15. E. B. Wedmore and H. A. N. Dellow, *Some Problems of the Winter Cluster* (Bee Research Association, London, 1953).
16. M. D. Allen, *J. Exptl. Biol.* **36**, 92 (1959).
17. A. Himmer, *Biol. Revs. Biol. Proc. Cambridge Phil. Soc.* **7**, 224 (1932).
18. O. Sotavalta, *Ann. Zool. Soc. Zool.-Botan. Fennicae Vanamo* **16**, 1 (1954).
19. V. G. Milum, *Am. Bee J.* **92**, 411 (1952).
20. V. Hallund, *Nord. Bitidskr.* **8**, 106 (1956).
21. E. B. Wedmore, *The Ventilation of Beehives* (Bee Craft, Petts Wood, Kent, England, 1947).
22. O. S. Lvov, *Pchelovodstvo* **31**, 37 (1954).
23. A. E. Sutherland, *Bee World* **25**, 90 (1944); **26**, 44 (1945).
24. H. Heran, *Z. vergleich. Physiol.* **34**, 179 (1952); C. Meyerhoff, *Arch. Geflügelz. Kleintierk.* **2**, 36 (1953).
25. E. P. Jeffree, and M. D. Allen, *J. Econ. Entomol.* **49**, 831 (1956).
26. E. Herold, in *Biene und Bienenzucht*, A. Büdel and E. Herold, Eds. (Ehrenwirth, Munich, 1960).
27. G. H. Vansell, *J. Econ. Entomol.* **23**, 418 (1930).
28. E. H. Hazelhoff, *Physiol. Comparata et Oecol.* **3**, 343 (1954).
29. M. Lindauer, *Z. vergleich. Physiol.* **36**, 391 (1954).
30. I. Okada, T. Sakai, H. Obata, *Rept. Intern. Beekeepers Congr. 17th Congr.* (1958), p. 87; J. Simpson, *Rept. Rothamsted Exptl. Sta.* (1958), p. 150.
31. J. Grziwa, *Z. Bienenforsch.* **3**, 199 (1956).
32. H. Verron, *Insectes Sociaux* **2**, 57 (1955).
33. L. Le Bigot, *Apiculteur* **97**, 39 (1953).
34. G. A. Abetisian, *Pchelovodstvo* **27**, 533 (1950); V. Hallund, *Nord. Bitidskr.* **8**, 78 (1956); G. F. Taranov and K. I. Michailov, *Pchelovodstvo* **37**, 5 (1960).
35. J. Simpson, *Bee World* **35**, 149 (1954).
36. A. Büdel, *Z. Bienforsch.* **3**, 221 (1957).
37. E. Braun and J. E. Geiger, *Can. Dept. Agr. Publ. No. 689* (1955); M. H. Haydak, *J. Econ. Entomol.* **51**, 332 (1958).
38. P. Lavie, *Insectes Sociaux* **1**, 39 (1954).
39. C. G. Butler and J. Simpson, unpublished experiments on hive ventilation in winter.

Data Processing by Optical Coincidence

This unconventional use of punched cards provides a flexible and rapid means for hand tabulation.

John D. Campbell and Herbert S. Caron

The task of evaluating data is common to all sciences. Sometimes this problem can be readily solved, but when a study embraces more than a few variables, examination of the interrelationships between them poses technical difficulties. Even though we are working in an age of high-speed computers, there is a need for further development of readily available processing methods that will permit flexibility in analysis. Such flexibility facilitates the development, reformulation, and rapid follow-up of hypotheses. The present article offers one such technique, a method for storing data and obtaining cross tabulations. Among its specific advantages are the following: (i) convenience—there is no reliance on complex and bulky machines typical of central-office installations; time-consuming communications with processing personnel and the wait for return of data are eliminated; (ii) flexibility—the storage provides the equivalent of an IBM card with an infinite number of columns, and in subsequent processing, complex multivariate tables can be constructed with ease; (iii) speed—the method is faster than other hand-operated procedures for data tabulation; (iv) accuracy—simplicity of operation permits easy and frequent checks; (v) economy—economy of effort has already been mentioned; the economy of the technique in dollars and cents is equally striking. For example, in one application of this procedure, an outlay of approximately one dollar would enable the research worker to set up shop.

