Evaluation of Sorting Methods

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INTRODUCTION

I HAVE BEEN asked to report to you on the present state of the art of sorting. In order to do so, I have obtained help and information from more people than I can thank individually. My former employers, Arthur D. Little, Inc. have allowed me to spend many hours of their valuable time, and my present employers, The Farrington Manufacturing Co., of their, I am glad to say, even more valuable time, on sorting out the information received.

Definition

For my purpose, sorting means putting things in order according to some numerical, alphabetic, or geographical key. The things sorted may be mail or checks, which in themselves should arrive in one piece at a specified destination, or items of information which may be transferred from one medium to another without loss.

Importance

Sorting is an important subject. To lower costs per unit of output, people usually increase the size of their operations. But under these conditions, the unit cost of sorting, instead of falling, rises. Sorting is a major reason for using punched cards. Up till now it has often been a major reason for not using magnetic tapes and otherwise high speed systems.

Why Sort?

The usual reasons for sorting are: to enable information to be found easily, as in a telephone directory; as a step in bringing together pieces of information, for example, in reconciling incoming checks with billing information; to bring files up to date, as in an inventory system; in sorting mail and handling checks; in making a summary report.

How Sort?

In order to get sorting done expeditiously, you can either hire someone who knows the alphabet, or, as they do in the post office, someone who knows geography and is a good pitcher; you can use filing devices, like card indexes; you can build a specialized machine like Erma’s sorting mechanism [1]; you can use punched card sorters; you can use electronic clerical machine sorters.

Techniques

In all the various sorting systems, a relatively limited number of techniques is used. These I propose to describe in turn.

Terms

Before discussing the various techniques, let me define one or two terms for my purpose. An item, sometimes called a record, is a unit which is being sorted. It may be a letter in the mail, a check or the details of a transaction, such as what Mrs. Murphy

bought at Filene's yesterday, or the number of parts #3792 extracted for job #767.

The key (or designator) is the information on the item which indicates the order in which it is to be sorted; e.g., the address on an envelope in the mail, the part number in an inventory system, the catalog number in a mail order transaction, the subscriber's name in a telephone directory, or the town or district in a fulfillment system.

A string is defined as a number of items whose keys are in ascending or descending order.

A block is a number of items read into a computer in one operation in some systems.

Distribution

The simplest technique and probably the oldest is distribution. This is the system used in the post office where mail is sorted into geographical categories. The number of categories in each sort is limited by the accuracy of the mail sorter's aim, and is usually about twenty. Each of these categories is subsequently broken down into 20 more and so on.

Digital

The next technique is generally known as digital, but also as column, character, decimal, alphabetic, or diverging sorting. This is the method normally used in sorting punched cards.

Merge or Mesh

The next technique is known as merge, mesh, or collate. This is the most commonly used in machines using magnetic tape.

Inserting, Address Calculation, Selection, Exchange

Several other techniques are practical in dealing with information carried in a relatively high-speed memory, such as a magnetic drum. One of these is the method of inserting, a special form of which is called address calculation; another is the method of selection, in one form called "nth" degree selection; another is the method of exchange.

Avoid Sorting

The last important technique is to avoid sorting altogether. This can be done by making somebody else do it. An example in ordering parts from inventory is to supply a form containing all the part numbers in order and to make the person ordering fill in requirements on this form. Another method is to use a large rapid or random access memory. Several of these are gradually becoming available.

Illustration of Techniques

Distribution Systems

As mentioned earlier, the oldest of the distribution systems is mail sorting. The Canadian post office [2] has recently been bringing this up to date by translating the address on the envelope into a coded key which is printed on the back of the envelope in dots and can subsequently be read by photo-electric devices controlling the sorting operation. Other mail sorting systems are being developed in Europe. Another system of this kind which has been at work for a long time is the matrix bar sorter which returns the matrices to the magazine in an Intertype [3] or Linotype [4] typesetting machine [Fig. 1(a) and (b)]. In this case, a binary key is permanently cut in the metal of the matrix and the matrix is slid along the matrix bar till it reaches the first point where the voids in the matrix bar match with the teeth in the key. Here it falls off into a pocket.

Jack Rabinow [5] some time ago developed an ingenious conveyor belt sorter [6] of this general type for the Bureau of the Census (Fig. 2). In this case, each item to be sorted is placed in a carrier on a moving belt or chain and at the loading station a series of cams attached to this carrier is set up to represent the key of the item. The carrier then passes along over a number
Fig. 2—Rabinow belt sorter at the Bureau of the Census.

