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LEGISLATIVE DISTRICTING BY COMPUTER SIMULATION

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The political districting process can be thought of as locating geographical boundaries that enclose electoral populations. Equal population, as specified by the Supreme Court, suggests the use of quantitative procedures in districting that would draw district boundaries on an impartial basis. Such analytical procedures could unquestionably aid in achieving equitable representation on a population basis. The purpose of this paper was to create rational districting schemes through the development of analytical techniques. The intent was to provide an efficient means of generating many impartial districting arrangements that would satisfy both the equal population requirement and a number of traditional districting criteria including contiguity, compactness, preservation of existing political boundaries, and regular representation.

This paper demonstrates that an abstract computer simulation model can be used effectively in creating rational districting solutions based on population equality. It also shows that additional criteria can be programmed into the model to accommodate current districting requirements. Moreover, the computational speed of the digital computer permits rapid calculation and determination of superior arrangements.

The political districting process can be thought of as locating geographical boundaries that enclose electoral populations. In 1961 the U.S. Supreme Court ruled in Baker vs. Carr that federal courts have jurisdiction to insure equality of representation in cases concerning state reapportionment laws. Thus, states are currently faced with the necessity of developing apportionment plans that satisfy federal constraints; principally the "one man-one vote" population ruling in Reynolds vs. Sims. The purpose of this paper is to describe two computer simulation programs that locate district boundaries, using equality of population as the principal criterion. Particular reference is made to districting examples from the state of Iowa.

CRITERIA FOR DISTRICTING

Until the recent Supreme Court decisions many options were exercised in the districting of state legislatures. Some criteria that have historically been incorporated into the districting process (see Harris, 1964, and Weaver and Hess, 1963) include:

1. Equality of Population—Each district should contain a population nearly equal to that of every other district.
2. Contiguity—Districts should be composed of contiguous territory.
3. Compactness—Districts should be composed of compact territory. Although a precise definition of compactness is not generally accepted, in a geographical context it means closely united so as to economize space.
4. State Law—Districting must adhere to state constitutional requirements.

1 Presented before the 1966 American Meeting of The Institute of Management Sciences, February 17, 1966. This study is also presented in Thoreson (1965).
2 Apportionment refers to the allocation of legislative seats among previously defined districts. Districting is the process of drawing the geographic boundaries defining those entities.
5. Homogeneity—Districts should contain communities of common economic and social interests, and allowances should be made for other ecological and psychological factors.

6. Singular Representation—There should be one and only one member representing each district.

7. Preservation of Political Boundaries—District lines should follow boundaries of existing political regions, such as counties, townships, or cities. Legislators frequently ask that district boundaries be drawn so that seats of incumbent members are preserved.

8. Natural Features—District boundaries should follow geographic and topographic features, such as rivers or mountains.

While population equality is now recognized as the primary criterion, it does not follow that all of the remaining principles listed above are to be overlooked in developing a computer districting model. Traditional criteria may be retained so long as the resulting arrangement complies with population guidelines.

**HISTORICAL PRECEDENTS IN IOWA**

In any redistricting situation it is difficult to reach a solution acceptable to all parties concerned since the political balance of a legislature is usually at stake. Recent court cases in Iowa illustrate typical redistricting difficulties.

At the time Iowa became a state in 1846, the Iowa Constitution essentially provided for apportionment of the legislature on the basis of population equality. However, in 1901 and 1928 amendments to the Iowa Constitution altered the laws governing the composition of the legislature.

Recent court cases in Iowa illustrate typical redistricting difficulties.

The 59th General Assembly (1961) began the reapportionment process by enacting a proposed amendment to the State Constitution. This amendment, commonly known as the "Shift Plan," called for a 58-member Senate and a 99-member House. One House member was to be elected from each county, whereas the Senate districts were to conform to other criteria including preservation of county boundaries. Although the amendment was subsequently passed by the 60th General Assembly (1963), it failed to gather the necessary popular support and was rejected when submitted to the people at a special election in December 1963.

As a consequence, the 60th General Assembly required an Extraordinary Session to enact a new reapportionment law. The resulting act of this session provided for composition of the 61st General Assembly and for a so-called "permanent plan" of reapportionment. In the temporary plan, population was introduced as a factor in the House. This plan required 59 Senate and 124 House members. However, as a consequence of the Reynolds vs. Sims decision following the Extraordinary Session, the 61st General Assembly in 1965 abandoned the permanent plan and revised the 59-member Senate and 124-member House plan, arguing that the Senate plan was not apportioned on a population basis. Thus, the most recent "temporary plan" for future Assemblies provides for a 61-member Senate and a 124-member House with no change made in the previous House plan. This temporary Senate plan is discussed in more detail later.

Also the 61st General Assembly (1965) passed a proposed constitutional amendment that would limit the number of members in the Senate and House to a maximum of 50 and 100 respectively. Population equality along with compactness, minority protection, and permissive subdistricting to achieve geographic representation are prescribed for each legislative body. Particularly, the preservation of county lines would no longer be a requirement. In order to address these concerns, the Senate plan was subsequently passed (unaltered) by the 62nd General Assembly (1967) and by the people at a popular election.

Current litigation is centered around subdividing districts with more than one legislator.

**DEVELOPMENT OF ANALYTICAL PROCEDURES**

Equal population, as specified by the Supreme Court, suggests the use of quantitative procedures in districting on an impartial basis. This paper presents two such analytical techniques. The intent in both is to provide an efficient means of generating many impartial districting arrangements that satisfy population requirements and a number of other districting criteria.

The approach taken in both methods was to simulate random districting logic with an abstract model. The model was then programmed for use on the University of Iowa IBM 7044 digital computer, the speed of which permits rapid generation of many alternative arrangements. Additionally, the computer permits rapid calculation and tabulation of population measurements concerning each simulated districting arrangement. Based on these quantitative measurements, the most equitable plans then be selected as the better districting arrangements.

A prerequisite to the application of the approach discussed above is a decision of how to measure population equality nationally. A second prerequisite is how to represent quantitatively other factors such as contiguity and compactness.

**Measurement of population equality**

One quantitative measure used to evaluate population equality is the "population variance ratio." This measure is defined as the ratio of the largest to the smallest population per representative.

A second measure is the minimum percentage of the states' citizens that reside in districts electing a controlling majority (see Silva, 1965). This percentage is obtained by ranking the districts on the basis of their population per representative from smallest to largest. The population of each successively larger district is summed until a majority of legislators is accounted for. At this point the summed population is divided by the state population yielding the minimum percentage figure.

The allowable deviation from "perfect" equality is not fixed. However, the American Political Science Association Committee (1951) has recommended that a district population should be kept within ten percent of the state average, and in no event should it exceed 15 percent.

Bonfield (1964) contends that the Courts use both the variance ratio and percentage controlling majority in their interpretation of population equality. Table 1 summarizes recent Supreme Court decisions studied in the Bonfield paper. The rulings appear to be based on unconstitutional deviation of equal population, since the court rejected all plans except the one for the Colorado House. While the Supreme Court did not render a decision on the Colorado House (since it found the Colorado to be unconstitutional), it did note that the Colorado House "is at least arguably apportioned substantially on a population basis."

The Bonfield paper also discusses Iowa population statistics for temporary and permanent reapportionment plans passed by the 60th General Assembly (1963). Based on population, the temporary and permanent arrangements for the House and Senate population variance ratios of 2.2 and 1.8 respectively with percent controlling majorities of 44.8% and 45.8%. The temporary Senate plan, with a slightly higher ratio of 3.2 and a percent controlling majority of 38.9%, was much more equitable in a population sense than the permanent Senate plan. As a result of it in the interpretation of the Reynolds vs. Sims decision, the 61st General Assembly (1965) passed a new temporary Senate plan with a ratio of 1.7 while the previous House plan with a ratio of 2.2 was unaltered. As will be shown subsequently, plans generated by computer simulation can be found that further reduce these ratios.

In all the above, total population has been assumed to be the appropriate population measure although various other
measures have been proposed including the population of voting age, population excluding aliens, and registered voters.

Contiguity
One of the hazards encountered in analytical districting procedures is the formation of enclaves. This phenomenon occurs when the formation of a district isolates one or several population regions. Normally the limited population of the trapped regions prohibits their being formed into an acceptable district. If the creation of enclaves is not prevented, the final districting arrangement will likely violate the contiguity or equal population criterion or both.

The principle of contiguity is generally considered essential in the development of districting arrangements. Quantitative measurement is unnecessary because there is no concept of "best" contiguity. A district is either contiguous or not.

Compactness measures
Compactness is generally used as the third principle of scientific districting procedures. Together with equality of population and contiguity, compactness limits the number of possible solutions. Various attempts at quantifying compactness have been discussed in the literature.

Harris (1964) applied a trial and error solution technique in arranging Congressional districts in Colorado. For a compactness measure he minimized

\[ \sum_i |L_i - W_i| \]

where

- \( n \) is the number of districts
- \( L_i \) is the maximum length of district \( i \)
- \( W_i \) is the maximum width of district \( i \)

and where the parallel bars indicate absolute values. An optimal arrangement using this measure would require that all districts be circular or square.