The method departs from procedures conventionally employed. Ordinarily the *individual* or the *case* serves as the basic conceptual entity—the central unit about which observations are collected. In the behavioral sciences, for example, we ask questions of the individual, we measure his responses, we observe his behavior (*1*). Having collected the data on a case-by-case basis, we then typically store it in the same fashion. The interview schedule, the case file, or other data constitute a record that may be preserved intact or may be evaluated in a variety of ways. When the research worker begins to summarize data on a considerable number of persons, he may for purposes of data processing set up a code sheet for each person included in a study, and may enter suitably coded information on each individual on one or more punched cards. Thus, in conventional procedures the unit for data collection, the individual, remains the unit for data storage.

The alternative method, with which we have been experimenting, employs as a basic principle one that has been profitably used in some bibliographic and indexing work in recent years (*2*). As used in indexing, the system inverts conventional procedures by using conceptual categories, rather than documents, as the units for storage. All documents are assigned code numbers, and concept cards (as opposed to document cards) are used for recording, in writing or by punched position, all documents pertaining to the concepts in question. Thus, to identify all documents which contain information in all of several specific concept areas, the appropriate concept cards are selected and the document numbers that appear on all the cards selected are obtained (*3*).

In applying this system to data analysis we use punched cards as a medium for storage, but again the system differs from conventional procedures, for the storage system is organized in terms of coded characteristics ("male," "female," "only child," "first born," "later born," and so on) rather than of individuals. There is a card for each characteristic, and each individual is assigned the same position on every card. If a given characteristic is associated with a particular individual, a punch is made in his specified position on the card for that characteristic. To illustrate, Card *A* in Fig. 1 has

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numbered positions for 28 individuals. Punches have been made in 12 of these positions (including position number 21 which identifies Charlie Brown)—an indication that the characteristic, "male," is associated with each of the 12 individuals. Similarly, card *B* shows that nine of the 28 individuals are in the "only child" category. (Since Charlie Brown is not an only child, no punch has been made in position 21.) To determine the number of males who are only children, one superimposes card *A* on card *B*, as shown in Fig. 1 (bottom). Only in cases in which the individual's position has been punched on *both* cards (cards for "male" and "only child") will perforations coincide when card *A* is superimposed on card *B*. The number of such instances of coincidence can then be determined visually. In Fig. 1, there are five perforations common to the two cards; this number represents the total for one cell of the 2- by 3-cell table which relates sex and birth order. Completion of a tabular analysis relating these two variables (or "dimensions") then becomes a matter of selecting all of the category cards for the two dimensions and systematically pairing them, successively superimposing each category card for one dimension on every category card of the other, and counting the number of perforations common to each such pair. In this fashion the frequencies for each of the six cells of the table relating sex and birth order may be obtained.

These are the essential elements of the system. The more detailed exposition that follows describes procedural details that have proven effective in our exploration of the possibilities of this approach.

Input

Code sheets. Storage of data is accomplished by punching holes on category cards. For ease of processing it is convenient to record data on code sheets prior to punching. Since the data are about individuals, we code on an individual-by-individual basis. But the organization of the code sheets discussed below facilitates subsequent punching on a dimension-by-dimension basis.

