user communities. In several instances Mathematical Committee members were making tables primarily because they enjoyed the process of making tables and not wholly for the benefit of the target users.

A similar separation can be found in the Works Project Administration Mathematical Table Project created in 1930s New York and described by David Grier in Chapter 10. Here the table makers were not willing volunteers but unemployed workers desperately in need of work. Arnold Lowen, the project's leader, sought to gain approbation for the project within the American mathematical community, albeit with limited success. Here the table makers were intellectually, culturally, and socially separate from the community of users they sought to serve.

Another table-making community, the actuaries, is discussed by Lewin and de Valois in Chapter 3, and touched on by Higgs in Chapter 8. It is often assumed that actuarial table makers had little in common with either the mathematical or astronomical communities, their products being used in different spheres of human endeavour. However, this assumption proves to be much too simplistic. The skills for producing actuarial tables were equally applicable to making astronomical or mathematical tables and *vice versa*. For example Edmond Halley, British Astronomer Royal 1720–1742, was author of a highly influential life table published in 1693.[5]

Perhaps the most significant contact between the actuarial, mathematical, and astronomical communities occurred in early nineteenth-century Britain. In 1820 the Astronomical Society of London was founded with the aim of standardizing astronomical calculation and collecting and distributing data. Its founding members included Francis Baily and his brother Arthur, successful London stock brokers; their colleague Benjamin Gompertz; currency exchange expert Patrick Kelly; the financier Henry Thomas Colebrooke; West India merchant Stephen Groombridge; the mathematician and astronomer John Herschel; and Charles Babbage, the mathematician son of a London banker and briefly actuary of the Protector Assurance Society. The predominance of businessmen, most of whom had practical experience of actuarial table making as well as an interest in astronomy and mathematics, is remarkable.

Adversity too has shaped mathematical table-making communities. During both World Wars mathematicians and astronomers came together and applied their table-making skills to the preparation of ballistics and other tables required by the armed services. During the First World War it was primarily mathematicians such as Karl Pearson in Britain and Oswald Veblen in the US, but in the Second World War the net was stretched wider. In Britain the staff of the Nautical Almanac Office were joined by graduate mathematicians to create the Admiralty Computing Service which produced almost one hundred tables of direct relevance to the war effort.

Table making as a communal enterprise has thus been part of the history of mathematical tables from ancient times. Today so many businesses, universities, and individuals run Microsoft Excel spreadsheet software that the community of table users with the ability to share spreadsheet data on a world wide basis is truly worldwide.

Making tables

A theme that surfaces in many of the chapters of this book concerns the way in which tables were actually calculated. One can discern five distinct styles of table making: the solitary table maker; communal computing; computing bureaus; mechanized computing; and, finally, computerization. Although this is the order in which these five different styles evolved, solitary and communal, manual and mechanized computing styles have co-existed throughout the history of table making.

The working methods of the early table makers are shrouded in mystery. We do not know the extent to which tables were solitary or communal endeavours, but both modes clearly existed. The solitary table maker is a heroic figure, though the tradition is perhaps exaggerated. For example, according to D. E. Smith, it was said that when Napier and Briggs first met—the latter having completed the tables the former had begun 'almost one quarter of an hour was spent, each beholding the other with admiration, before one word was spoken.'[6] However, as Jagger writes in Chapter 2, Napier at least had a little help from his friends. But the lone table maker continued to work long into the twentieth century. For example, Emma Gifford 'an extremely cultured lady but by no means a mathematician' was occupied for several years in the solitary task of compiling and publishing her 500 page volume of *Natural Sines*.[7]

However, from the earliest times big table-making projects had to employ several human computers. One of the best known examples of such a group endeavour is the *Nautical Almanac*, published continuously from 1767. As described by Wilkins in Chapter 11, the Astronomer Royal Nevil Maskelyne employed a network of computers, many of whom served for decades. The computers were all freelance, located all over England, and their work was entirely coordinated though the postal system.[8] Such clear evidence of the way computing is organized is rare; much more usually the historian is left with just a tantalizing hint. For example, as explained in Chapter 1 by Eleanor Robson, table making in Mesopotamia was very much a collective activity, but the surviving artefacts are necessarily silent about how the work was actually organized. The *Opus Palantinum* of Rheticus published in 1596 (and the source book for Gifford's *Natural Sines*) was said to be the work of eight computers. Leibniz hints at the existence of major table-making projects, noting in 1745 that his newly invented calculating machine 'has not been made for those who sell vegetables or little fish, but for observatories or halls of computers.'[9] In the twentieth century, as Croarken explains in Chapter 9, the British Association Mathematical Tables Committee made use of small calculating teams as well as solitary calculation.