A similar formulation mentioned by Harris and also by Celler (1952) would minimize the sum of district lengths divided by the widths. Although the optimal district shape would again be circular or square, this measure does not account for the disproportionate area between districts as does the previous criterion. For example, a district with dimensions one mile by three miles is by this definition identical in compactness with a district 100 miles by 300 miles. Normally the former district is considered more compact.

Hess and Weaver (1965) use a minimum moment of inertia concept together with integer linear programming for solution of Delaware redistricting. This suggests a conceptually different definition of compactness. Whereas the Harris procedure measures geographic compactness, the moment of inertia method is a measure of the dispersion of population about the center of population.

The programs described in this paper measure population equality using both population variance ratio and percent controlling majority. The Harris measure, sum of maximum lengths minus widths, is used as the main measure of compactness although the moment of inertia statistic is also calculated. Each of the two methods developed (hereafter referred to as Methods 1 and 2) requires that the state be divided into population regions for which census data are available. Districting is then accomplished by forming combinations of the regions. While data and constitutional requirements peculiar to the State of Iowa are used as examples, the programs could easily be applied elsewhere.

Method 1 is most suitable for a limited number of population regions such as the 99 counties in Iowa. It is particularly applicable in situations where regions are not uniform in size or when political boundaries such as county lines must be preserved. Extensive use of this method has shown it to be an extremely rapid and flexible tool.

The primary advantage of Method 2 is the greater number of population units that may be included, such that more equal population representation is achieved where major political boundaries need not be preserved. By decreasing the population per unit, the likelihood of improving population equality among districts is increased. The method assumes that the population units are approximately uniform in geometry. In Iowa the nearly 1600 townships are approximately uniform and may be used without serious difficulty although the use of census enumeration tracts in some would still be desirable.

Following the presentation of each of the two methods is an illustrative example. The example following Method 1 uses county data as the smallest population unit while the Method 2 example uses township data. The resulting plans from these examples are then compared with the temporary reapportionment plan passed by the 61st General Assembly in 1965.

METHOD 1

The method presented in this section is an expanded implementation of some basic concepts discussed by Vickrey (1961).

The method presumes that equality of population, contiguity, and compactness are the more important districting criteria. Additional criteria such as singular representation and preservation of existing political boundaries may also be included. It is also assumed that the number of members to be seated, \( k \), is known.

This method is divided into two parts, Phase 1 and Phase 2. Phase 1 provides a single-member district where possible. The optional Phase 2 procedure consists of forming successive two-member districts using two single-member Phase 1 districts to further reduce inequality of representation. This method is divided into two parts, Phase 1 and Phase 2. Phase 1 provides a single-member district where possible. The optional Phase 2 procedure consists of forming successive two-member districts using two single-member Phase 1 districts to further reduce inequality of representation.

Phase 1 algorithm

A description of the Phase 1 districting algorithm follows:

1. Partition the state into regions with their enumerated populations. Define an arbitrary coordinate system and for each region approximate the point location of the geographical center. The regions may have different shapes. The most densely populated regions should contain a lower population than the state average per member. If some above average regions are used, step la must be performed before step 2.

2. In cases where a region contains a population above the state average member and where subdistricting is not permitted, seats must be apportioned according to previously established rules. One such rule, Option 1, would be to assign to each above average region a number of members found by dividing the region population by the state average population per representative and rounding the result to the nearest integer. If the application of this simplified rule adversely affects the population variance ratio, a more complex rule may be applied. A second rule, Option 2, might be as follows:

A. Regions with populations greater than or equal to a preassigned lower limit and less than a preassigned upper limit are assigned a single member.

B. Regions having populations greater than or equal to the upper limit and less than or equal to the lower limit are combined with additional regions to form a two member district following procedures similar to step 4 below.

C. Regions with populations greater than twice the lower limit are apportioned a number of members equal to the population of the region divided by the state average, rounded to the nearest integer.

(In our programs Option 2 has only been utilized with the Phase 2 procedure described below.) Continuing assigning members as above until the remaining regions are below the lower limit.

Choose an arbitrary reference region; call this region \( A_1 \).
3. Determine which of the unassigned regions is farthest from $A_1$; call this $B_1$.
4. Starting with $B_1$, assign to the district contiguous unassigned regions in order of increasing distance from $B_1$. Continue adding regions using the above distance-contiguity criteria until an additional combination would exceed the "population quota." Population quota at each stage is the ratio of unassigned population to unassigned seats. At this point abandon the distance criterion and select the contiguous region that will minimize the absolute deviation from population quota. If the resulting total for the district is below quota, once again select the contiguous region that will minimize the deviation from quota. This constitutes an election district.

5. Repeat steps 3 and 4 by finding which of the present unassigned regions is farthest from $A_2$. Call this $B_2$, and form a new district about $B_2$. In general, new districts are formed about $B_i, i = 1, 2, \ldots$, until all regions and members are assigned. Completion of this step constitutes a districting plan.

6. Calculate the statistics associated with the completed arrangement. These include quantitative measurement of the population equality and compactness criteria.

7. The arrangement of the districts is dependent upon the choice of reference region $A$ in step 2. Although the selection of a few reference regions may result in identical plans, generally the resulting arrangements will differ. Thus, repeat the districting process (steps 1 through 6) by selecting alternate reference regions $A_i$. Continue forming new districting schemes until each region has been used for reference or until sufficiently equitable districting has been achieved. Select as the final arrangements those plans most acceptable on the basis of population equality and compactness measures.

**Phase 2 algorithm**

Normal districting difficulties compounded by constitution restrictions such as preserving county boundaries often produce Phase 1 districting schemes that are not deemed sufficiently equitable on an equal population basis. If the criterion of singular representation can be abandoned, a second stage or Phase 2 procedure may be adopted to reduce the inequalities. If adopted, this procedure is applied at the completion of step six of the above operational procedure.

In Phase 2 successive two-member districts are formed using two single-member Phase 1 districts. One district in each combination is currently involved in the population variance ratio. Thus, with each combination the ratio term is reduced. The Phase 2 procedure is terminated when further reduction in population variance ratio would require three-member combinations or violate the requirement for contiguity.

The Phase 2 routine presumes that the two members in the combination are elected at large. Thus, average population per member can be used as the population represented by each member.

**Discussion—Method 1**

The likelihood of enclosures being formed is reduced by moving from the extremes of the state toward a fixed point. This reasoning is reflected in the selection of $B_i$ farthest from $A_i$.

The procedure presumes that some difference in the population of the final districts is to be tolerated. The possibility that the excesses or deficiencies might accumulate, leaving excessively large or small residual population in the last district, gives rise to the "quota" term. By recalculating quota after each district is established, in terms of the remaining number of districts and the remaining population, residual population is controlled. In effect, this "floating average" tends to correct variations as they occur.

The formation of districts about $B_i$ in order of increasing distance tends to form "compact" districts. Although distance is partially abandoned in favor of population equality and contiguity in selecting the last regions in each district, the resulting loss in compactness is relatively small.

Concerning step 7 our computational experience has shown that the formation of a Phase 1 plan for each point $A$ can be accomplished in well under a minute on the IBM 7044 depending upon the degree of subdivision of basic population data and the number of members to be seated. Thus in our runs we were always able to use each of the 99 counties in Iowa as a starting $A$ value. The Phase 2 procedure, when used, requires a longer time since data reorganization is needed after Phase 1 to insure contiguity among the newly formed districts. Our more limited experience with these times indicates a requirement of about 20 to 30 additional seconds per plan, utilizing Iowa's 99-county data in allocating 61 seats.

**Sample problem—Method 1**

The illustrative example involves the solution of a 61-member Senate plan for the state of Iowa. Although our experience indicated that numbers other than 61 yielded more favorable plans, this number was chosen to conform with the number in the temporary plan passed by the recent 61st General Assembly. In addition to the principles of population equality, contiguity, and compactness, other Iowa districting requirements in effect at that time were:

1. District boundaries must follow present county boundaries.
2. A number of members may represent a single county.
3. Those districts composed of more than one county may include no more than two members.

Iowa population data were gathered using 1960 census material. The geographical center of each county was approximated for use in the unnecessary distance calculations.

Two alternative solutions are presented. The first plan involves only the Phase 1 procedure while the second involves both the Phase 1 and Phase 2 portions of the algorithm. These have been separated to illustrate a plan in which singular representation has been preserved as opposed to a plan involving two-member combinations. Both plans adhere to the requirements listed above. The Phase 1 plan utilizes only Option 1 of step 1a of the algorithm.

We next discuss the statistics of the better Phase 1 plans. Each of the 99 Iowa counties was used as an initial reference region in the simulation of this districting procedure. The criteria measurements associated with the better simulated arrangements are shown in Table 2. These 6 of the 99 simulated plans 11 were the best. The 99 simulated plans were the worst. Each pair of values is associated with the best plan with each pair of values being related to one of the 99 counties.