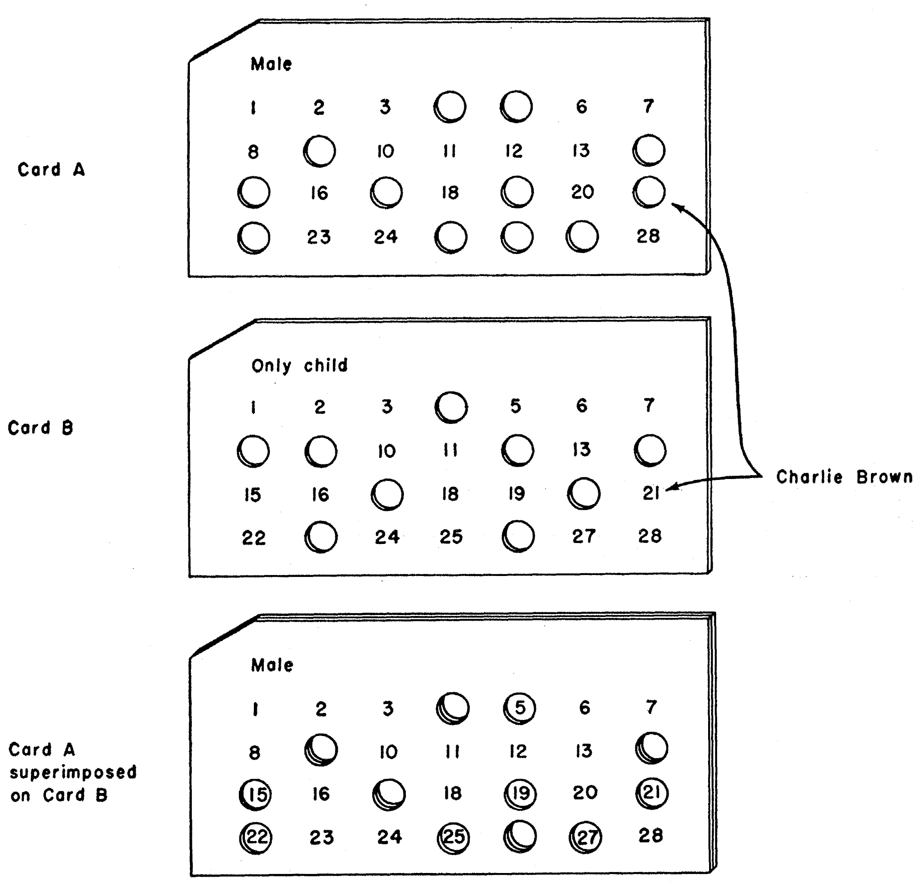

Fig. 1. Cards for optical coincidence detection.

The code sheet best adapted for this system may be conceived of as a coordinate system, in which each one of *l* rows identifies an individual for whom data are recorded, and each one of *k* columns identifies a dimension (variable or attribute) on which data are obtained. Figure 2 shows a fragment of such a code sheet. In the left-hand column are the case identification numbers, usually (but not necessarily) sequentially assigned. The column headings, *A1*, *B1*, *C1*, and so on, are the code labels for specific dimensions to be recorded.

Typically, entry of information on the code sheet proceeds in a case-by-case fashion. Thus, the appropriately coded information on the person to whom code number 1 has been assigned is entered in row 1: His code on dimension *A1* is recorded in row 1, column *A1*; similarly, the code for this individual for dimension *B1* would be entered in row 1, column *B1*; and so on. And in the same fashion the information on the second individual is entered in the second row; information on the *i*-th individual, in the *i*-th row.

Unless one is working with a very small sample and a restricted number of variables, the number of individuals for whom data are to be recorded will exceed the number of rows on a single tabular sheet, and the number of dimensions with which the investigator is concerned will be greater than the number of columns. It is, however, a simple matter to "extend" the size of the coding matrix by adding additional sheets, which can be conveniently and compactly assembled in a looseleaf binder.

Four advantages of this procedure are worth noting. (i) Even before cards are punched, a visual inspection of the appropriate columns of the coordinate code sheets can provide a quick initial impression of the nature of the relationship between any two variables. (ii) Use of a coordinate system for recording data can effect an appreciable reduction in storage space over that required by a procedure in which a single code sheet is used for each individual. (For example, on a coordinate code sheet consisting of 30 rows and 20 dimension columns plus a case-identification column, one could record 80 different types of information on 300 individuals on a total of 40 sheets. This is in marked contrast to the 300 code sheets that would be required if a code sheet were used for each individual.) (iii) Coordinate code sheets have a flexibility that is not found in individual code sheets. The same coordinate sheets that permit subsequent storage of punched-card data according to the dimension-by-dimension pattern described here may, if they are reordered, readily be used in conventional case-by-case storage of punched-card data. (iv) Coodinate code sheets constitute an "open system." Not only additional individuals but also additional variables may easily be added by the research worker at any stage of the research process.

