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AUTOMATIC DATA PROCESSING PARTIAL PROCEEDINGS OF AN INFORMAL MEETING HELD SEPTEMBER 15, 1960 AT LAWRENCE RADIATION LABORATORY

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Edited by Paul V. C. Hough and John L. Brown

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Following the Conference on Instrumentation in High-Energy Physics held at Lawrence Radiation Laboratory on September 12 through 14, 1960, there were two days of informal meetings attended by those especially interested in automatic processing of bubble chamber data. Those papers presented on the first day (Thursday, September 15, 1960) of the informal meetings that will not appear in print elsewhere are contained in this report.

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A MATHEMATICAL REPRESENTATION OF THE ORBIT OF SLOW PARTICLES

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In reconstructing the orbits of charged particles in bubble chambers with magnetic fields it is common practice to fit the measured points to a parabola or higher-order polynomial, since least-squares fits may be made very easily to this form of curve. However, in large chambers these orbits may be more accurately represented by circles or spirals. The use of a circular representation also has the advantage that the measurement error enters naturally perpendicular to the track, as is actually the case with most measuring machines. This note points out a simple, analytic method of fitting to a spiral which should be accurate for arbitrarily long slow tracks.

Assuming that the magnetic field has negligible components in the plane upon which the orbit is projected, we may write the instantaneous projected radius of curvature as

$$\rho = \frac{p \cos\lambda}{0.3B} , \qquad (1)$$

where B is the magnetic field, p the momentum, and λ the dip angle of the track. We may further assume

$$p = qR^{\alpha} , \qquad (2)$$

where R is the residual range and q and α are assumed to be constant over the length of track considered. Letting R_0 be the residual range at the center of the track and s the projected arc length measured from the center, we may write

$$\frac{1}{\rho} = \frac{0.3B}{q(\cos\lambda)^{1-\alpha}} (R_0 \cos\lambda - s)^{-\alpha} = -\eta \frac{d\phi}{ds} , \qquad (3)$$

where ϕ is the azimuthal angle of the tangent and η is +1 for a positive track and -1 for a negative track. B is assumed to point along the z axis of a right-handed coordinate system. Small variations in the magnitude of B (although we have neglected components in the plane of projection) may be taken into account by expanding B about the center of the track. Thus, for

$$B = B_0 (1+\beta_1 s + \beta_2 s^2) , \qquad (4)$$

we may expand Eq. (4) in powers of s and integrate to obtain

$$\phi = \phi_0 - \eta/\rho_0 \; s (1 + C_1 s + C_2 s^2) , \qquad (5)$$

where

$$C_1 = \frac{1}{2} \left(\frac{\alpha}{R_0 \cos\lambda} + \beta_1 \right) \qquad (6)$$

and

$$C_2 = \frac{1}{3} \left(\frac{a(a+1)}{aR_0^2 \cos^2\lambda} + \frac{a}{R_0 \cos\lambda} \beta_1 + \beta_2 \right) . \qquad (7)$$

A general relation in differential geometry gives

$$\rho e^{i\theta} = \int e^{i\phi} ds , \qquad (8)$$

where θ is the azimuthal angle of the vector from the center of curvature of the mid-point to the point at which ϕ is evaluated. Expanding the integrand in powers of C_1 and C_2, but not using the small-angle approximation, we find

$$\rho^2 = \rho_0^2 \left[1 - 4C_1 s + 4\rho_0 C_1 \sin s/\rho_0 - 12 C_2 \rho_0^2 (\cos s/\rho_0 - 1) - 6 C_2 s^2 \right] , \qquad (9)$$

where we have used the relation

$$\theta_0 = \phi_0 - (1 + \eta/2) \pi . \qquad (10)$$

For this one gets immediately, in the small-angle approximation,

$$\rho^2 = \rho_0^2 - 2/3\, C_1 s^3 - 1/2\, C_2 s^4 . \qquad (11)$$

From Eqs. (5) and (9) one may also relate ϕ to the easily measurable angle θ according to the equation

$$\phi = \theta + \pi (1 + \eta/2) - \eta \left[C_1 \left(\frac{s^2}{\rho_0} - \frac{s^4}{12\rho_0^3} \right) + C_2 \frac{s^3}{\rho_0} \right] , \qquad (12)$$

and hence compute the tangent angle at either end of the track.