<table>
<thead>
<tr>
<th>Reference Region Code (A)</th>
<th>1</th>
<th>5</th>
<th>15</th>
<th>73</th>
<th>78</th>
<th>88</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest population per member</td>
<td>55000</td>
<td>55000</td>
<td>55000</td>
<td>55000</td>
<td>55000</td>
<td>55000</td>
</tr>
<tr>
<td>Smallest population per member</td>
<td>30282</td>
<td>30282</td>
<td>30282</td>
<td>30282</td>
<td>30282</td>
<td>30282</td>
</tr>
<tr>
<td>Population variance ratio</td>
<td>1.56</td>
<td>1.56</td>
<td>1.56</td>
<td>1.56</td>
<td>1.56</td>
<td>1.56</td>
</tr>
<tr>
<td>Percent controlling majority vote</td>
<td>46.52</td>
<td>46.52</td>
<td>46.52</td>
<td>46.52</td>
<td>46.52</td>
<td>46.52</td>
</tr>
<tr>
<td>Sum of lengths minus widths</td>
<td>50.79</td>
<td>48.22</td>
<td>52.35</td>
<td>48.08</td>
<td>39.46</td>
<td>50.67</td>
</tr>
<tr>
<td>Moment of inertia measure (X10⁴)</td>
<td>2.24</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
<td>2.15</td>
</tr>
</tbody>
</table>

By stepping through the data, I have determined that the Iowa county plan was the best. The 61st General Assembly plan was the worst. This plan was used to illustrate a plan in which singular representation has been preserved as opposed to a plan involving two-member combinations.

Other solutions used both the Phase 1 and Phase 2 portions of the algorithm. Again all 99 starting points were used in the solution process.
1. Place a grid over a map of the state so that the entire state is contained within the grid. Each cell of the grid should be as geometrically uniform as possible. The cells should be of such size that no cell population exceeds the average population per district.
2. Estimate the population in each cell as accurately as possible. (Harris, 1964, discusses several approaches for estimating population densities.)
3. Using the grid cells and their associated population densities, form a population matrix by assigning subscripts to each element.
4. Choose an arbitrary element of the matrix for reference; call this element $A_1$.
5. Determine which of the unassigned elements is farthest from $A_1$; call this element $B_1$.
6. With $B_1$ as a starting point, group elements about $B_1$ into column and row vectors such that combining each successive vector would result in a contiguous rectangular district. Let the first vector consist of the single element immediately above $B_1$. Continue in a counterclockwise manner until the summed population of the unassigned elements exceeds the district population quota. Population quota is defined as the ratio of unassigned population to unassigned members.
7. To form the district first assign $B_1$; next consider the elements within each successive vector. Add to the district the unassigned elements within each vector.
8. Calculate the statistics associated with the completed arrangement. These include quantitative measurements of population equality and compactness criteria. The method again assumes that the number of members to be seated, $k$, has been specified.

**Method 2**

The resulting equality of population of the analytical methods discussed in this paper is naturally somewhat dependent on the population within the individual population regions. Deviations among the populations of the districts may be further limited by defining units with small populations, say less than five percent of the average desired. Such practice, however, increases the total number of population units required. While the operational procedure does not limit the number of units, computer storage requirements provide a practical limitation.

The method presented below was developed to permit computer solution of problems involving a larger number of population units. The criteria for this method are population equality, compactness, contiguity, and singular representation. In particular it should be noted that the use of fine population subdivisions permits the crossing of larger governmental boundaries (such as Iowa county lines) in establishing district lines. The method prescribes that the individual population units have been defined by partitioning the state into a square grid arrangement. Minor deviation from this assumption may be justified. Discussion of this point follows the presentation of the algorithm. The method again assumes that the number of members to be seated, $k$, has been specified.

**Method 2 Algorithm**

A generalized description of this algorithm follows:

1. Place a grid over a map of the state so that the entire state is contained within the grid. Each cell of the grid should be as geometrically uniform as possible. The cells should be of such size that no cell population exceeds the average population per district.
2. Estimate the population in each cell as accurately as possible. (Harris, 1964, discusses several approaches for estimating population densities.)
3. Using the grid cells and their associated population densities, form a population matrix by assigning subscripts to each element.
4. Choose an arbitrary element of the matrix for reference; call this element $A_1$.
5. Determine which of the unassigned elements is farthest from $A_1$; call this element $B_1$.
6. With $B_1$ as a starting point, group elements about $B_1$ into column and row vectors such that combining each successive vector would result in a contiguous rectangular district. Let the first vector consist of the single element immediately above $B_1$. Continue in a counterclockwise manner until the summed population of the unassigned elements exceeds the district population quota. Population quota is defined as the ratio of unassigned population to unassigned members.
7. To form the district first assign $B_1$; next consider the elements within each successive vector. Add to the district the unassigned elements within each vector.
8. Calculate the statistics associated with the completed arrangement. These include quantitative measurements of population equality and compactness criteria. The method again assumes that the number of members to be seated, $k$, has been specified.

**Discussion – Method 2**

The grid arrangement of population units, subscripted to form a matrix, permits several simplifying assumptions for computer programming purposes. First, the distances between elements can be calculated using the subscripts for position coordinates. In a strict sense, square cells are assumed. However, the distances are relative to other cells such that similar, although somewhat nonuniform, grids may be used without loss of generality. Second, contiguity data are defined by the matrix subscripts. The computer program assumes that cells with adjacent subscript notations are contiguous. For example, element (3,3) is defined contiguous with elements (2,3), (3,2), (4,3), and (3,4). Finally, it is assumed that the subscripts may be used for identification.

Deviation from a perfectly square grid is permissible to the extent that subscripts provide accurate relative distances and contiguity. Violations of these assumptions...
may cause the formation of noncontiguous districts.

In general, the discussion following Method 1 is also appropriate for this method. However, the Phase 2 procedure is not used with this method since the size of the matrix elements may generally be reduced until sufficient population equality is achieved. This method assures singular representation in all districts.

Computationally we observed an average execution time of about 30 seconds per plan using Iowa township data.

Sample problem: Method 2

Iowa townships conform sufficiently to the above assumptions to permit their being used as matrix elements.

The example problem using this algorithm also involves 61 members such that results may be compared with all arrangements presented. The solution presented for this method was based on the population statistics from a total of 150 simulated plans using randomly selected reference elements from the nearly 1600 possible townships.

The statistics from the program indicated that the plan associated with the subscribed township (4, 7) was the “best,” based on population. This plan exhibited a population variance ratio of 1.30 and a percent controlling majority of 49.6%.

More than 70% of the simulated plans had a variance ratio of less than 2.0. Using data elements containing relatively small populations increases the likelihood that a single random starting point would result in

CONCLUSIONS

Our experience utilizing the described programs has shown that computer simulation can be used effectively in creating districting solutions based on population equality. Moreover the computational speed of the digital computer permits rapid calculation and determination of the superior arrangements. It has also been shown that additional criteria can be programmed into the model to accommodate local districting requirements.

Table 4 illustrates the “temporary” Senate plan actually passed by the 61st General Assembly. A comparison of this arrangement is now made with the computer plans generated as a part of this paper.

The 1.56 and 1.40 variance ratios of the Method 1 computer plans are clearly superior to the 1.71 ratio exhibited by the legislators’ plan, Senate File 508. Likewise the percent controlling a majority vote in each of the computer plans is higher than that of the temporary Senate plan. Thus, on the basis of population equality the computer plans are more equitable.

Although the example township plan of Method 2 is not directly comparable, its potential in achieving further population equality is apparent.

It should be noted that the Phase 1 form of Method 1 of this paper was used in submitting districting plans to members of the 61st General Assembly.

REFERENCES


COMPUTER SIMULATION OF CHANGE IN PERSONAL BELIEF SYSTEMS

by Kenneth Mark Colby

Department of Computer Science, Stanford University

This paper deals with the following questions and answers: Are models the same as theories? No. Can a computer program serve as a model of human belief systems? Yes. How do humans change their minds? We know little about it. How can models of belief systems be corroborated? By engaging the person whose belief system is being modeled in repeated on-line dialogues, dehumanizing to use a machine such as a computer as an agent for mental change? No.

PSYCHOTHERAPIES, whether individual or group, consist of a communicative exchange of semantic information between persons in an attempt to alleviate those personal and interpersonal misunderstandings which are involved in mental suffering. I shall discuss some work in computer science which is intended to contribute to the psychotherapies by increasing our understanding of change in certain thought processes.

MODELS

By now it seems overworked even to say that the term "model" is overworked. But models are here to stay so we might as well get used to repeated explanations of them. Models themselves are not so much the trouble as the nature and consequences of metaphor.

We know we link two systems in a metaphor we are inclined to say "A is a B." We mean in an implied comparison that A, the primary system, is like B, a secondary system, in at least some respects. To say human minds are like computers is only to claim that they are to be taken as alike in those ways which we wish to emphasize. We hope to increase our understanding of minds, something we do not know much about, by comparing them with computers, something which, if we do not know much about, we can readily know much more about because of their properties of tangibility, traceability, and manipulability.

This metaphor connecting mental processes with computer processes should be understood as involving not static entities, but comparable forms of information processing. An inert or idling computer is just hardware. But a computer run, combining hardware and program into a single active system, represents the correct analogy to human thinking

A computer run harmonizes power, energy, and information. It stands as an analog model with its symbolic representations being processed in a physical medium (computer) known to be different from the physical medium (brain) in which thought takes place. The distinction between this type of model and scale models, mathematical models, and theoretical models has been well outlined by Black (1962).

Some theorists feel that models and theories are the same. If so, one should just say "theory" instead of "model." The useful distinctions are as follows

A theory, as opposed to a model, is a theory which has been subject to scrutiny and testing by the scientist. It is a theory which has been "in the field." Theorists believe that a theory is a metaphor for some aspect of some system.