Punching equipment. Once the data have been recorded on code sheets, the process of storing information on the cards may begin. The system requires a means for precisely locating punching positions and a convenient method for punching.

The stub-pencil researcher can assemble all the materials he needs for punching at a relatively low cost. To set up this procedure on the least expensive basis possible, one would need to purchase a simple conductor's punch and a number of file cards of an appropriate size. A 5- by 8-inch file card can readily handle a couple of hundred cases. Such file cards do not at the outset have precisely placed punching positions defined on their surface. Two ways of meeting this problem are suggested. One might print (by accurate stencil duplication or other means) a suitable grid for punching on each card. Alternatively, one might identify and punch every position on a master card and then use this card as a template in subsequent punching.

More expensive, but at the same time more convenient and able to accommodate a larger number of cases, are cards and punches devised for conventional data-processing applications. Though these were designed for use with typical individual-by-individual input, they can be effectively employed in the dimension-by-dimension application of the techniques under discussion. The Sperry-Rand Corporation markets a special hand punch and a card for use in connection with it. This card could accommodate up to 540 cases. Other inexpensive commercial punching equipment consists of the IBM Port-A-Punch board and the cards used with it. The card, identical in size to the conventional IBM card, has 480 punching positions prescored on it. It

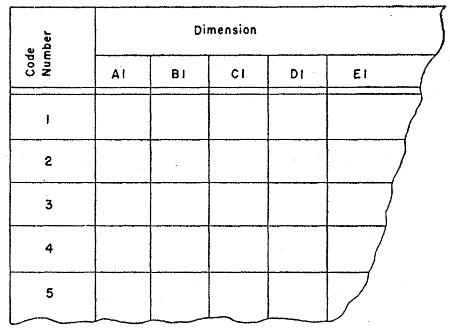

Fig. 2. Coordinate code sheet.

is slipped into the punching board, and then a stylus, resembling a mechanical pencil, is used to push out the bits of cardboard and make the holes.

Principles of data storage. No matter what the exact nature of the card and punching equipment, the basic principles of information storage by this method remain the same. Each card has a fixed number of positions on it. A single specified position is assigned to each individual for whom data have been obtained. The location of the position assigned to an individual on one card is identical to the postion assigned to him on every other card (*4*). Thus, if in the fourth column of a card the fifth punching position is assigned to the individual who has the code number 45, the fifth punching positions in the fourth columns of *all* other cards in the deck similarly "belong" to that individual—whether they are punched or not. (A procedure is described below that permits one to use this feature of fixed position to considerable advantage in subsequent data analysis.)

Punching of a given dimension requires as many cards as there are coded categories in the dimension. For example, in a study of child rearing, the dimension "sex of oldest child" (if no twins are included in the sample) would require two cards—"male" and "female"; the dimension "number of children in family" might be handled by four cards—"one child," "two children," "three children," and "four or more children." Each card is labeled with designations of both the dimension and the specific category. These labels may, of course, either be recorded in full or be written in suitably encoded form. The latter method has the dual advantage of being more rapid and of simplifying subsequent filing.

In practice, several alternative procedures may be used to locate and name each punching position: (i) numbers may be printed on the cards to identify the positions; (ii) columnar and row designations may be printed on the surface of each card, and the position may be identified by a grid coordinate reading; (iii) one card may be set up as a template with labeled positions as a guide in punching.

Card punching. The punching operation is a simple one. The category cards for a given dimension are set up, and punching on the first-category card proceeds. The punch operator reads down the column containing code entries for the dimension in question, and each time the first category appears he punches the category card in the position assigned to the case number associated with the particular row on the code sheet in which the entry occurs. The punching of each additional category card necessitates a rescanning of the appropriate dimension column of the code sheet (*5*).