Since one may show that in the small-angle approximation the momentum determined from a least-squares fit to a circle would be correct at the center if the particle were losing momentum linearly, a good first approximation to the momentum may be obtained from a circle fit, and from this the correction terms C_1 and C_2 may be computed as well as the arc lengths for each point. A second least-squares fit may then be made to the form given in Eq. (11). As pointed out by Solmitz,[1] an analytic least-squares fit to a circle may be made if one minimizes the χ^2 function

$$\frac{1}{\epsilon^2} \sum_i \left[\rho_i^2 (a_1^* b^*) - (\rho^*)^2 \right]^2$$

to find the optimum values of the coordinates of the center, a^* and b^*, and the optimum radius ρ^*. Here ϵ is the assumed error normal to the track. A similar analytic fit may obviously be made to Eq. (9) so that no iterations are required and no convergence problems arise. The projected radius of curvature at the center, ρ_0^*, determined from this fit may then be used in conjunction with a range-momentum table to yield the momentum of the particle at either end of the track.

According to the least-squares criteria one may define an error matrix

$$G^{-1} = \begin{pmatrix} \overline{(\Delta\rho_0^*)^2} & \overline{(\Delta\rho_0^* \Delta a^*)} & \overline{(\Delta\rho_0^* \Delta b^*)} \\ \overline{(\Delta a^* \Delta\rho_0^*)} & \overline{(\Delta a^*)^2} & \overline{(\Delta a^* \Delta b^*)} \\ \overline{(\Delta b^* \Delta\rho_0^*)} & \overline{(\Delta b^* \Delta a^*)} & \overline{(\Delta b^*)^2} \end{pmatrix}.$$

By use of the above method, this error matrix may easily be shown to be the inverse of the matrix

$$G = \frac{1}{\epsilon^2} \begin{pmatrix} n & \sum_i \cos\theta_i & \sum_i \sin\theta_i \\ \sum_i \cos\theta_i & \sum_i \cos^2\theta_i & \sum_i \sin\theta_i \cos\theta_i \\ \sum_i \sin\theta_i & \sum_i \sin\theta_i \cos\theta_i & \sum_i \sin^2\theta_i \end{pmatrix}.$$

Using G^{-1} to compute the errors in the azimuth and the curvature of the track, one may show that in the small-angle approximation these errors reduce to those of Willis,[2] using a fit to a parabola.

The magnitude of the correction to a circle fit described above reaches a maximum of from +3% to+4% for tracks that are actually stopping. This result agrees well with that of Gregory,[3] who calculated a similar correction to a parabolic fit to stopping tracks. Although this correction is usually no larger than the multiple-scattering error in liquid hydrogen, it is a systematic effect and should therefore be taken into account whenever high accuracy is required.

1. Frank T. Solmitz (Lawrence Radiation Laboratory), private communication.
2. William J. Willis, Error Matrix for Bubble Chamber Track Measurements, Brookhaven Internal Report (unpublished).
3. B. Gregory, private communication.

DIRECT THREE-DIMENSIONAL MEASUREMENT

Klaus Gottstein

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The stereoprojector constructed by Mr. Luetjens at the Max Planck Institut fuer Physik (Munich) is not yet operating, but I have been asked to say a few works about it.

The principle is as follows:

The 2 stereo views are projected on a metal screen on which a cross hair is engraved. The three coordinates of a particular bubble and the fiducial marks are measured by bringing their two images in coincidence with the cross hair. Since polarized light is used for projection, an observer wearing analyzer glasses can see the event in space and has the impression that in this position the cross hair is in spatial coincidence with the bubble or fiducial mark. A precision cross stage is used for moving the two stereo pictures together in the x and y directions by joy-stick control. For measuring the third coordinate a plane parallel glass plate can be tilted in one of the two light beams. This in effect changes the distances between the two pictures--i.e., the stereo angle--and gives the illusion to the observer that the whole chamber moves back and forth in the third direction with respect to the stationary cross hair.

The x and y movements of the x stage are digitized with linear Ferranti digitizers and the tilting movement of the plane parallel glass plate with circular Ferranti digitizers. The data are put out on punched tape.

So far we have used film on which the two stereo pictures are photographed on one strip of film. The film is carefully guided, and we therefore hope not to have any trouble with inaccuracies due to misalignment. The proof, of course, will be obtained by repeated measurements of the same bubble, and such measurements are now being undertaken after the arrival of the third circular digitizer, which we received only a few weeks ago and which was installed just before I left. Preliminary measurements on a model machine which allowed readings of the third coordinate with an accuracy of only about 1% of the chamber depth showed that measurements of these coordinates were reproducible with at least that accuracy. (We had the impression that with a little bit of experience one could really be sure that one particular bubble was in coincidence with the cross hair, and the neighboring bubbless in a track were not, but this remains to be confirmed by numerical measurements with the new digitizer).