The model is analogous to a program. It is a program of thought. A model of a system is a program which represents a system.

In attempting to account for the introspective reports of persons, programs are complex enough to satisfy our notions regarding the complexity of thought and they generate symbols at the proper level of concrete detail to match the output of persons. At the end of a run not only can the output stream be examined, but one can retrieve in full the step-by-step operations which generated this sequence. Programs are speculative instruments, strategy simplifications or "under-complexifications," whose remote consequences can be tested by running them through.

Models must be built for real situations too complex to manage directly or for technological situations which cannot be experimented with during their operation. One should not experiment with a bridge while building it or with a human heart while operating on it. The psychotherapies represent applied technologies which are difficult to experiment with because of the large numbers of uncontrolled and non-independent variables. However, models of the processes believed to be involved can be constructed and tinkered with in order to develop the if-then generalizations and law-like statements typically yielded by controlled experimentation. Initial states can be repeated or varied and alternative inputs can be tried to estimate the relative contributions of internal state variables and external input to final output.

THE PERSONAL CALCULI OF BELIEF SYSTEMS

Several programs have been written which simulate belief systems (Abelson and Carroll, 1965; Colby and Gilbert, 1964; and Colby, 1965). In this essay I shall summarize some work from our laboratory and describe the directions of our current efforts.

Details of the actual programs can be found in Colby and Gilbert (1964), and Colby and Enca (1967).

We define a belief as a basic molecular unit of symbol processing. It is a proposition accepted as credible by the system. A belief is represented in the program by a string of words in an internal English-like language, for example, "I like AI." The string is a semantic kernel which can be extracted from a natural language source. A semantic kernel in the internal language is that which remains invariant under combination in natural language.

The atom of a belief molecule consists of concepts about interpersonal relations organized as directed graphs; that is, nodes connected by pointers which indicate interrelations between concepts. Concepts are linked to form beliefs which state propositions, judgments, or attitudes about persons, including the self, and relations between persons.

In addition to this semantic component, a belief has three assigned weights: a credence, a fixed charge, and a current charge. Credence represents personal subjective probability or credibility, a degree to which a belief is held as true. Charge represents the degree of import or interest a belief has in the system. The fixed charge is a more stable weight changing very slowly over time, while

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current change fluctuates more readily according to the immediate fates of a belief. The stability of a belief in the program is the product of its credence and its current change.

A belief may or may not be supported by other beliefs. Favorable beliefs gain their position of becoming reasons by being warranted by a more general belief termed an implication. For example, a reason for "I criticize father" is "because father is responsible," which is warranted by the implication serving as a substitution rule. "A parent rejects a child implies a child criticizes a parent." These implications also have credences and changes and they are supported by beliefs which instance them.

The program is written in BALGOL and runs on an IBM 7090 connected via a direct-data device to a Digital Equipment Corporation PDP-1. Both the 7090 and PDP-1 connect to an IBM 1301 disk file which permits use of extremely large data base during on-line experimentation using teletypes and display scopes of the Stanford THOR time-sharing system. The program first forms a pool of the relevant beliefs around a nucleus which is the highest charged belief in the system at that moment. Then, successively, the highest charged belief in the pool both comes into view of the user's mind and it is matched against the others in the pool in a search for conflict. Two beliefs are considered to be in conflict when they involve the same or similar agents and objects and when the agents' verbs are antagonistic. Related, such as "I hate mother" and "a child ought to love a mother." If no conflict occurs the regnant is expressed as an output belief along with the values of monitors which keep track of how well the system is functioning at the moment. A belief relevant to the output belief is then selected to take its place in the pool. If high-level conflicts occur, various transformations of the semantic component of the regnant are attempted until one is found which creates a belief not in conflict with other beliefs in the pool, and which hence can be expressed. The transformations change the agents, actions, objects, or combinations of these by computing suitable substitutes from the directed graph of a conceptual dictionary. The resultant belief construction is a distortion of the original regnant. It is such distortions which represent pathological beliefs in a belief system. The categories healthy or pathological are not properties of an individual belief but of a belief relative to a belief system.

Given such a personal calculus with its conflicts and self-adjustment processes the question arises how it can change itself or be helped to change by external corrective input from another source of information to a healthier, more optimal state of consciousness. Ideally, such a change would involve a reduction of a severe and wrenching conflict between beliefs which in turn would lead to a reduction of those misbeliefs and misconceptions generated by transforming attempting to cope with conflict. In persons the theoretical problem is how do we change our minds?

TO CHANGE A MIND

BridgeMAN said, "There is some fundamental incoherence in the way all of our minds work. We really do not understand how to handle our minds properly; in particular, we do not understand descriptively how minds change, or even normatively how minds should be changed. There is plenty of evidence that our minds, as indicated by our beliefs, change during a lifetime. A belief which once had great importance, "Santa Claus is coming," no longer does. A belief once held with a personal probability close to unity, "frogs cause warts," now brings only a smile. Also it is evident that other persons' minds change. Key experiences with other persons, individual beliefs and even entire belief structures. In this sense we can write on one another's programs during that single irreversible pass through the world called life. We remake and revise our own programs continuously, mainly in quite small steps except for key experiences and mostly within that character, which is within certain boundaries. Patients in psychotherapy report that they have changed the meaning of their beliefs, their ways of looking at old facts about themselves and others. While psychotherapists have some fair, but incomplete theories about origins of mental suffering, they have only the crudest notions about mental change. As a practitioner, a psychotherapist is a decision maker using heuristic rules of thumb which tell him what to say and what not to say in certain contexts. He needs a variable set of rules by which he can influence and change his patient in facilitating or accelerating mental change which occurs "naturally" in human minds. From clinical experience he knows that the rate at which corrective inputs can be generated and communicated by a therapist and the rate at which they can be accepted by a defensive, ontogenetically battered system, must be measured in calendar rather than clock units, given our present state of knowledge. A belief system combines external input with stored information in accordance with current values of state variables and parameters of a personal calculus. Input information from another person must first attain some interest and second, it must be evaluated as credible to some degree before it can be accepted into the system as one of its elements. Belief systems in adults are notoriously defensive. Paradoxically, they are also gullible. By a source of information, almost anything it reports is accepted as having credibility unless there is counterevidence against it. Among persons, saying it does tend to make it so, at least in other belief systems, when counterevidence cannot be marshalled and when the source is believed to be trustworthy.

Through self-observation one can observe moments called reflective when we engage in an internal dialogue designed to change a belief or belief structure. We bring into play a personal log in attempting to dislodge or transform a belief. A belief can be changed by changing its content, its degree of credibility, or its degree of import. We are currently trying to simulate these processes by an on-line dialogue with the program which first attempts to lessen the credence of a belief by weighing evidence for and against it. This is achieved by consulting all the relevant beliefs in the system to produce evidence for the contrast of a belief. If no evidence is found for the contrast than the original, the original belief's credence is lessened. This in turn may affect the credence of a belief for which it can serve as a supporting reason. If the main belief serves as a reason in some other belief's reason structure, and so on, the result is a series of small but far reaching chain reactions in the degree to which some beliefs are now accepted as true. Preliminary results indicate that input designed to weaken the reasons for a belief is more effective in changing the program than trying to weigh evidence for and against the belief directly.

In this program, since severe conflict leads to belief distortions and conflict is a function of both credence and current charge, we are also trying to posit mechanisms for reducing the charge on beliefs. It is not clear to us yet how these parameters interact or should interact, but over time these methods should probably change more rapidly than charges.

CORROBORATION

Added to the number of difficulties in writing and running these programs is the problem of validating or corroborating the model. As yet we have no objective testing models of belief systems for their correspondence with empirical observations on persons being simulated. Since the program simulates an individual belief system, one would like some means of comparing it with output from the individual person involved.

We are developing an on-line method for testing the model by observing the research cooperation of a person whose belief system is being simulated (Colby and Ems, 1967). This program tries to build up a cognitive model of a person in much the same way a psychiatrist constructs and refines his thought model of a patient. A person sits at a teletype and participates in a continuous written dialogue in natural language regarding his close interpersonal relationships. Each of the natural language input sentences undergoes a pattern recognition analysis in an attempt to find semantic kernels which then become representations of this person's beliefs inside the machine. As information comes in, additions are made to a graph representing belief systems. When some beliefs have been accumulated the program then asks the person...
whether or not it is correctly representing certain of his beliefs. He is free to confirm, reject or express ambivalence. As in psychotherapeutic practice negotiation is much more ambiguous than absent, and the program must decide whether to revise its representations of the person’s beliefs or whether the semantic area is so conflictive as to give rise to denial.

Having the cooperation of a person in real time and maintaining a continuous and repeated on-line dialogue, we are trying to build up and progressively improve a model of that person’s belief system. This type of man-machine communication gives us a much more ambiguous interaction at close range with the system it is representing and gives it a chance to be improved through new information obtained by immediate feedbacks from a person. But this type of man-machine cooperation and communication will, in the rapidly approaching third generation of computers, accentuate the growing issues of man-machine relations. The situation becomes particularly acute once a computer can be led to a good understanding of a person’s belief system. Then it can be programmed to take the next step of attempting to change the mind of a person with whom it is communicating. Can a computer be a more powerful influence of a person than another person? Can a computer function as a change agent in psychotherapy? (See Colby, Watt, and Gilbert, 1969.)