DISTRIBUTION SORT

(a) Keys distributed into “hundred” blocks (first step).
(b) The first “hundred” block distributed into “ten” blocks (first step of second round).
(c) The second “ten” block of the first “hundred” block distributed into “unit” blocks (second step of third round).
(d) The second “hundred” block distributed into “ten” blocks (second step of second round).

(a) 00 10 20 30 40 50 60 70 80 90
   TO TO TO TO TO TO TO TO TO TO
   09 19 29 39 49 59 69 79 89 99
   017 028 032 044 076 098
   013
   019
   018
   016

(b) 0 1 2 3 4 5 6 7 8 9
   013
   016 017 018 019

(c) 00 10 20 30 40 50 60 70 80 90
   TO TO TO TO TO TO TO TO TO TO
   09 19 29 39 49 59 69 79 89 99
   010 128
   140 157 167 172 196
   101 123 146 154 173
   122 175

Fig. 3—Distribution sort.

Digital Systems

The theory of digital systems can be seen from Fig. 4(a) to (g), p. 42. The new Underwood [7] Rapid-Sort (Fig. 5, p. 43) is a device for digital (or distribution) sorting items like checks, sales slips, or invoices, which are not machine-coded. Each item in turn appears at the top of a pile and can be read by the operator who then presses a typewriter key corresponding to the digit or character against which sorting is being done. The item is then rapidly transported to the corresponding pocket by a series of driven and idler rolls. As soon as the item has passed through the solenoid operated gate, the keyboard is unlocked and the key for the next item can be pressed. Up to 50 pockets are available on this machine.

Card sorters in general operate on the digital system. The familiar IBM [8], Remington Rand [9], and Underwood-Samas [10] sorters all operate on generally the same principle. The mechanism of the IBM sorter (Fig. 6) is the easiest to describe and is shown in Fig. 7(a) and (b). At the reading station the solenoid opens a gap between two of the chute blades as the card is fed forward. Thereafter the card is guided by the chute blades into the correct pocket. In the others, cards are guided into pockets by gates. The correct delay between reading and gate opening is derived from a mechanical disc and bail memory.

The Eastman Kodak Minicard system (Fig. 8) has a digital sorter with a circular transport system and is arranged so that cards can be automatically fed into and out of the pockets. No manual operation is therefore required between passes.

Having studied gamesmanship under Stephen Potter [12], I was naturally constrained to turn to Jack Potter [13], for instruction in sortsmanship. He is building a tape sorter which is exactly analogous to the standard card sorter. By making use of a single drive system for all the tape mechanisms, and by using other shortcuts, he hopes to be able to produce a ten-tape sorter for something less than $10,000. The logical system in this device can, of course, be extremely simple since all it has to do is to count to the correct digit position in the key, detect the digit and transfer the item to the tape corresponding to that digit. The information from the 10 tapes in turn is then transferred to the input tape and the operation repeated for the next digit.

Presumably the Marchant Tape Information Processor [14] now being developed with quick change tape magazines will provide comparable results.
(a) Begin sorting on least significant digit (beginning of first round).

(b) Finish sorting on least significant digit (end of first round).

(c) Sort "zero" column by second digit (beginning of first step of second round).

(d) Begin sorting "one" column by second digit (beginning of second step of second round).

(e) Complete sorting on second digit (end of second round).

(f) Sort "zero" column by most significant digit (first step of third round).

(g) Complete sort on most significant digit (end of third round—final step).

Fig. 4—Digital sort.
In their check-handling system for banks, International Telemeter [15] attach a heat-sensitive punched tape to the edge of each check. From then on the checks can be handled in decks on a sort of double skewer and independently on nearly standard punched tape handling equipment. In sorting, the key is read from the holes in the punched tape and when the check reaches the correct position a paddle wheel moves up one notch and removes the check from the conveyor (Fig. 9).

In the Burroughs [16] Todd [17] Addressograph-Multigraph [18] system for handling checks, the key and other information is contained in dots on the check printed in fluorescent ink [Fig. 10(a)]. The checks are physically sorted by the Todd sorter shown in Fig. 10(b) to (g), p. 44.