In 1790, Gaspard Riche de Prony established the Bureau du Cadastre to produce a new set of tables for the French ordnance survey. The Bureau marked a transition from small, informal computing teams to a large-scale, highly organized bureaucracy. De Prony's innovation was path-breaking for two reasons. First, the sheer scale of the activity: the new French tables of logarithms and trigonometrical functions were of an unprecedented precision and were computed *de novo* (unlike earlier tables which had generally been compiled from previously existing tables). Second, de Prony consciously adopted an industrial metaphor. He had been influenced by Adam Smith's classic *Wealth of Nations* (1759), in which he gave his famous description of a pin-making factory where, by division of labour, a community of specialized workers was vastly more productive, per person, than one solitary worker who undertook all the processes of pin manufacture. In an evocative passage, quoted by Grattan-Guinness in Chapter 4, de Prony decided 'to manufacture logarithms as one manufactures pins.' The Bureau du Cadastre was in every sense a computing 'factory'. The Bureau employed three classes of labour: a small advisory group of eminent analysts; an executive group of between six and eight professional mathematicians; and a large number of between 60 and 80 relatively unskilled computers. By employing the Method of Differences, which required only the operations of addition and subtraction, it was possible to use the lowest grade, and therefore the most economical, computing labour. Organized computing bureaus became the norm for large-scale table making projects. In the 1830s, for example, the Nautical Almanac Office's network of freelance computers was replaced by a permanent office of about a dozen computing staff. The processing of census data was another example of the large-scale employment of low grade staff for table production. In the case of the British Census, as explained by Higgs in Chapter 8, Census tabulation used the 'ticking method' which was extremely tedious but required only the lowest form of clerical life.

The computing bureau style of operation remained popular for major table-making projects until after the Second World War. The best documented was the WPA Mathematical Tables Project established in New York in the 1930s depression, described by Grier in Chapter 10. The WPA project was established partly as a make-work project for the unemployed, but also as a genuinely needed computing service. At its peak the project employed 200 computers, and it came into its own with the computation of LORAN tables in the early years of the war. The WPA project was by no means the only such computing organization in wartime America. For example, the Army's Ballistics Research Laboratory and Moore School of Electrical Engineering at the University of Pennsylvania employed a team of 100–200 female computers (each equipped with a desk calculating machine) to make ballistics tables. This tide of table making, which threatened to overwhelm existing methods, led the Moore School to become the birthplace of the modern computer.[10]

The difference engine was the most radical departure from manual methods of table making. Although table makers sometimes used calculating aids (such as logarithm tables or desk calculating machines), the difference engine was intended to entirely remove the human element, and once set up an engine would churn out results indefinitely. As Mike Williams explains in Chapter 5, Charles Babbage was the most important figure in the history of the difference engine. He was one of the foremost economists of his day, and thoroughly conversant with the principle of the division of labour.[11] However, in the 1820s human labour was starting to be challenged by machinery and the pin-making factory was giving way to the pin-making machine. For reasons discussed by

Williams, and Doron Swade in Chapter 6, Babbage failed to complete a full-scale machine—being diverted by the Analytical Engine. However, he inspired several imitators, notably Georg and Edvard Scheutz in Sweden. A copy of their machine was purchased by the General Register Office to make a new life table, although the machine required much coaxing, and did only a fraction of the job. Other difference engines followed: Martin Wiberg in Sweden, George Grant in the United States, and Christel Hamann in Germany. The difference engine concept was never really commercially viable, however, and special-purpose machines had died out by the First World War. By contrast, after the 1890 US Census, Herman Hollerith recognized that census data processing was not a big enough market for his punched card machines, and so he developed equipment for ordinary businesses. Thus, by the time the British census came to use Hollerith machines in 1911, census tabulation was only one of many applications for punched-card machines. It seems that table making was too specialized and too narrow an activity to support a dedicated technology. This was clearly understood in the late 1920s by L. J. Comrie who, as described by Williams in Chapter 5, adapted commercial calculating machinery for the *Nautical Almanac*, ushering in an era of mechanized table making at last.