The advantages of this system can be summarized as follows:

1. The stereo projection eliminates the difficulty of correctly identifying the two images of a given track in a multiprong event. Errors due to misclassification of tracks are thereby reduced.

2. Each track has to be measured only once instead of twice. Thus measuring time is saved.

3. Corresponding points are immediately visible and need not be constructed by the computer. This saves computing time.

4. All three coordinates are directly measured. This also saves computing time--and may, moreover, result in better accuracy in depth measurement.

The disadvantage is that the system cannot easily be made to automatically center and follow tracks. However, it may prove quite useful in investigations in which a number of events not excessively large have to be inspected and measured.

DISCUSSION

Don Gow noted that the pictures that were measured were from the 19-inch hydrogen bubble chamber, where the stereo angle is only 7 deg. The question arises as to how the device will work on large stereo angle pictures. Gottstein suggested two alternatives: (a) reproject the pictures with a smaller stereo angle; the images (now distorted) will then fuse over a small area, and a computer can straighten out the effects of the distorted projection; (b) dispense with spatial reconstruction and simply superimpose corresponding bubbles.

Ted Bowen asked what the procedure would be when three or more views were photographed. Gottstein replied that you would either measure the best pair, or else measure all pairs of views, with a corresponding increase in measuring time.

GUTS

Peter Berge

Introduction

GUTS is a large computer code designed to obtain a least-squares adjustment, subject to the constraints of energy-momentum conservation, of variables pertaining to tracks associated at a single nuclear interaction vertex. GUTS also makes an estimate of the error matrix on the adjusted variables. It is coded for the IBM 704 EDPM. In one form or another, GUTS is now used at Brookhaven by Horace D. Taft and at Berkeley and UCLA by groups making use of the hydrogen bubble chamber data-analysis system. The method used was developed by Taft and Frank T. Solmitz at Berkeley in the summer of 1958, and the original coding was done by Taft. There has been a running version of GUTS since the summer of 1959, and the program has been fairly thoroughly written up. For descriptions of the method, see UCRL-9097 and Alvarez Group Memos 86 and 190. For the flow diagrams, see Memo 192, which will soon appear as UCRL-9309. Since these references are generally available, I shall avoid algebra and shall emphasize some of the little-known facts gained by the experience of the groups at Berkeley.

Two Uses of GUTS

Since the spring of 1959 we have run GUTS (embedded in an equally large and complicated routine, KICK) on about 10,000 events (one event may contain several vertices). These events are produced in a variety of beams, targets, and chambers:

Beams, π^-, K^-, K^+, $\bar{p}$;

Targets, H, D;

Chambers, 15-inch, 72-inch.

The events processed represent just about every possible bubble chamber track configuration: elastic scattering, pion production, associated production, particle decay, etc. In these experiments, GUTS has been used in two basically different ways:

(a) In an unambiguous event, GUTS has been used to sharpen the precision of knowledge about the track variables describing the interaction.

(b) In ambiguous events, GUTS has been used to separate ambiguities.

We have had considerable success with both uses of GUTS in experiments involving the 15-inch bubble chamber. An example of the first type of the first type of use occurs in $\Sigma^{\pm}$ production by low-energy K^- in flight:

$$K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp} .$$

Although direct measurement may determine the K^- momentum to a precision of only 20%, after the GUTS fit, a typical precision might be 3%. An example of the second type of use is in the kinematic separation of the reactions

$$K^- + D \rightarrow \begin{pmatrix} \Sigma^0 \\ \Lambda^0 \end{pmatrix} + p + \pi^- .$$

Since the K may interact at rest or in flight, there is a fourfold ambiguity. In a particular sample of several hundred such events, Nahmin Horwitz was able to sort unambiguously all but about 7% of the data into the four possible categories. This success was due principally to the possibility of assigning to the measured variables reasonable estimates of the errors in the reconstruction of tracks in the 15-inch chamber.

Our experience with the 72-inch chamber has not been so successful because of two factors:

(a) The assignment of errors to measurements in the 72-inch chamber is not well understood at this time and is therefore not reliable. Although the χ^2 distribution for some types of events is acceptable, this distribution from the kinematic fits done by GUTS on some supposedly unmistakeable events scales too high by a factor of from 1.6 to 2. The misassignment of errors (attributed mainly to optical problems and perhaps to some turbulence—not to programming mistakes) makes it rather hard to tell what an acceptable fit is.