Another check sorter, which is also applicable to other documents, is made by Halm Instrument Co. [19] and used in conjunction with Intelligent Machines Research Corp. equipment, among others. The Halm sorter [Fig. 11(a) and (b), p. 45] is designed in such a way that the check is never gripped by anything more violent than a suction cup. The idea is that it shall do no more harm to the checks than occasionally throwing them on the floor.
(a) Check imprinter.
(b) Over-all view of sorter.
(c) Checks being fed from the top of the pile.
(d) Skewed belt and balls align check with edge of track.
(e) Reading section open showing check entering chute blades.
(f) Distribution section open showing check entering turning bar.
(g) Check entering pocket upside down to maintain original order.

Fig. 10—Todd check-sorting equipment using fluorescent ink dot code.
ERMA was somewhat coy about her sorting equipment and all I have is a photograph (Fig. 12) taken in the dark. I was, however, told that her sorting mechanism involved electrical, mechanical, and air-operated devices. No doubt in the immortal words of T. S. Eliot she “gives promise of pneumatic bliss.”

The Automatic Message Accounting System (Fig. 13) devised by the Bell Laboratories [20, 21] for the telephone companies is one of the few examples of punched tape sorting equipment. This operates on a decimal-digital system.

The Sperry Rand File Computer [43] is primarily an inventory machine but has been built to have as much flexibility as possible. Its coding distributor and large capacity drum memory allow the machine to be programmed to perform a digital sort on two decimal digits at a time thus halving the number of passes required with a normal digital sort.

Mesh or Merge Systems

These systems are the commonest with magnetic tape equipment. The theory of two of them is explained in Fig. 14(a) to (m), pp. 46 and 47, and Fig. 15(a) to (g), pp. 48 and 49.

The Underwood Elecom File Processor [22–24] uses a two-way merge sorting system.

The RCA Bizmac Sorter [25, 26] uses a two-way merge system.

Univac [27–31] at first used two-way merge sorting and the Univac sort generator was the first major automatic routine to be completed. It has been in use since 1951. A three-way sort routine has now been devised for Univac. Also available is a more sophisticated merge system making good use of the high speed memory and known as the Arranger [32].

For the IBM 705 [33–36] a sophisticated three-way sort routine is available.

The Datamatic 1000 [37, 38] allows a very fast read in from its wide tape and its sorting capabilities are rumored to exceed those of the other machines.

Time is saved at the beginning of most of these merge-sort routines by reading blocks of items into the internal memory and then sorting them into strings at
(a) Input tape; items represented by strips; the length of the black part representing the key.
(b) Beginning of first pass; input from Tape A; output to tapes B & C; two input registers each holding one item.
(c) Read first two items into input registers.
(d) Compare, read smaller and then larger into Tape C.
(e) Read next two items in ascending order into Tape D.
(f) Repeat till Tapes C & D each contain a series of strings of two.
(g) Exchange input and output; read from each input tape into corresponding input register; compare; read smaller into output Tape A; immediately replace with next item from the tape the smaller came from; compare and read smaller into Tape A.

(h) Continue thus until the first two strings of two in Tapes C & D have been merged into a string of 4 in Tape A.

(i) Merge the next two strings of two into a string of 4 in Tape B.

(k) Repeat till all strings of two have been merged into strings of 4 in Tapes A & B.

(l) Merge these into strings of 8 in Tapes C & D and then into strings of 16 in Tapes A & B.

(m) Merge these into a string of 32 in Tape C.

Fig. 14—Binary mesh (merge) sort; equal strings; input in random order.
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(a) Input Tape A; items in random order.
(b) Read first three items into input registers.
(c) Compare A with B and smaller with C; read smaller into output buffer D.
(d) Read next item into empty input register; compare with output buffer D; if larger continue.

(e) Read output buffer into Tape D; compare input registers; read smallest into output buffer D.
(f) Read next item into empty input register; compare with output buffer D; if smaller hold until change of output tapes.
(g) Read output buffer into Tape D; compare remaining input registers; read smaller into output buffer D.
(h) Read next item into empty input register; compare with output buffer D; if smaller hold until change of output tapes.
(j) Read output buffer into Tape D; read remaining input register into output buffer D; read next item into empty input register; compare with output buffer D; if smaller change output tapes.

(k) Compare input registers; read smallest into output buffer E.

(l) Continue in the same way to read a string into Tape E.

(m) Continue to read a string into Tape F.

(n) Continue to read further strings into the output tapes in turn.

(o) Change input to output; read first item of each input tape into corresponding input register; compare and read smallest into output buffer A.

(p) Continue to merge Tapes D, E, & F into strings in Tapes A, B, & C.

(q) Change input to output and merge these strings into one string in Tape D.