An alternative method that readily suggests itself, of course, is one in which the operator follows down a column only once and, shifting back and forth between category cards, punches the coded entry for each individual in the natural sequence of progression down the column. In our own experiments with input procedures we have tended to reject this method for three principal reasons: It does not permit positive reliability checks as readily as the first method; in actual operation it takes more time than the first method; and it does not facilitate combining of categories as an integral part of initial punching (a procedure described below).

For a variety of reasons one might wish to combine categories in certain subsequent analyses. For example, such pooling might be considered when the frequency of cases in one or more categories is small, or when utilization of some scale analysis procedures might be facilitated by such combination. With "optical coincidence" procedures, combining categories is a process that can be incorporated in the initial punching routine with minimum effort. In addition to the specific category cards, one sets up combination cards. To return to a previous example, that of punching for the dimension "number of children in family," we might, for some phases of our analysis, want to reduce this dimension to two categories: "one child" and "two or more children." The latter category would then be indicated on an additional combination card. Then, in the punching operation the combination card would be placed in position behind the "two children" card while that category was punched. Next it would be aligned for punching with the "three children" card and finally with the "four or more children" card. Combining categories in this fashion is an economical procedure; in this case, for instance, we obtain four cards for the punching price of three.

If categories of a coded dimension are mutually exclusive, one may build in a positive and complete check of reliability of the punching operation. This is a logical extension of the process of combining categories. Required for such a check are a pre-punched master card (a card in which holes have been punched in each position for every individual actually included in the study) and an initially unpunched "total-check" card. The total-check card is aligned behind the first category card for the given dimension, and punching is accomplished in the same fashion as in combining categories. On completion of first-category punching, the total-check card is placed behind the second category card and punching continues. After data for all categories have been punched in this fashion, the check card should then contain perforations in every location assigned to an individual included in the study.

One may now make two checks. (i) The total-check card is superimposed on the pre-punched master card. If, on inspection, all perforations in the two cards are found to correspond, then no case has been omitted in punching. (ii) Specific category cards are then paired with one another, and in this case coincidence of perforations indicates erroneous punching. Any errors detected in this fashion can be corrected by reinserting one of the punched-out bits or by otherwise masking the erroneous punch. After checks have been completed, a count of all perforations in each category card is recorded on its surface. This recorded information is then always available as a check on marginal frequencies in subsequent tabulations. When appropriate checks have been made, the cards, identified by dimension and category, may be filed until they are needed for subsequent tabulations (*6*).

Output

To obtain tabular information by means of the system described is a simple process which we have found to be more rapid than other hand-manipulated procedures. Further, in our experience, we have found it to be frequently preferable to central-office data processing.

"Readout" is always accomplished by superimposing appropriate cards. No special equipment is needed, but a card alignment board is both a convenience and a timesaver. It makes precise superimposition of cards an automatic process. The alignment board may consist merely of a piece of heavy cardboard or hardboard, slightly larger than the card, and of two card-alignment strips, one located at the bottom edge, the other at one side of the board. A board with a dark surface is desirable for contrast with the light cards. Or one could construct a more elaborate viewbox with a light shining through a translucent panel on which the cards would be placed. If the IBM Port-A-Punch is used for input, the board also serves adequately for readout purposes.

Obtaining information on "straight runs" (simple marginal frequencies for all variables) requires almost literally no work at all. The procedure for storing information essentially amounts to a pre-sorting of all cases for every dimension for which data are recorded. Hence, the recorded frequencies of perforations on the cards for the various categories of the dimensions in question provide the desired information on marginal frequencies. From an inspection of such frequencies the research worker may, on occasion, decide that for subsequent analyses certain data categories for a given dimension should be combined. This can be done by superimposing, in turn, on a combination card each category card pertaining to the new pooled category and making corresponding perforations on the combination card.