**THE MODIFICATION OF MAN**

Much of what I shall now say is more philosophic than psychiatric or scientific, but this is a good time to look at our presuppositions and suppositions about changing people’s minds. We assume that as part of cultural evolution man wants to change himself in some sense of improving his efforts towards a goal. We also suppose as part of this assumption of personality that he wishes to liberate himself from beliefs that he wishes to be too heavily weighted or inappropriate to contexts of a changing social and physical environment.

The stored past of a belief system may over-influence it in attempting to deal with new information from new situations. Clinical examples of this provide a large portion of a psychiatrist’s work. Cultural values of increasing freedom and increasing individual autonomy direct us to find ways of changing our minds about certain personal beliefs, especially the misbeliefs and misinformations acquired from repeated childhood experience with parents and other key persons who have lived in a world quite different from our current one.

Physical reality is now easier for many, but painful aspects of social reality remain worthy of being denied and distorted by transformations of their symbolic representations. Granted that some illusions are necessary for everyone, a large number of social misunderstandings could be reduced if people’s minds could be changed about their misperceptions and misbeliefs. But change can be seen as threat as well as opportunity because major social challenges fundamental beliefs about the nature of man. If a man-computer metaphor is taken seriously enough that people work at it, one of the threats is how man is to be looked at in his relations with machines. Metaphor now becomes not only the hub of it but the root of it.

Opponents of the metaphor claim that if men are viewed as being like machines then men will be treated, like machines, as something less than human. The comparison is seen as involving dehumanization. It has obviously been useful to view some behavior or persons as machine-like, for example, comparing the heart to a pump. The better question is what kind of human activities can be compared to what kind of machine. Classical mechanists compared men to clockworks or engines, real or idealized. Now that a lever as a model of physical description has given way to the electromechanical field, a computer would seem a more appropriate secondary system for the modern mechanist to involve in a man-machine metaphor.

But it is routinely supposed that we are very clear about what a machine is, perhaps because we can see it, point to it, and touch it. We act as if we were confident about the nature of machines and their implications and now all we must do is to clarify our concepts about the nature of man. Yet if we take a computer as a primary system, it is very unclear what is a suitable secondary system with which it can be compared. As new machines are invented and the meaning of the term ‘machine’ changes radically.

To Descartes a machine was a system of ropes and pulleys. To my grandfather a machine was what we went for a ride in on Sunday afternoon. To me a jet airplane is a machine. A computer is a kind of machine, which does not look like these and does not do the same kind of work. For a programmer a computer is simply a device for processing symbols which in turn stand for his concepts about some subset of the world. His most direct concerns are not with hardware, but with programming languages and how best to represent his ideas in them. Ultimately, when the program runs these ideas will be represented in the medium of hardware, and naturally someone must worry about keeping the hardware fit. For the programmer’s practical purposes, a computer as a primary enough to have an extended language as a secondary system. This metaphor then asserts that a computer is a language in that it provides a system of symbols and operating rules which we may relate to our concepts. If man, as part of cultural evolution, decides he should change his mind—and he seems to have done so—then the question is whether he can do so aided by a machine such as a computer. Can the study of man-computer communication improve our knowledge of man-machine communication and its misunderstandings?

By itself a computer does nothing. It is a conceptual and technical aid to a person’s thinking and knowing. If it can be used to further our understanding and treatment of mental suffering there can be no question of its value. If it can be used as a psychotherapeutic instrument for thousands of patients in understaffed hospitals, we have no choice but to use it because the healing professions are unable to supply sufficient manpower to meet this great social need. If a computer can teach children better than teachers can because each child is thereby enabled to learn at his own rate, then its use is quite consonant with our values of respecting individual dignity and promoting the growth of autonomy. To me it is dehumanizing to put a child in a class with 40 other children and one teacher. It is dehumanizing to herd thousands of patients into mental hospitals where they will never see a doctor. If a computer can teach and if a computer can provide therapeutic conversation, then there can be no hesitation in exploring these potentials. It may give us a chance to rehumanize people now being dehumanized by our educational and psychiatric systems.

**REFERENCES**


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RECENT DEVELOPMENTS IN THE PSYCHIATRIC CASE HISTORY EVENT SYSTEM

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Originally presented in 1964, the Psychiatric Case History Event System has been implemented on a large scale in a study of the decision-making process in psychiatric diagnosis. The Event System is a generalized information-processing system for conversion of case history data into acceptable form for subsequent retrieval and analysis. The details of the processing of data from point of transcription to computer output are now presented. In so doing, the logic of the system, and its generalizability for application in a variety of clinical and research endeavors, are made evident.

The Psychiatric Case History Event System (PsyCHES) is a generalized information-processing system for storing and analyzing the complete body of information contained in the clinical case record. It was first presented at the American Psychiatric Meetings in 1964 (Edsion, Brooks, and Motto, 1966). In the intervening years the Event System has undergone considerable development, as it has been implemented on a large scale in an investigation of the decision-making process in psychiatric diagnosis. In this project the factors affecting decision-making processes are studied through the analysis of the structure and content of psychiatric case history records. Such an analysis involves many interrelated variables within a large body of complex data, and requires the use of information processing, statistical, and other analytical techniques which can be practically implemented only through computer processing of the data. A requisite of the project, therefore, was a system for the conversion of case history source documents into computer-acceptable form.

In this paper we shall present the present stage of development of the Event System. The model to be demonstrated is the Event Model which provides the structure or format for converting the entire body of data into a form acceptable for computer processing. Then we shall discuss the actual processing of data, from the point of transcription to computer output. Finally, we will mention clinical implementations and refer to some research applications to date.

TRANSCRIPTION OF CLINICAL DATA

The Event Model

Definition of an event: The structure of an event can be illustrated by establishing the general model for an element of data which we shall call an event. The definition of an event is predicated on the Event Concept. This concept, in turn, is predicated upon the occurrence of a patient or to a single data element.

Events are actual happenings, such as illnesses, appointments at the clinic, the behavior of a doctor, failure in another subjective or judgmental phenomenon which have a physical or outside validity and may be considered as objective, factual data. Events also include psychological phenomena such as fears, fantasies, reactions of a student to a patient or to a whole event. These are all events which cannot be observed but must be inferred; these have poor outside validity. Included in the second group are attitudes, opinions, impressions, evaluations, and other subjective judgments which psychiatrists find as relevant in describing the behavior of the patient as the more objective information. Anxiety, hostility, relationships, and authority, are examples of this kind of event.

Studies have shown that the Event Concept can encompass all of the basic content or kinds of information found in the body of the record. Thus the event becomes the basic unit for systematically organizing the total body of information in the record.

The Event Statement: The Event Statement contains certain basic elements of data which are common to all events: the event name, which indicates the general type or category of the event, and the location, date, subject, object, and reporter associated with the event. These data elements are derived from the source material by the rules and conventions of this system and with the aid of lexicions, and form a set of fixed fields which constitute the codified portion of the event. The event generally contains further specific or supplementary data which are unique to it; this information is organized as a series of modifiers to the event, each consisting of a modifier name, which indicates the general type of category of the supplementary information, and a modifier entry, which contains the supplementary information itself. This set of modifiers forms a set of variable fields which constitute the uncodified portion of the event. Thus the Event Concept provides a morphological model for the structuring of narrative as well as nonnarrative data into a set of computer-acceptable information units.

A special type of event is generated by the occurrence of any individual report contained within the case history. This report event is analyzed in the computer processing of the data, and pertinent information concerning the origin of the report (report type, author, location, and date) is appended to each event derived from that particular report. In this way, data concerning the origin of the event become an integral part of the event itself.

The model for the Event Statement contains the following fields:

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report Date</td>
<td>Event Name: Report*</td>
</tr>
<tr>
<td>Date*</td>
<td>Event Date Type*</td>
</tr>
<tr>
<td>Location*</td>
<td>Reporter*</td>
</tr>
<tr>
<td>Modifier: Context*</td>
<td>Modifier: Circumstance</td>
</tr>
<tr>
<td>Modifier: Name</td>
<td>Modifier: Location</td>
</tr>
<tr>
<td>Event Data</td>
<td>Event Name*</td>
</tr>
<tr>
<td>Date (Beginning)*</td>
<td>Date (Ending)*</td>
</tr>
<tr>
<td>Date Type*</td>
<td>Reporter Subject*</td>
</tr>
<tr>
<td>Location*</td>
<td>Object</td>
</tr>
<tr>
<td>Modifier*</td>
<td>Modifier: Attitude</td>
</tr>
<tr>
<td>Modifier: Change</td>
<td>Modifier: Circumstance</td>
</tr>
<tr>
<td>Modifier: Concurrent</td>
<td>Modifier: Content</td>
</tr>
<tr>
<td>Modifier: Degree</td>
<td>Modifier: Duration</td>
</tr>
<tr>
<td>Modifier: Example</td>
<td>Modifier: Frequency</td>
</tr>
<tr>
<td>Modifier: Location</td>
<td>Modifier: Test finding</td>
</tr>
</tbody>
</table>

In each field only a number, words, or symbols which are in a class specified by that name are expected. It is not essential that all fields specified for an event be used at all times.