Fig. 15—Ternary mesh (merge) sort; unequal strings; random input.
high speed. This takes the place of the first few passes. Another method of time saving, used for example in the 705 routine mentioned, is to read the information from the input tape into the internal memory in large blocks. This saves much of the time used normally in starting and stopping the tape. The Arranger [32] routine already mentioned makes use of the internal memory to convert the input into variable length strings, any of which may contain more information than the capacity of the internal memory. In merging it effectively uses parts of the high speed memory as large input registers and output buffers to reduce the number of passes needed.

The National Cash Register Co. [39] designed a processor, the Model 303, which incorporates a built-in sort command to sort the contents of a full drum channel and a built-in merge command to merge two sorted channels.

Address Calculation

Address Calculation, a relative newcomer among sorting routines, was lately described by Mr. Isaac of SRI [40]. In a way the system is similar to that used in the Savasort [40] hand sorting system shown in Fig. 16.

Fig. 16—Savasort manual sorting device.

In this manual system the operator makes a guess at the approximate position in the file, turns the file to that point, and then checks the exact position in which to insert the item. The address calculation method for rapid access memories requires some knowledge of the characteristics of the keys of the items to be sorted. From the information, an approximate relation is established between the key and the address in which it has to be inserted. Suppose that 50 items are to be sorted into 100 pockets and that their keys are random numbers between 0 and 999. Suppose the pockets are numbered 0 to 99. A good approximation at sorting would be obtained by dividing the key by 10 and inserting in the pocket corresponding to the answer. Fig. 17(a) to (h) shows the theory and the routine for making slight corrections, if the pocket happens to be full. This system is only efficient if the number of pockets available is nearly twice as great as the number of items. Otherwise, too much comparing and moving is needed.

Another insertion is used by Monroe [42] in their Monrobot under some conditions. They program the search so that the required address on the drum is traced as being first in one half, then in one half of that half, and so on.

Selection Systems

The theory of this technique is shown in Fig. 18(a) to (j), p. 52.

A variety of this technique has been described by Mr. Friend [44] under the name “Nth Degree Selection.”

A similar method has been used by the ERA group of Sperry Rand [43].

The system is used by The Laboratory for Electronics in Diana (of the Chase National Bank) [45, 46]. Their system [Fig. 19(a) and (b), p. 53] uses slow-speed, high capacity drums and sorting is not normally used until a printed output is required. By means of a selection system, after an initial run of a few minutes, the Diana sorter produces sorted information at the rate of 2½ items per second, which is enough to match the speed of a line-at-a-time printer. Sorting on the Diana computer takes twice as long.

Exchange Systems

This method has very simple logic but requires too large a number of operations to be of much use generally. Items in addresses 1 and 2 are compared and the one with a smaller key read back into address 1. The key of the remaining one is compared with that of the item in address 3 and the smaller read into address 2 and so on. Walter Soden [47] has suggested a modification which he claims reduces the number of operations.

Avoid Sorting

The Clevite [48, 49] “TapeDRUM” [Fig. 20(a) and (b), p. 53] which effectively gives magnetic drum type access to a page at a time of information carried on a wide tape, can be used by various means to avoid sorting. For example, where information about transactions is coming into a system and has to be used to update a large file, the file can be held on the tape of a “TapeDRUM” and the incoming items can be temporarily stored on a normal magnetic drum with enough capacity to hold the number of items which comes in in the time required for the “TapeDRUM” to go through the whole length of the tape. In use, the “TapeDRUM” scans a page at a time and wherever the key of an item on the high-speed drum corresponds with the key of an
Fig. 17—Address calculation sort.
(a) By a series of comparisons, select smallest key in each track (one revolution).
(b) Read these items with the number of the tape they came from into the three partial sort tracks.
(c) Select item with smallest key in each partial sort track and read item into final sort track.
(d) Replace each item removed from the partial sort tracks by the next smallest in the track it came from.

(e) Select the smallest in the final sort track and read it into the output.
(f) Replace this by the smallest in the partial sort track it came from; replace the latter by the smallest left in the track it came from.
(g) Read out the smallest in the final sort track; replace as before.
(h) Continue selecting and replacing.
(i) Continue as before.

Fig. 18—Selection sort—example: 9 tracks each containing 3 items are sorted by using 3 partial sort tracks, 1 final sort track and an output.

From the collection of the Computer History Museum (www.computerhistory.org)
item on the "TapeDRUM," that item is transferred to the "TapeDRUM." If the final information has to be sorted by more than one key, two "TapeDRUMS" can be used.