Simple cross tabulations of two dimensions are easily and quickly effected. First one sets up the format of the table on tabular paper and selects from the file all category cards for the two dimensions that are being related to one another. One then superimposes the first-category card of the first dimension on the first-category card of the second dimension and counts the number of instances in which the perforations on the two cards coincide. This count is then entered in the appropriate cell of the table. The first-category card of the first dimension is next paired with cards for each other category of the second dimension, and these counts are recorded in the appropriate cells. The table is completed by following the same procedure with the succeeding categories of the first dimension. After entries for all the cells of the table have been obtained in this way, column and row marginal totals are obtained, and these totals for each category are checked against the totals recorded on each category card of the two dimensions employed in the table. Illustrative of the speed with which such cross tabulations can be made is the fact that the total time required to count and record the information in a 5- by 5-cell table for relating general sociometric data on 264 children at two different points in time was less than four minutes; all of the "equipment" needed for this tabular operation can be readily placed in one's coat pocket.

Complex cross tabulations with three or more variables are simply the logical extension of the two-dimensional tabulations described above. One sets up the desired tabular format on paper, selects the necessary dimension cards from the file, stacks the category cards defining a particular cell together, and then counts the perforations common to the several cards. (In a three-dimensional table, for example, cards are stacked together three at a time, one category card from each dimension.) One similarly determines every other cell entry for the table by stacking the appropriate cards and then making a count of the number of coinciding perforations. After entries have been made in all the cells, the routine marginal check can quickly be made. It is worth noting that in a 3- by 3- by 3- by 3-cell table—that is, an 81-cell table—only 12 different cards are used in the total cross tabulation, and the number of separate "stacks" of cards used by the tabulator is much smaller than would be the case with any conventional method of hand sorting.

In addition, by observing the coincidence of perforations in the several superimposed cards one may directly identify, from position numbers, individuals with a particular combination of characteristics. Such identification can prove useful in deviant case analysis.

Short Cuts and Timesavers

In our explorations of the usefulness of the procedures described above, two techniques have proven to be effective timesavers in the data-analysis process: (i) the use of code numbers for individuals as a means of preclassifying them with respect to one or more variables that will play a major role in subsequent analyses, and (ii) a technique for obtaining data for several tables "simultaneously" in a way that reduces the amount of card manipulation necessary.

Preclassification by position. In data processing by optical coincidence each individual is assigned the same position on each card. The assignment of such positions could be based on any one of several schemes. For example, positions could be assigned alphabetically, or in numerical sequence according to the chronological order in which data on individuals were obtained, or in a completely random fashion. An alternative procedure, in which designation of position is deliberately related to relevant research variables, can materially speed the subsequent tabulation process.

If the investigator plans to include one or two fundamental variables in a large number of his tabulations, he may designate specific areas of the card for each category of these variables. This may be described as preclassification by position. Thus, if one were primarily interested in examining the relation between maternal age and a series of other variables, the preclassification procedure could be as follows. (i) Determine the total number of different maternal age classifications to be used (for example, "under 20," "20–24," "25–29," "30–34," "35–39," "40 and over"). (ii) Assign to each of these categories a *region* of the card. For example, one might simply divide the card into six fields, each field consisting of a sufficient number of columns to permit the assignment of one position to each individual included in the sample who falls in that age field. (iii) Assign code numbers in such a way that a given sequence of code numbers applies to a given field, identifying a particular age classification. (iv) Proceed with input procedures as described above. The information stored on each category card would thus be automatically preclassified by age.

The advantage of this procedure becomes readily apparent when we consider output. Let us assume that we want to study the way in which responses to a series of questions about child development are related to maternal age. If we break a five-category classification of "mother's affectional warmth toward child" according to "age of mother," our end product is a 5- by 6-cell table. If we use the optical-coincidence procedure *without* preclassification we have to manipulate 11 cards (six for age and five for affectional warmth) in 30 separate pairings. In marked contrast to this, however, the employment of preclassification coding procedures on one dimension, "age of mother," permits us to read off entries for the table directly simply by making the appropriate age-field counts on each of the five "affectional warmth" cards. Similar economy (a sixfold reduction in card manipulation) would of course be obtained in every instance in which age was one of the variables on which the tabulation was based.