The emergence of the digital computer first transformed the way tables were made, and then undermined their very existence. Computer power enabled an explosion in the production of tables—not all of them of obvious utility. For example the Harvard Mark I computer produced some fifty volumes of Bessel function tables, many of which were barely used, and earned the computer the nickname 'Bessie'.[12] At first it was thought that computers, by giving more individuals and institutions the capability to do computing, would encourage the production of many new tables. However, when it became clear that computers could calculate function values on-the-fly, the need for tables—whether on punched cards or in printed form—evaporated. In Chapter 9 Croarken describes rather poignantly how one institution, the British Association Mathematical Tables Committee, came to terms with the fact that the life's work of its members was no longer needed.

From Sumer to spreadsheets

The history of tables is not just an arcane corner of the history of science (mathematics, computing, or astronomy). We have already touched upon some aspects of economic history in the way that labour and machinery were organized to construct tables. We have seen that tables have a social history too, or at least their producers and users do. The communities they worked in, and the support those communities gave or denied them, played a major part in how tables were developed, published, and circulated. But we can also examine the internal structure of tables, as greatly overlooked evidence for cognitive history. They tell us much about how people have selected, classified, and manipulated quantitative data at different times and places. Tables also speak to us about the history of literacy and numeracy. The material culture of tables—from clay tablets, papyri, and manuscripts to printed books and shrink-wrapped software packaging—sheds new light on the history of the book and the transmission of knowledge.

While the *list* has been hailed as a major breakthrough in cognitive history, most famously by the anthropologist of literacy Jack Goody,[13] the table as a pre-modern phenomenon of structured thought has been completely neglected. Indeed, for Goody (non-numerical) tables are no more than a means for modern scholarship to present 'the communicative acts of other cultures, non-literate and literate . . . a way of organising knowledge about classificatory schemes, symbolic systems, human thought . . .' whose 'fixed two-dimensional character of may well simplify the reality of oral communication beyond reasonable recognition, and hence decrease rather than increase understanding'.[14] For Goody, then, tables are a means by which Western academia imposes inappropriate, simplifying order on the complexities of other cultures. Higgs's chapter on the General Register Office's tabulation of data in nineteenth-century Britain does indeed show that 'the construction of tables involves decisions about what is important and what is not, and what should be collected and presented, and what can be 'ignored' but that 'there is nothing necessarily sinister about such processes of truncation'.

Robson's chapter on the uses of numerical tables in many aspects of literate life in ancient Iraq (Chapter 1) shows that tables are by no means an invention of modernity but have been in lively, inventive, and constructive use for millennia. It is not difficult to assemble examples from other ancient cultures. Over a hundred arithmetical tables are known from the world of Classical Antiquity, written in Demotic Egyptian, Coptic, and Greek,[15] and a similar number of astronomical tables have been recovered from the first five centuries CE, 'with links not only to the Greek theoretical astronomy of Hipparchus and Ptolemy but also backward to the Babylonians and forward to the astronomers of Byzantium, Islam, and the Latin West.'[16] This list could perhaps be extended indefinitely.

The two-dimensional structure of the table was elaborated remarkably quickly, in the blink of an eye in historical terms, but it took millennia for the amazing power of the deceptively simple table to reach its zenith. In Chapter 1 Robson traces the functional development of administrative tables in early Mesopotamia over a period of just 50 or 60 years in the nineteenth and eighteenth centuries BCE. Categorization and data selection come first: these first tables were no more than multi-column lists of different named types of empirical data. Column headings and row labels, were an integral part of tables right from their inception, even though it was to be millennia before titles, headings, and subheadings were applied to works of connected prose, whether literary epics or royal decrees. Thus quantitative and qualitative information could be separated, producing a great efficiency both in recording and retrieving structured information. The scribe no longer had to waste time and effort in describing each item accounted for, but could simply tabulate it in the correct row and column, while the supervisor could take in at a glance the finished document and the pattern of information it contained.

Within very short order—a decade or so—the computational power of tables was discovered. First, one could use the very structure of tables as an aid to calculation. Columns could be totalled; products could be found across rows; cross-checking for errors became easier. Second, tables could be used to store basic functions used for more complex calculations, from integers and their squares or cubes to reciprocals.