Examples of large capacity rapid access memories other than that of Diana are the IBM multiple magnetic disk memory [50, 51] usually known as the Juke Box [Fig. 21(a) and (b), p. 54] and the Potter [13] and Telecomputing [52] rapid access magnetic tape memories. All of these are especially suitable for systems in which the information has to be arranged always according to one key. The Photoscopic [15, 53] information storage system (Fig. 22, p. 54) being developed by International Telemeter operates on different princi-
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(a) The read-write head is raised or lowered and inserted mechanically.
(b) The disks which hold up to 5 million characters.

Fig. 21—IBM 305 disk (Juke Box) memory.

Fig. 22—International Telemeter Photoscopic Memory.

In this case, the information is contained in a photographic film attached to a rotating glass disk. The access time in this system is much smaller than in the other systems and an access time of 50 milliseconds to any word in a 20 million bit store is being talked of. The main difference between this system and the others is that, being photographic, the information is not erasable. There are, however, a number of applications where this is not very important. Examples are a mail-order catalog, a dictionary, and the information required for sorting mail down to mailmen's routes. If a relatively small number of corrections and additions are required, this can be achieved by using a magnetic drum memory in parallel, having a capacity some small proportion of that of the Photoscopic store.

COMPARISON OF SYSTEMS

A great deal has been written about methods of comparing the speeds of various sorting routines [54–59] but in a paper of this kind all I can do is to provide a bibliography and extract some generalizations. In choosing between various sorting systems, it appears to be unsafe to reach a decision without first examining all the requirements, all the available equipment and several possible systems. It can be said in general, however, that distribution systems are likely to be faster when the number of possible keys is small compared with the number of items; that digital systems are good when the number of possible keys is about equal to the number of items and where very simple logic is a help; and that merge systems are suitable when the number of possible keys is large compared with the number of items, where more complicated logic can be used to speed up the process, or where items are partially ordered to start with.

Actual sorting time cannot be computed until information is available on the number of words per item, the number of digits in the key, the number of items, the speeds of the various parts of the sorting mechanism, and the details of other clerical functions which can be combined with sorting.

To achieve economy in a clerical system, it is necessary that the various parts be in balance; that is to say that no one function such as tape handling acts as a bottleneck and prevents other parts of the equipment from operating at full capacity. In line with this reasoning, many of the recent improvements in sorting have been brought about by increasing the speed at which information can be read in and out of tapes (vide the Datamatic 1000 [37], which uses 3 inch wide tapes traveling at 100 inches a second read at a rate of 56,000 characters per second). The use of ample buffer storage which permits reading, computing, and writing at the same time is now common practice.

In some cases, economy is achieved by separating sorting and computing functions. The commonest case is where the information is on cards which can be sorted very economically. In many clerical systems involving
magnetic tape files which have to be kept up to date a very large proportion of the tape handling time is taken up in sorting input transactions and merging these with the main file. In a typical case 5,000 items out of a file of 100,000 may have to be brought up to date. If this were done in a computer, most of the computer operating time would be spent searching tape and only a small part of the time in computing. One approach to this problem, used in Bizmac [26], Miniac [14], and Elecom [24], is to have a separate relatively unsophisticated fixed program selecting, merging, and sorting machine which prepares short tapes for the main computer's concentrated attention. The logic of selecting, merging, and two-way merge sorting is very similar. Of course, this choice would not be economic if it involved idle computer time. This again emphasizes the necessity for analyzing the job and using balanced machine elements. Diana [46] has a separate sorter with some additional parallel computing components which allow a sorting output twice as fast as that from the computer.

I have touched lightly on many facets of a wide field. I shall have accomplished my purpose if I have sorted and put in logical order the gist of the great volume of material which has been generated about sorting over the past few years.