This principle can readily be extended to two-dimensional preclassification. Thus, if *both* age of mother and sex of oldest child are variables of principal interest, we may use a "grid" approach in which age fields are defined vertically and fields for sex of oldest child horizontally. It is even possible to preclassify for three or more variables, but in some applications this may become cumbersome.

It should be noted that preclassification in no way limits the data-tabulating procedures. Thus, in the example just described the following operations are possible: (i) examination of the relationship of age of mother to one or more additional variables; (ii) examination of the relationship of sex of oldest child to one or more additional variables; (iii) examination of the way in which *both* age of mother and sex of oldest child relate to one or more additional variables; and (iv) examination of the relationship between any other variables studied (the role of mother's age and sex of child being ignored).

The greatest output saving, of course, would result when preclassification variables are related to one or more additional variables. Thus, if six different maternal-age categories and two categories for sex of oldest child serve as the basis for establishing the precoding grid, a 12-fold saving in card manipulation is effected for any analysis in which these two variables are simultaneously related to one or more additional variables.

Careful thought should be given to the selection of variables for preclassification, since it is not convenient to change plans once the input procedures are begun. One cannot readily change, of course, because the basic requirement of this method is that a fixed position for each individual be retained on all storage cards, so that all relevant cards in the set may be used for readout.

"Simultaneous" tables. When one variable is cross-tabulated against another by means of the procedure described above, the minimum total number of manipulations of category cards is equal to the number of cards in the variable that has the smaller number of categories, plus the product of the number of cards in one variable and the number of cards in the other. Thus, in obtaining the information for a 4- by 4-cell table, 20 individual manipulations are required. If many tables are to be run in which one particular variable is cross-tabulated against each of a series of other variables, it is possible to keep the total number of manipulations of the category cards of the first variable to one for each such card. For example, let us assume that we wish to relate the working status of mothers to the following seven dimensions, seriatim: socioeconomic status, age, race, number of children in the family, age of youngest child, husband's occupation, and mother's score on a parental attitude scale. If we had three categories of maternal employment status (full-time employment, part-time employment, and no employment outside the home), and if we completed each table relating maternal occupational status to a second variable before proceeding to another table, each category card for maternal occupational status would have to be manipulated seven times, for a total of 21 card manipulations for this variable. If, however, we take the first-category card for maternal employment status and successively pair it with each of the category cards for all of the other variables being cross-tabulated, we can complete one column in each of the seven tables described with only one manipulation of the first-category card for maternal employment status. This same procedure would, of course, be followed with the other two cards for maternal employment status, with some over-all saving of time.

We have described a simple type of data processing that differs markedly from many other procedures, machine- or hand-operated. The economy and convenience of the method make it, in our estimation, superior in some cases both to other hand-processing methods and to punched-card operations that rely on central-office machine installations. Speed and flexibility are its major advantages. It has, of course, some limitations: punching by hand is slower than punching by conventional machine methods, and cards can accommodate only a limited number of cases. These drawbacks are in many instances more than outweighed by the advantages. The individual research worker looking for in-almost-any-pocket convenience at in-almost-any-pocketbook price may well wish to consider this method as a means for solving his data-processing problem.