(b) The 72-inch chamber has been used at high beam energies and in experiments of the type that produces a large number of ambiguities.

Variables, Errors, Constraints

GUTS obtains its fits by minimizing the quantity

$$\chi^2(x_i) = (x_i - x_i^m)\,(G)_{ij}\,(x_j - x_j^m)$$

subject to the set of conditions $F_\lambda(x_i) = 0$. The parameters x_i are the variables specifying each track. The x_i^m are the measurements; the matrix $(G)_{ij}$ is the inverse error matrix. The constraints $F_\lambda(x_i)$ are the four components of the relativistic energy-momentum four-vector.

The basic variables of GUTS are ψ, the azimuth projected onto the XY plane; $s = \tan\lambda$, where λ is the latitude measured from the xy plane; and $k = 1/p \cos\lambda$, a quantity proportional to the projected curvature. These variables were chosen because they are nearly normally distributed. Each particle is completely described by the set of these three variables and by an assigned mass. These variables may or may not be measured. If some variables are not measured, then some of the four constraint equations are used to eliminate occurrences of the unmeasured variables in the remaining constraint equations. At most four variables can be unmeasured. So far, GUTS has been written to allow only for the most common combinations of unmeasured variables, but these allowed combinations account for the overwhelming majority of the cases encountered in practice.

The input error matrix $G_{ij}^{-1} = \overline{\delta x_i^m \delta x_j^m}$ is manufactured from the estimates of variances made in PANG. GUTS allows one to specify covariances between variables pertaining to a single track, but not between variables pertaining to different tracks. Examples of such intratrack covariance terms that are nonzero are the terms $\overline{\delta K \delta \psi}$* for a track whose momentum is measured by curvature and $\overline{\delta K \delta s}$ for a track whose momentum is measured by range. The second of these we have included in our version of KICK, as it may be very important input in defining the error on the momentum. The first of these may also have a correlation coefficient of nearly one. In Berkeley we have not so far included this $\overline{\delta \psi \delta K}$ term in the output from our geometry program. Taft tells me that he has done so with his version of a geometry program, but I do not know his experience in detail.

After the fit has been obtained, the error matrix G^{-1} is evaluated at the point x_i^* which satisfies the constraints and minimizes χ^2. This matrix is obtained by using the assumption of linearity,

$$G_{ij}^{*-1} = AG^{-1}A^{+} = \frac{\partial x_i^*}{\partial x_k^m} \overline{(\delta x_k^m \delta x_\ell^m)} \frac{\partial x_\ell^*}{\partial x_j^m} .$$

The evaluation of the derivative matrix $\frac{\partial x_i^*}{\partial x_j^m} = A_{ij}$, if one assumes strict linearity of the constraints, involves only the first derivative matrix of the constraints. Actually, since the constraints F_λ (x) are nonlinear, the proper evaluation of the matrix A for a correct linear transformation of the error matrix involves also the second derivatives of the constraints. This involves a very long, tedious job of coding which has not been done to date. In this sense, the estimates of the fitted errors output by GUTS are incorrect.

One major advantage of a single multivertex fit over a series of connected single-vertex fits, as done by GUTS, is that these incorrectly computed errors do not enter. The entire fit proceeds directly from the input variables and errors.

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*Since we measure k at the middle of a track and ψ at the ends of the track.

Test Functions

With proper input a large sample of fitted events must yield a χ^2 distribution, and so one may use χ^2 as a test function to check the computation of measurements and the errors by the geometry program.

GUTS provides another set of test functions (called the "stretch" or "pull" functions) in its output which are potentially more useful than χ^2 itself for such a purpose.

Given a configuration of variables with their specified errors and having knowledge of the constraint derivatives, one can compute the rms residual $\left\{\overline{(x_i^* - x_i^m)^2}\right\}^{1/2}$ in each variable. Dividing the actual residual by this rms residual, one obtains a set of functions

$$\xi_i = \frac{x_i^* - x_i^m}{\left\{\overline{(x_i^* - x_i^m)^2}\right\}^{1/2}}$$

which has some very useful properties:

(a) There is one of these functions for each variable that was measured.

(b) Given the correctness of the assumptions about normally distributed variables and correctly assigned input errors, one can see that ξ_i must be normally distributed with mean 0 and variance 1.