When we substitute, say, paper for clay tablet, Bessel functions for squares of the integers, or EU farming subsidies for tables of goats and sheep, one can see that the similarities between tables ancient and modern are much greater than their differences. Right to the present day, the table can be seen as an elaboration of the basic theme of homogeneous values arranged in rows and columns. This remains true even in the age of the spreadsheet. User surveys tell us that spreadsheets are most commonly used to write lists and to keep simple accounts: two basic human needs, unchanged through the millennia.

Tables are quintessential cultural objects of the civilizations that created them, improved and perfected by each succeeding generation. For example, in logarithmic tables, residual errors were gradually eradicated, values truncated or extended, and intervals reconsidered according to the dictates of the day. It is likely that, at least in theory, an ancestral line could be drawn from the logarithms of Briggs to the four-figure tables used in schools in the early twentieth century. Tables have followed the fashions of the day with regard to typeface, the use of rules and 'white space', and even the colour of paper. Indeed, as Swade describes in Chapter 6, such attention to typographical niceties made the printing part of Babbage's difference engine almost as complex as the calculating part. This trend continues even into the modern spreadsheet—where competing brands are distinguished not by their function, but by their user interface, and each 'upgrade' combines the best of the old leavened with a little of the new.

As Martin Campbell-Kelly has noted in the closing chapter, the two-dimensional table is almost an historical necessity—suggested by the two dimensional writing surface common to all civilizations. We know that different civilizations independently invented (or perhaps, like the integers, discovered) the table. Would the civilizations of another planet use tables? We like to think so.

Notes

1. G. J. Toomer 'Ptolemy', pp. 186–206 in *The Dictionary of Scientific Biography*, New York 1970 and *idem, Ptolemy's Almagest*, Princeton; Princeton University Press 1998.
2. J. D. North, *The Fontana history of astronomy and cosmology*, London: Fontana, 1994, pp. 184–5.
3. J. D. North, *The Fontana history of astronomy and cosmology*, London: Fontana, 1994, pp. 207–13.
4. S. L. Chapin, 'Lalande and the Longitude: a little known London voyage of 1763', *Notes and Records of the Royal Society*, Vol. 32, no. 2, March 1978, pp. 165–80 and D. Howse, *Nevil Maskelyne: the seaman's astronomer*, Cambridge: Cambridge University Press, 1989, p. 47.
5. E. Halley, 'An estimate of the degrees of mortality of mankind . . .', *Philosophical Transactions of the Royal Society*, Vol. 17, 1693, pp. 565–610 and 654–6.
6. D. E. Smith, *A Source Book in Mathematics*, Vol. 1, Dover Publications, New York, 1959.
7. E. Gifford, *Natural Sines*, Manchester: Haywood, 1914. Quote taken from A. Fletcher *et al.*, *An Index of Mathematical Tables*, 2nd edn, Oxford: Blackwell, 1962, Vol. II, p. 818.
8. M. Croarken, 'Tabulating the heavens: computing the Nautical Almanac in eighteenth century Britain', *IEEE Annals of the History of Computing*, forthcoming.
9. Translation from *Works of Babbage*, Vol. 2, p. 181.

10. H. H. Goldstine, *The Computer: From Pascal to von Neumann*, Princeton University Press, 1972.
11. Indeed, he refined the concept into a more nuanced variation known as the Babbage Principle, which advocated that manufacturers should purchase no more than the lowest quality labour that could perform any given task. M. Berg, *The machinery question and the making of political economy, 1815–1848*, Cambridge: Cambridge University Press, 1980.
12. I. B. Cohen, *Howard Aiken: Portrait of a Computer Pioneer*, Cambridge, Mass.: MIT Press, 1999.
13. Jack Goody, *The domestication of the savage mind* (Cambridge: Cambridge University Press, 1977).
14. Jack Goody, *The domestication of the savage mind* (Cambridge: Cambridge University Press, 1977), pp. 53–4.
15. See the catalogues by D. H. Fowler in *The mathematics of Plato's Academy: a new reconstruction* (2nd edn), Oxford: Oxford University Press 1999, 268–76 and 'Further arithmetical tables', *Zeitschrift für Papyrologie und Epigraphik* 105 (1995), 225–8.
16. Alexander Jones, 'A classification of astronomical tables on papyrus', in N. M. Swerdlow (editor), *Ancient astronomy and celestial divination*, Cambridge, Mass.: MIT Press, 1999, pp. 229–340, quote from p. 335.