References and Notes

1. Although the illustrative examples in this article are drawn from the behavioral sciences, the general technique is equally applicable to any situation in which an investigator wishes to examine relationships obtaining between two or more variables.
2. Basic descriptions of this procedure may be found in *The Uniterm System of Indexing: Operating Manual* (Documentation Incorporated, Washington, D.C., 1955). The most detailed exposition of the use of punched cards in applying this principle to indexing is a paper by W. A. Wildhack and Joshua Stern, "The peek-a-boo system—optical coincidence subject cards in information searching," in *Punched Cards: Their Application to Science and Industry*, R. S. Casey, J. W. Perry, M. M. Berry, A. Kent, Eds. (Reinhold, New York, ed. 2, 1958).
3. Those who are convinced that there is almost nothing new under the sun will find their opinion supported by evidence which suggests that the basic principle here described is a very old one. On the site of ancient Sumer, clay tablets have been discovered that may have been used in a similar fashion for medical diagnosis. Each tablet referred to a single symptom and listed the diseases in which it was present. A comparison of symptom tablets would presumably have enabled the ancient medic to reach an appropriate diagnosis. [Reported in *Proceedings of the International Study Conference on Classification for Information Retrieval* (Aslib, London; Pergamon, New York, 1957), p. 106.]
4. That there is an upper limit to the number of positions on a card restricts the utility of this method for very large samples, but anyone working with a sample of 400 or less would encounter no difficulties on this score. For studies in which the size of the sample exceeds the number of cases that can be accommodated on a card, the investigator may set up additional sets of cards. For example, if two sets of cards were needed, entries for every table would in effect be obtained by adding corresponding cell entries of two separate tables. There are, of course, limitations to this method of expanding the system's capacity.
5. Although the punching operation in this method of data processing is slower than conventional procedures in which equipment such as an IBM key punch is used, input is probably at least as rapid as that of any method that does *not* require a major piece of hardware for punching purposes.
6. When the categories are not mutually exclusive —that is, when a punch for an individual may be made in more than one category—reliability checks are more problematic (this is also the case with conventional data-storage methods). The total-check-card method is, however, still applicable.

Behavioral Thermoregulation

Behavior is a remarkably sensitive mechanism in the regulation of body temperature.

Bernard Weiss and Victor G. Laties

Behavior is one of the fundamental mechanisms by which organisms regulate body temperature. But, although one can point to numerous illustrations of its importance, quantitative data on the role of behavior in thermoregulation are rare. Among these are Kinder's findings on nest building in rats. Employing a technique originally developed by Richter, she showed that as the ambient temperature fell, rats increased the amount of paper that they used for nest building (*1, 2*).

In this article we discuss a recent series of studies (*3*) on how behavior contributes to the regulation of body temperature. The major aim of these studies was to specify the relation between body temperature and a response which provided an exteroceptive source of heat.

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The apparatus employed is illustrated in Fig. 1 (*4*). It consists of a Plexiglas cylinder containing a plastic lever attached to a telegraph key. The red-bulb infrared heat lamp above the chamber goes on for a few seconds on certain occasions when the rat presses the lever.

The duration of the burst of heat from the lamp is varied by a timer, and the intensity is varied by a variable transformer. The chambers are located in a refrigerated room, the temperature of which can be controlled to within 1°C. The apparatus that is used to automatically record and program the relevant events is located in an adjoining room.

The fur of the rats used in these experiments was removed by clipping before a session. This procedure makes it impossible for the rat to maintain a normal body temperature at the environmental temperatures used in the experiments.

Initiation

After a rat with no experience in this situation is put into a chamber, it typically spends the first few minutes exploring its surroundings. During this time it occasionally strikes the lever with enough force to close the contacts on the key. This event turns on the heat lamp for several seconds. After this initial flurry of responses the rat usually spends most of the next few hours merely huddling and shivering. Only occasional responses are made during this time. At some point during the session the rat suddenly begins to press the lever at a steady and substantial rate, which it maintains for many hours.

Why does the rat's behavior change so swiftly? It is known that the temperature of a furless rat put into a cold environment undergoes a progressive fall. Perhaps body temperature has to descend to a certain critical point before the burst of heat from the heat lamp becomes reinforcing.

One can test this hypothesis by exposing the rat to cold before putting it into the chamber. Such an experiment was performed with 14 pairs of rats. One member of the pair, randomly selected, was put into a wire-mesh cage in the cold room after being clipped. Its partner was kept at room temperature. Five hours later, both rats were put into test chambers and exposed for 16 hours to a cold-room temperature of 2°C. The heat lamp was set to 250 watts, and each reinforcement (burst of