(c) If the input error estimates are too "tight," the variance will be >1 for a large sample of ξ_i; if they are too "loose," the variance will be <1 for a large sample of ξ_i.

These functions have not received use commensurate with their potential. The first person to make extensive use of these ξ_i was Bruce McCormick, who had a rudimentary GUTS running on the IBM 650 in 1957. He was able to use the ξ_i distribution to find some systematic distortions in the 10-inch chamber.

Nahmin Horwitz, who has done a careful analysis of a sample of events fitted by GUTS, has plotted ξ of each variable for one particular track type in several hundred events in the 15-inch chamber. He finds that

(a) the distribution is normal out to about 2.5 standard deviations;

(b) the mean for ξ_ψ, ξ_s is zero;

(c) the variance for ξ_ψ, ξ_s is about 1.2;

(d) ξ_k is slightly skew and broadened, indicative of a systematic momentum error misassignment by PANG; it was to detect this misassignment that the distributions were originally plotted.

Convergence

To date our biggest problem with the use of GUTS has been the frequent failure of GUTS to converge to a fit. There are several nonanalytic requirements imposed on GUTS which must be satisfied on each step. These are requirements such as $p^2 > 0$, that the constraints improve between steps, and so forth. Imposing these restrictions on each step may make it impossible for GUTS to find a fit. In some cases this may be a function of the manner in which these constraints are imposed. There are limits as to how long GUTS is allowed to seek a fit; a reject is given if these limits are overstepped. In many cases one can see that the hypothesis being tested is not the correct one. In an appreciable fraction, however, this is not so obvious, and one needs to investigate each of these cases in detail. More work is needed on the general question of convergence, to see whether better procedures can be designed for calculating acceptable steps. (See Frank Solmitz, Alvarez Memo 189.)

Conclusion

GUTS has been a running program for about a year and a half. I hope in this talk to have given some idea of our experience with this type of program and to have indicated some areas where further work is needed.

References:

UCRL-9097
9098
9309

Alvarez Memos 4310-03 M6
4310-03 M7

No. 86
186
187
188
189
190
192

DISCUSSION

Although a poor distribution of ξ's indicates something wrong with the error assignments, Solmitz pointed out that it is not trivial to decide which assignment was wrong; he also noted that this check of ξ distributions works best for events that are highly overdetermined. Button remarked that it was the study of the ξ distributions which led to the writing of EXTEND, a program to make the "last-bubble correction."

There was considerable discussion among Solmitz, Thorndike, Horwitz, and others as to the "efficiency" of the program. In a study of 400 well-measured events by Horwitz, GUTS picked a kinematic hypothesis 95% of the time. The statement was made that the program seldom would choose the wrong hypothesis on a well-measured event; what it did on poorly measured events, or whether it rejected good events in some fraction of the cases, was not so clear. Apparently no one has processed a batch of events whose identity was known a priori, e. g., a set of events generated by a Monte Carlo process. Button and Solmitz remarked that to get reasonable kinematic fits it was necessary to set a lower limit to the assigned errors; this was justifiable because even on a "perfectly" measured event there were still uncertainties in the track reconstruction, owing to uncertainties in optical constants, etc. Correlation of the errors becomes a problem when they are assigned in this way.

FOG, CLOUDY, AND FAIR PROGRAMS

Howard White

ABSTRACT

A general description is given of the FOG, CLOUDY, and FAIR programs developed for the IBM 704 computer. These programs perform the spatial reconstruction of events photographed in a bubble chamber and calculate the momentum components of the tracks. The parameters are transformed into special reference frames, quantities of physical interest are derived, and various kinematic constraints are applied. The results of the calculations for each event appear as page output, and selected parameter distributions for a group of events can be obtained as CRT displays. Notable features of the programs include the manner in which human and digitizer errors are controlled, and the extensive use made of library tapes for storing data. The latter makes it possible to output all the relevant information concerning an event as a single unit, thereby reducing the amount of external correlation required of the physicist.

Introduction

The high rate at which bubble chambers are capable of producing data makes the use of an automatic computer imperative in the analysis of the photographs. We wish to describe a set of data-reduction programs that has been compiled for the IBM 704 EDPM. Though written with the 30-inch propane bubble chamber at Berkeley specifically in mind, the programs can be adapted with little modification for use with most instruments.

An event, or origin, is a single scattering, decay, or interaction giving rise to a set of tracks leading to or stemming from a common vertex in the bubble chamber. Two or more origins may be associated with each other in that they have a common particle connecting them. Such a collection of related events is referred to as a chain when handled as a single unit.