Transcribing sentences into events

The procedure for the conversion of source material into a series of events is specified and illustrated in the Transcription...
The abstraction procedure involves the following steps, each of which is fully described in Edelson and project staff (1960):
1. The statements of the case records are organized into sets of discrete events.
2. The category, and thus the event name, is determined for each event.
3. The dates, time, reporter, subject, and object associated with the event are determined.
4. The supplementary data of the event are organized as a set of discrete modifier entries arranged in logical order, retaining as far as possible the words and phrases of the source material. Dependence or relationship of the event to other events is noted as a particular type of modifier entry.
5. The category, and thus the modifier name, is determined for each modifier entry.

When this logical process has been completed, all data elements of the event have been determined and are ready for recording in standard form.

Commonly, every sentence is transcribed into a single Event Statement. The rationale underlying the general convention is that the English sentence as a linguistic unit contains one independent piece of information, with other modifying or descriptive words or phrases. Frequently, however, English sentences are very complex. They can contain more than one independent clause, as well as dependent clauses or phrases which convey data. Therefore, certain conventions apply in regard to determining the number of events in a sentence. This is accomplished by use of the Modifier: Reference.

When the sentence is a complex, or new event should be introduced whenever any change occurs in the fields of subject, object, reporter, date, or duration of the original event.

Example: "Following Terry's detention at Juvenile Court, the parents consulted their own attorney."

This would be parsed into two events:
The first event has as its subject: Terry (patient)

Event Name: LEISRAL ACTION
Modifier: Nature
Consuliation
Event Name: CONSULTATION
Modifier: Nature
Consulted their own attorney
Event Name: Previous event

When a sentence has two ideas, but one is dependent on the other, both are transcribed under one event. In order to determine which idea has priority as the event, the independent part of the sentence takes preference.

Example: "Being tied to his parents, he accepts the values they place on education."

Event Name: VALUES
Modifier: Nature
Being tied to his parents

In general, the preference in transcribing complex data according to the Event System is to parse the data into as small discrete units as possible without destroying the meaning of the information recorded. Thus, it is possible to transcribe all record data sequentially sentence by sentence. This sequencing, plus the use of the cross-reference modifier, bridges the isolation of discrete units demanded by the Event System.

Event representation

To demonstrate the exact event representation under the present format, examples...
of the transcription of sentences from clinical narrative are presented.

Example 1: Sentence containing data that could be objectively validated: "hard data in its original and transcribed format: Original text: 'The patient's maternal aunt reported that in July 1967, Diane eloped with her boyfriend in a common law marriage in North Dakota.'

Transcription: Report Data
Event Name
Date
Type
Location
Reporter
Modifer: Context
Modifer: Name
Event Data
Event Name
Date (Beginning)
Type
Location
Reporter
Subject
Modifer: Nature
Modifer: Location

Example 2: Sentence containing "soft" data. This is presented to show that this kind of information is transcribed in the same way as more objective data above: Original text: 'The patient's emotional behavior in general seemed constricted and repressed.'

Transcription: Report Data
Event Name
Date (Beginning)
Type
Location
Reporter
Subject
Modifer: Nature
Modifer: Location

Transcription: a sentence presented originally in Edmonson, Brooks, and Motto (1966) is presented at this time for comparison.

Transcription: a report data follows the same format as in Example 1, so it is not presented there.

The Event Lexicon
The Event Lexicon presently in use in the Psychiatric Case History Event System consists of some 200 events. On the basis of empirical analyses of records studied at child psychiatric facilities, these events have emerged as categories for classifying the content of the narrative text, questionnaire, and medical form data found in psychiatric clinical case records. The events were selected primarily on the basis of the frequency with which the kinds of information they convey were found in the case records. As such, this lexicon of events represents the kinds of data most likely to be recorded in the psychiatric record of the child patient and his family.

The lexicon is open-ended. New events are added when their usage by clinicians is sufficient to warrant the construction of new lexicon entries may also be added to the lexicon. The lexicon is open-ended. New events are added when their usage by clinicians is sufficient to warrant the construction of new lexicon entries. The inclusion of new events is not arbitrary, but is based on the needs of the particular clinician.

The Event System includes terminology descriptive of many levels of abstraction and conceptualization. This has resulted from the empirical orientation of the Event System, in which adherence to the working vocabulary of the clinician is emphasized. New events are added to the lexicon when they appear in the clinical material and meet certain criteria. Further, the attention to the working vocabulary of the clinician has shown us that no single frame of reference distinguishes written data. While oper-
Manual of Transcription Procedures

The generality of the Event System has been demonstrated in a number of feasibility studies involving different purposes and using different kinds of data. As a result, several institutions have expressed the desire to utilize the Psychiatric Case History Event System for their own research, clinical, and administrative procedures. Toward this end, a Manual of Transcription Procedures was published (Edelson and staff, 1966). This publication provides the explicit procedures governing transcription to the point of keypunch.

In the manual, separate sections cover each format field used in translating narrative material into the logical scheme of the Event System: event field, date field, location field, subject and object fields, modifier fields, report date fields. Each section is divided into two parts. The first discusses the general rules of usage; the second establishes the limits of entry for the preferred event is a manual process, it is currently being automated.

Samples of transcribed sentences in the manual document the procedural conventions.

CHAIN OF TRANSCRIPTION AND COMPUTER OUTPUT

Transcription by dictation

In the original development of the Event System, data presented in the clinical record were manually transcribed by trained re-
A review of a sequential event number is generated for each event and, together with the case number, serves as an index to this event for future reference. Each report event is analyzed in a particular way, and information extracted from this special type of event is appended to each of the events which follow; in this way, supplementary information concerning the origin of each event can be made an integral part of that event for searching when events are studied out of context.

Simultaneously with this processing, a case history listing is produced which parallels the source documents. This listing is a fully expanded English language version of the case history as interpreted and edited by the computer program from the input data; invalid entries are noted as such by specific error messages in context. This initial version of the case is then returned to the transcriber for verification, correction, and edition. The listing is reviewed for computer generated error messages and is compared against the original for those logical errors which cannot be detected by the computer program such as omissions and the substitution of valid but incorrect field entries, which may occur either in transcription or in keypunch.

Correction data is generated by annotation of the listing or by redaction, as applicable. Only those specific elements of data required to correct the master file must be identified; however, these elements must be preceded by their corresponding event numbers and field codes for analysis by the computer program. The correction data deck is identical to the case number and by the current version number of the case. This version number, which is automatically incremented each time the case is corrected, must be verified as current by the program since correction procedures may involve the addition or deletion of events, and thus the resequencing of the event numbers of the case. The correction data deck is then input to the computer; the data is analyzed by the computer program and the master file according corrected, edited, and verified. A revised case history listing is produced, complete with specific messages indicating all corrections and editions performed. This procedure may be repeated as often as necessary until the case history is verified to be in complete and accurate form.

The case history master file thus generated and maintained on magnetic tape is in a concise and regular format designed for ready access and retrieval, and for linkage with sort, report generation, and statistical analysis programs; at the same time, the format allows listing of any portion of the data in a fully expanded English language version retaining the meaning, intelligibility, and most of the phrasing of the original.

The example of a fully expanded event in the standard PsychCHES System format illustrates the basic and supplementary information typically contained in an event; optionally, the listing of supplementary data such as field names, origin, and case and event numbers can be suppressed for brevity or to avoid redundancy.

The Psychiatric Case History Event System computer programs are written in COBOL, a high level programming language which provides flexibility in the processing of large volumes of nonnumeric data, compatibility between computer systems, and relative ease in programming and program maintenance. The programs were originally written for the IBM 7040-7041 computer system available at the Health Sciences Computing Facility, School of Medicine, University of California, Los Angeles. They have since been converted to the IBM System 360, Model 75, recently installed at that facility.

At the present time, the entire data base of psychiatric case history records is in computer-accessible form with considerable potential power for the retrieval of data on any combination of parameters, and its subsequent processing by sort, report generation, and statistical analysis programs. Actual retrieval procedures and linkages are relatively unsophisticated at this time; however, and generally involves the programming and setup procedures for any particular study.

Current system development is therefore directed toward the design and implementation of retrieval programs of increasing power, generality, and simplicity of application. These retrieval programs are here considered to include special report generation procedures specific to the project material and aims, the generation of raw statistics, and automatic linkage to utility sort and statistical analysis programs.

The retrieval programs are being planned to ensure logical development of a modular system which will steadily increase in power, generality, and flexibility, while the need for special programming decreases. Ultimately, it is hoped that the retrieval system will be fully automatic and may be applied by the researcher without intervention by programming personnel. Specific developments of the retrieval system will depend partially upon the directions in which our basic investigation progresses and the complexity of the questions being asked of the system; however, some of the basic considerations are as follows:

1. Master file data will be searched and retrieved on any combination of parameters which are definable by the system. Raw data statistics will be generated optionally. The data or statistics so retrieved will automatically be reformatted as required for input to sort, report generation, and statistical analysis programs.

2. An important concept in the retrieval system as planned is the capacity for arbitrary classifications to be assigned to related data elements, either as sets or hierarchies. For example, a set of event names will be grouped for retrieval purposes, and classified as "identifying data." These events may then be retrieved and processed either by reference to individual event names or by their status as members of the "identifying data" class. Such classification may be temporary, as in a one-time test of a hypothesis, or it may be made permanent if the classification appears to be of general value. This procedure will be developed as warranted by requirements.