BIBLIOGRAPHY

[3] Intertype Corporation, 360 Furman St., Brooklyn 2, N. Y.
[18] Addressograph Multigraph Corporation, 1230 Babbitt Rd., Cleveland 17, Ohio.
[19] Halm Instrument Company, Glen Head, L. I., N. Y.
[20] AMA (reprints from Bell Laboratories Record) Bell Telephone Laboratories, Murray Hill, Summit, N. J.
[22] Electronic Computer Division, Underwood Corporation, 35-10 36th Ave., Long Island City 6, N. Y.
[25] RCA Victor Division, Radio Corporation of America, Camden, N. J.
[27] Univac Division of Sperry Rand Corporation, 314 Fourth Ave., New York 10, N. Y.
[33] EDP program brief 3-705 sorting table; three way merge without record storage unit (times required under various conditions). IBM form 22-6644-0 (1955).
[34] EDP program brief 3-702 sorting techniques; two-way merge. IBM form 22-6656-0 (1955).
[38] Raycom data processing system, designed for business. Raytheon Manufacturing Company, Computer Department, Waltham 54, Mass. (now incorporated in Datamatic above).
[41] Savasort Corporation, P.O. Box 2428, 530 24th St., W. Palm Beach, Fla.
[48] The TapeDRUM new Brush rapid access high capacity magnetic memory. Clevite Research Center, 540 E. 165 St., Cleveland 8, Ohio.
[57] Schwartz, B. L., Criteria for Comparing Methods of Sorting, Read at ACM Conference (September, 1955).
[58] Schwartz, B. L., Mathematical Analysis of Sorting Procedures—WADC Tech. Rep. 53-605, Appendix B (unclassified), available through ASTIA.
CURIOUSLY, the ACM First Glossary of Programming Terminology has no entry for the word "document." The American College Dictionary defines it as "a written or printed paper furnishing information or evidence, a legal or official paper." Without becoming lexicographers, we might observe that "write" means "to trace or form (characters, letters, words, etc.) on the surface of some material, as with a pen, pencil or other instrument or means; inscribe." Quite clearly these definitions reflect long-existing techniques for economically reducing information to a form suitable for storage and evidential use, if necessary. The definition of a document is quite restrictive for it specifies a substance (paper), the method of making marks on it (writing or printing), and its use (furnishing information or evidence, legal or official). Actual or potential use of business documents for legal or official purposes occurs frequently. Laws and regulations covering content and retention have an important bearing on areas of document processing open to change and the rate at which changes can be made. Interestingly, however, "writing" is defined broadly enough to encompass most or perhaps all of the output techniques used in conjunction with computers for preparing legible copy.

Function of Document

The traditional function of business documents is to identify the parties to and nature of a transaction and to serve as a temporary storage medium (but often for rather long periods) for input to record-keeping systems. A small firm has a high proportion of its transactions with other firms (interfirm) so that the evidential aspects of a document for settling disputes may be fairly high. A large firm, on the other hand, has a high proportion of intrafirm transactions so that internal responsibility and managerial control are more important objectives. The record-keeping systems of individual firms, whether large or small, are usually operationally disjointed and incompatible (in view of the techniques available at any time) so that manually or mechanically generated documents serve as the connecting link for manual input for the records of both firms involved in a transaction. The notion is widely held, although some exceptions will be pointed out later, that information may be machine processable by one firm but that others must handle it manually with little or no benefits from technical developments of the past fifty years or so.

Substantial intrafirm economies have been and will continue to be achieved in data processing. A striking, but far from ultimate, development in this area is integrated data processing built around the intensive use of punched paper tape within a firm. Little has been done to date, however, to improve interfirm information processing. The originator ordinarily relies upon manual processing and almost universally the recipient is forced to do so. Important technical developments in document processing and their widespread adoption may greatly change the traditional nature and use of documents.

History of Documents

We tend to think of documents as being individual pieces of paper, either thick or thin, serving as the initial record of a transaction. This has not always been the case, however, even after the widespread usage of paper in Italy and England by the 14th century. In the infancy of modern accounting some 500 years ago (and today in commercially less-advanced countries), the initial record of a transaction was made in a memorandum or waste-book. Such a book was notarized by a government official upon the user's representation that it would be kept currently although the bookkeeper was not available momentarily, and that it would contain a true and correct copy of transactions. In case of dispute, it served as prima facie evidence. This type of record, instead of individual documents, had several important features. Paper was economized by use of variable record length, only one party to a transaction had a copy of the record, the initial steps in the record keeping were kept current and the memorandum served as the basis for someone skilled in record keeping to treat more formally, when convenient.

As another example of nondocumentary records, for a long time the English government recorded collections by making notches on split sticks. Tally sticks had some good record keeping characteristics. Both parties had unique duplicates of the transaction record (by splitting the stick and giving part to each party) which were difficult to manipulate. Pen, ink, and paper replaced tally sticks so that they were abolished by Parliament in 1782 and finally discontinued in 1826. Disposing of these

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1 For example, contents, to some extent, but more particularly retention periods, for business records and supporting documents are specified by both federal and state laws dealing with income tax, insurance contributions, unemployment taxes, wages and hours, and utility regulations. Retention periods often run from one to six years.