3. Ultimately it is hoped that a retrieval language will be developed that will allow the researcher to employ the retrieval system in a highly flexible manner. This language would allow the researcher to specify in simple terms the nature and conditions of the inquiry, the statistical analysis required, and the types of reports desired. A System User's Manual will be produced which will describe the salient features of the system and will include specific directions for its application as a research tool.
IMPELMEMENTATION OF THE SYSTEM

Clinical
Although the Event System was developed primarily as a research instrument, its implementation has permitted a number of clinical applications.

Application to records collected by other facilities: The feasibility study attempted to assess the ability of the Psychiatric Case History Event System to handle clinical records gathered by five child psychiatric facilities in the Los Angeles area according to their customary procedures and for their own purposes. No difficulty was encountered in incorporating total data from records collected at other facilities into the Event System. Thus, the generalizability of the system for data generated at resources other than the one where it was developed, was demonstrated.

Application to a variety of source documents: In the course of transcribing a body of 50 records collected at our own and other facilities, certain source documents which were not routine in the psychiatric record were exposed to the Event System. These included:

(a) detailed medical and neurological examinational findings
(b) quantitative psychological test scores from such tests as the MMPI and the Rorschach
(c) EEG tracings
(d) clinical chemistry laboratory readings
(e) nurses' and aides' notes, referable to behavior during hospitalization.
(f) process notes of therapists in both individual and group diagnostic and treatment sessions.
(g) administrative and statistical records.

These documents presented event data, which supplemented those found more routinely in such reports as application blanks, notes, telephone calls, school reports, psychiatric examinations, summaries of psychological test findings, conference notes, and interview summaries.

The Event System was found to present an appropriate format for each of these new data forms.

Projected clinical implementation: To date, our interests have not demanded that any attention be given to incorporating a "real-time" capability in the Event System. At present closed record data, or data that have been gathered and typed into the record, have provided the basic source information. However, in the future, studies will be undertaken to evaluate the feasibility of putting information into computer acceptable form, as it is actively gathered. Simultaneously, certain methods of automating the entire input process are being explored.

Once active cases are routinely processed, it is anticipated that a number of clinical applications will become common practice. For example, the clinician would have available to him all or part of the previous contacts with the patient for "instant review." Such review is frequently demanded prior to subsequent patient contact. For this purpose, it may be helpful to have the information already obtained, updated, and listed chronologically. An example of this is provided in Figure 1.

It is conceivable that such a listing would be valuable in exposing omissions or omissions in information obtained to date. Chronological lists can also point to relationships or phase relationships in the temporal occurrence of events in the patient's life, or in his therapeutic behavior which warrant further exploration.

When data are sorted according to the event field first, gaps and discrepancies in the data bank become exposed. If the clinician desires to elicit further data to increase reliability or recall by the patient, he can readily do so.

The capacity to have available "instant review" a number of cases (or parts of cases) showing similar characteristics should provide the clinician with the kind of data that would be directly useful in enhancing his clinical services. Incipient or regular review of his own patient work, and that of his colleagues, regarding patients with similar symptoms and background, should sharpen his own clinical decisions and practices.

Research
In the course of investigations employing the Psychiatric Case History Event System, we became aware that a having a generalized information system essentially embodies a new research strategy. The new strategy rests on three capabilities: 1. having a total data pool available, 2. having the computer's capacity for easy and efficient accessibility to all stored data, and 3. having a common unit, like the Event Concept, for all behavioral, clinical, and environmental data.

The new concept has been applied in a number of studies, of which only brief reference is noted here. Their details, however, reveal the kinds of data collection and data analysis that have stimulated computer based approach permits.

Comparative studies of information content in records collected at different facilities: (Edison, Johnson, and Rotenberg, 1965) To what extent do clinical record data vary as a function of differences in institutional data collection practices? Fifty records, ten of which were gathered in each of five clinics, were transcribed into computer acceptable form using the Psychiatric Case History Event System, so that comparative studies of their structure and content could be undertaken.

Results pointed to significant differences among clinics in the length of records, or total numbers of events contained. However, the differences in the amount of total data gathered at the five clinics, the clinics distributed the information they collected essentially similar proportions among social history categories (medical history, family history, present illness data, and so forth) usually covered in anamnesis taking.

When the total cases in the sample were searched for data uniformly collected among all clinics, only two events were found to be invariant. Lowering the cut-off point to 40 cases introduced 5 more invariant events. When the sample is reduced to an N of 40, that is, 80% of the total, only 18 events were routinely present. Further, comparative
studies of data suggested that at best there is only moderate agreement among clinicians on the specific data that are likely to be relevant for the diagnostic evaluation of the patient: 40% of the total information was found in records of all clinicians; an additional 18% was common to three clinicians, while 17% of data were unique events, that is, found specific to a single facility. Further studies pointed to an incidence of 8-15% of data in the five clinical record samples as redundant. Types of redundancies and areas of information in which they appeared were also explored.

Comparative studies of learning problems in latent age boys: (Edidson, Johnson, and Rottenberg, 1966) Recent studies of children with learning problems identified a number of learning syndromes with specific clinical and psychodynamic features. These syndromes were established by investigators working in various psychiatric facilities. This raised the question of whether the various syndromes were in fact describing real differences in children with learning difficulties or whether the differences might be attributed to artifact, such as differences in the population samples, or to differences in the clinical information on which studies were based.

All information in the records formed the data base and was transcribed in events or variables and related modifiers. This converted the total body of record data into a form in which it could be readily manipulated, sorted, summarized, and subjected to statistical analyses. The capability of this computerized information-processing system is suggested by its role in this study, in which more than 350 variables in each of 50 learning problem records were searched and retrieved and the derived data summarized in a number of ways.

Presentation of the typical learning syndromes in each setting were displayed and compared with the clinical pictures obtained when total data were analyzed as a single sample. Results showed that the degree and ways in which the syndromes shift as a function of the number of variables introduced into the data pool from which the total picture is drawn.

Biochemical and behavioral study of an infant from birth through the first 96 hours of life: (Edidson and Lubitsch, 1967; Edidson and Edidson, 1967) Behavioral and biochemical studies of a newborn infant were undertaken for the first 96 hours of life. In these studies, certain behavioral parameters, such as state of arousal and movement, and certain biochemical parameters, such as amino acid analyses, were monitored on a 24-hour basis over a 5-day period. The data-collection methods involved time-lapse photography, observational charting, continuous urine output.

In order to compare data obtained from the various sources, all data were converted to the event as the common unit of information, and reasured to time. This permitted analysis of the temporal relationships existing among biochemical parameters and among behavioral dimensions independently, as well as relationships between certain behavioral and biochemical phenomena.

Findings from different data sources could also be compared for redundancy with transcription of data into the Event System also permitted study of the data as a function of reporter.

Studies of stress in the primary school situation: (Lambert) In order to facilitate an understanding of stresses on school children and to study the teaching strategies which are effective reducers or isolates from the stresses, observations of classroom incidents and relationships are being collected in the primary grades of a public school system under the direction of Dr. Nadine Lambert (in preparation) of the School of Education at Berkeley.

In the study, the Event System is being utilized as the basic data-collection method. A lexicon of school events pertinent to first grade assessment and to the instructional program, is being constructed. It is anticipated that this lexicon will eventually be adapted to the longitudinal school experiences of children individually and of children in a group. In addition, it is expected that empirical study of teacher-pupil interventions will provide a lexicon of strategies which are employed in the classroom situation.

Studies of clinical decision-making in diagnosis: The purpose of this research is to elucidate certain aspects of the decision-making process in psychiatric diagnosis. We propose to detail the steps or the mechanisms in the process of diagnostic assessment; and to understand the role that specific variables or kinds of information play in determining or leading diagnostic decisions.

The first phase of this study undertook comparative studies of the structural characteristics of records. It also studied the influence of certain initial patient variables such as age, sex, number of siblings, on these structural characteristics.

A further series of studies will investigate three aspects of the decision-making process: (1) the identification of the variables in patient data that are discriminating for diagnosis; (2) the sequential analysis of the decision-making process; and (3) studies of the clinician as a variable in decision making.

It is anticipated that these data will provide answers to the basic question: What constellation of discriminating events or groups of events obtained at specific points in the diagnostic study by specific clinicians have a strong predictive significance for interim diagnostic decisions, such as diagnosis, prognosis, and recommendations.

Every act that carries a definite damage to any other person belongs to the sphere of law, and every act that can be supposed likely to cause such a damage, to that of morality; and individuality has what is left.

If strictly pressed, [this demarcation] excludes individuality from every act of life that has an important social bearing. The demarcation between individuality and society, contrived in defence of the former, has pretty nearly annihilated it.

BERNARD ROSANQUER

Behavioral Science, Volume 12, 1967
MULTIVARIATE STATISTICAL PROGRAMS, Dean J. Clyde, Eliot M. Cramer, Richard J. Sherin, University of Miami. (CPA 242)

A series of programs written in FORTRAN IV for an IBM 7040 is available on a tape by writing the Biometric Laboratory, University of Miami, P. O. Box 9175, Coral Gables, Florida 33124.


OMNITAB has gone somewhat further than most comprehensive statistical programs, by bringing together an entire group of analyses under the control of a single statement. For instance: press COL ++, WEIGHTS IN +++, X IN ++ USE A DEGREE will cause the program to fit a polynomial of degree n, to store deviation of the computed values from the observed, to compute standard deviations of the coefficients, and so forth. Some of the programs make a scatter plot of the input to present visual summaries of the results.

VARGUS 6D: A Simple System for Producing "Noisy" Patterns (for IBM 1620 and IBM 1401), Selby H. Evans, A. A. J. Hoffman, and Malcolm A. Arnoux, Texas Christian University (CPA 244)

Description: Some kinds of research in pattern perception (such as Rappaport, 1967; Crook, 1957, Green, 1963) call for the generation of sets of patterns into which some controlled amount of "noise" has been introduced. The VARGUS 6D system provides a means of introducing random error into a 48 \times 48 black and white array, by transmitting each element of the array with some predetermined fixed probability of changing the element to its opposite state. Both the initial array and the noisy arrays are stored on cards that can be printed in black and white on an IBM 1401 with a second program, SCOPe 4 WRT.


Description: The general problem of multidimensional analysis is concerned with the three basic facets of persons or objects (P), variables (J), and categories or rubrics (C), and the problem of determining that the categories belong to a particular item. Given these sets, the problem for analysis is that of mapping P into Cj (j = 1, 2, ..., k) or, symbolically, P \rightarrow C_j. The characteristic function of Guttman (1950) is the set of three relations:

\[ e_{ij} = \begin{cases} 1 & \text{if } p = e \text{ or } f, \\ 0 & \text{otherwise}. \end{cases} \]

The binary matrix defined by the above function is called the attribute matrix E of (order n, X N, where n, is the total number of categories over all items and N = the number of persons), and constitutes the basic data matrix for both qualitative and quantitative data. This rectangular matrix can be visualized as a partial adjacency matrix of a graph, whose row captions represent categories as one set of entities and whose column captions represent persons as another set of entities. Consider any two categories of C, say b and c (b \neq c; c \neq C_m; m), and any member of the set P, say p. A partial order can be defined consisting of all those pairs for which \( e_{ij} = 1 \), as constituting one subset, and all those pairs for which \( e_{ij} = 0 \), as the other subset. Thus, the two partitions of the pth column of E consist of all those categories into which p falls, on the one hand, and all those categories into which p does not fall, on the other. If \( e_{ij} = 1 \), we can say that p is C; otherwise, p is not C, and this relation is symmetric, that is, \( e_{ij} = e_{ji} \) is automatically true. By using the foregoing notions it is possible to define a concept of distance and dimensionality for the special case of a partial graph (see Guttmann, 1964, for the treatment of these concepts in relation to square, symmetric matrices).

The specification of the multidimensional analysis of E can be written down following the lines in terms of smallest space theory (Guttman, in press a, Lingoes, 1957, in press b). For all pairs of relations between members of the category set and members of the person set, satisfy the following inequality: wherever \( \phi = 0 \), \( \phi \neq 1 \), \( \phi < e_{ij} \), \( \mu \leq d_{ab} \), then the Euclidean distance \( d_{ab} \leq d_{ab} \) is the smallest possible space, \( m \), for which the coefficients of multidimensional equation are a minimum. We are defining binary relations in terms of a function such that all points in one set (categories) which are related to points in the other set (persons) will have smaller distances in the joint space of persons and categories than all points (one set only) which are not related. Formulation nothing in this statement of the specification is implied about order within categories, within items, or within persons. Nor are any assumptions required regarding the marginal distribution of E. Nor are we imposing any constraints upon linearity of relationships among categories, items, or persons. The nature of the solution, however, will vary to degrees allow us to make inferences about both order and linear inferences of the three facets, whether the data be wholly quantitative, wholly qualitative, or a mixture of both quantitatively and qualitatively. All of this is a function of constraining interest relationships to satisfy the nonmetrical inequality.

A MSA-II solution will yield a set of distances which are partitionable into two classes corresponding to the two partitions of E, such that all distances smaller than the largest distance for which \( e_{ij} = 1 \), constitutes one class and the remaining distances the other class. The partitioning of D, the distance matrix, into these two classes based upon \( e_{ij} \), is referred to as the radius of inclusion, that is, the largest distance for which \( e_{ij} = 1 \), permits us to determine the value for the coefficient of reproducibility along lines similar to that of a standard scallor analysis (Guttman, 1964). All points lying within the radius of inclusion (most generally defining a hypersphere) for which \( e_{ij} = 1 \) will be judged as being non-functional purpose, however, in the MSA-II program, but does provide an interesting descriptive measure of how well E can be reproduced.

In summary, MSA-II analyzes the irreducible data matrix E, and measures of association based on E are employed both directly or upon a definitional system of a binary relation between many pairs of sets (categories and persons), within the smallest space theory, which is totally free of the usual assumptions of multidimensional analysis, nevertheless, as a product of the nonmetric restrictions imposed by satisfying a set of inequalities, a metric solution becomes possible in a new quadrant of minimum dimensionality. It would thus appear that MSA-II is excellently suited for the multidimensional analysis of a wide variety of data heretofore either unanalyzable, or subject to the nonmetric restrictions imposed upon unwarranted assumptions. The user of this procedure should become familiar with the structure of the smallest space theory (which, in addition to the following references, should include: Sheppard, 1962a, b; Kruskal, 1964a, b; and the paper describing this procedure in more detail, Lingoes, in press b).

MSA-II differs from MSA-I in that the point of solution may be said to be the remaining points, and the two classes are determined differently.
multidimensional scaling analysis (Lingoes, 1966a; in press b), in terms of rationale, the algorithm employed, computational speed, capacity, simplicity of contour boundaries, and in generality of data; but the examples run to date, the results are remarkably similar both in terms of dimensionality and configuration (for an example see Lingoes, in press b).

Running time: Approximately the same as SAS/1 (Lingoes, 1966b).

Availability: Copies of the FORTRAN II listings plus the write-ups (in the form of comment cards) can be obtained by writing to Professor James C. Lingoes, Computing Center, The University of Michigan, Ann Arbor, Michigan. For those desiring source decks and sample data, please send a new (or in good condition) IBM-7090, Mod. II magnetic tape, upon which will be written the BCI card images (14 words/record at 556 HPI), documented for conversion to other systems. Decks of cards cannot, unfortunately, be sent on request unless the cost of materials, labor, and postage is paid by the requester.

References:
Guttman, L. A basis for scaling qualitative data. Amer. Sociol. Rev., 1964, 29, 139-149.
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Kruskal, J. B. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika, 1964, 29, 115-129.
Lingoes, J. C. The multivariate analysis of qualitative data. Proc. Conference on Cluster Analysis of Multivariate Data, in press. (b)
Shepard, R. N. The analysis of proximities: Multidimensional scaling with an unknown distance function - I. Psychometrica, 1962, 27, 125-140. (a)
Shepard, R. N. The analysis of proximities: Multidimensional scaling with an unknown distance function II. Psychometrica, 1967, 22, 219-245. (b)

An IBM 7090 FORTRAN IV program to test linearity of regressions. Lennart Sjöberg and Lars Bergman, Psychological Laboratories, University of Stockholm, Stockholm, Sweden (CPA 246).

The program is designed for a variety of computer packages for the study of variables, and to provide no check of linearity. For this reason, it was considered desirable to have a separate program available to make the check on regressions. The present program may be used to calculate the correlation ratios in each regressions subset, and also the F tests of variance accounted for in addition to the linear regression model. Scatter plots may be obtained by the user, and by grouping all scores as in a cell together and by grouping all scores (repeated-measures) for a subject together, parallelizing the usual arrangement of regressions. Any combination of four transformations (power, log, reciprocal, and multiplicative) of the raw scores is allowed and the resulting scores may be printed out.

Output provides: (a) a complete F-table consisting of sums of squares, degrees of freedom, mean squares, Fs, and identification of error term used for each F. (b) printing data is simplified by grouping all scores in a cell together and by grouping all scores (repeated-measures) for a subject together, parallelizing the usual arrangement of regressions. Any combination of four transformations (power, log, reciprocal, and multiplicative) of the raw scores is allowed and the resulting scores may be printed out. Several analyses may be performed in one run on the computer.

Scatter plot criteria: Each pair of variables is checked according to three criteria in the following order: 1. If one of the variables in the pair is specified in advance by the user, a plot is performed. 2. If the variable is specified as interesting, a plot is performed. 3. The two Fs values are tested for significance according to the specified level of significance. A plot is performed if one F value in the pair is significant.
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by the actual regression of the dependent variable on the factor scores, but a short cut is available which increases computational accuracy and reduces computer time. For the mathematics see Beaton (1964), Haitovsky (1966), and the user’s instruction.

A brief description has been deposited as Document No. 9348 with the ADI Auxiliary Publications Project, Photo Duplication Service, Library of Congress, Washington 25, D. C., where a copy may be obtained by citing the document number and by remitting $1.25 for photoprints or $1.25 for 35 mm microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.

References:

The materialistic theory has all the completeness of the thought of the middle ages, which had a complete answer to everything, be it in heaven or hell or in nature. There is a trimness about it, with its instantaneous present, its vanished past, its non-existent future, and its inert matter. This trimness is very medieval and ill accords with brute facts.

Alfred North Whitehead