For convenience one can regard the individual programs as being divided into three main groups: the FOG, CLOUDY, and FAIR systems.

The purpose of FOG is to collate, store, edit, summarize, and retrieve basic data describing nuclear reactions. Its purpose is also to do the primary arithmetical calculations involved in converting the input data to a set of parameters describing the location, configuration, and momentum components of the particles participating in the reaction.

The CLOUDY system is responsible for computing the errors on estimates of angles and momenta. Unlike FOG, which treats origins separately, the CLOUDY system can carry out calculations associated with chains. It can apply kinematic constraints and reconstruct the lines of flight of neutral particles connecting two vertices. The Q values for decays can be calculated and center-of-mass transformations performed.

The FAIR system is solely responsible for outputting the results of the computations. The data can take the form of page output, or displays on a CRT unit of histograms and scatter diagrams.

One of the notable features of the programs to be described is the extensive use made of library tapes. Events are placed on the tape in order of increasing event numbers, regardless of the order in which they arrive at the computer. In addition to the input data, the results of all subsequent calculations are stored under the same identification number. This means that one may easily retrieve information concerning particular events from the library without having to keep an elaborate system of cross reference. Another consequence is that the assignment request data, in which the physicist assigns masses to the particles and indicates the types of calculation desired, etc., can be compiled independently of the measurement input. The program ensures that the two sets of information for the event are merged in the correct location in the library.

Preparation of the Input

A series of punched cards is produced which provides the following information: the date of the measurement; the numbers of the experiment, picture, scan card, and origin; the x and y coordinates of the fiducial marks in both stereoscopic views; and the coordinates of points lying along each of the tracks.

Prior to a run on the computer, the measurement cards for all recently measured events belonging to the same experiment are collected and sorted in order of increasing event numbers. They are then converted to magnetic tape and form the Measurement Input to the computer.

Meanwhile, the physicist prepares the scan data. These data carry the same set of identification numbers as characterized the measurement data for the event. In addition there is an assignment—list number which is the same for all origins belonging to chains that have the same general configuration. For example, if an experiment is being performed involving K^- stars producing Λ^0 hyperons, for all cases the K^- star might be labeled Origin 1, and the Λ^0 decay, Origin 2. The chains 12 will all be similar and will need to be processed together. The assignment list number is, consequently, made the same for Origins 1 and 2 of all these chains.

The scan data include the nature of the particles (i.e., proton, pion, etc.), and, if required, the signs of their charges, their estimated ionizations, and whether they came to rest in the chamber and should therefore have their energies determined by range. Provision is available also for the physicist to write comments concerning the event (perhaps a tentative interpretation), and these are later reproduced with the output data. Finally are recorded the numbers of other origins, if any, that are associated through a common particle with the origin in question, producing a chain.

The scan data are key-punched, sorted according to their event numbers, and converted to tape ready for input to the computer.

The FOG Program

The FOG program is concerned with taking new measuring and scan data and merging them into their correct locations on the FLI tape.

However, one does not need scan data to be able to work out the spatial positions of the tracks. Thus, after making certain tests to check for measurement errors, the FOG Program performs the spatial reconstruction.

Next, the FOG Program performs a curve-fitting to the spatial points to obtain the momentum of the track at the center of the fitted length. The azimuthal angle, β, and the angle of dip, α, and the error estimates for all these quantities are determined and are written onto the FOG library for later use by programs of the CLOUDY system.

Provision is made for searching through a large library of previous measurements for a particular class of events. For example, one may require a test for all origins having a certain number of outgoing tracks, or for which track 01, say, is negative and track 02 is positive, or for which one of the tracks is longer than another. In this manner a wide variety of phenomena can be traced in the library, with little effort by the physicist, in order to minimize the writing of repetitive scan data.

The FOG program can be contained in a computer having a storage capacity of 32,000 words.

The time taken to process an event through FOG is about 15 seconds.

The CLOUDY System

CLOUDY Selector Program

The input to this program comes from the FOG library, and the output, as it is produced, is merged into the CLOUDY library. The first operation is to take the new data from the FOG library and edit them in a form suitable for use in the CLOUDY calculations. It correlates the measurement and the scan data for each event. In particular, this is the first point at which a mass assumption from the scan data is actually associated with each measured track. In case the mass assumption was "generalized," the data are repeated on the CLOUDY library for each valid permutation of the assumed masses. Whereas the FOG library has all events stored together, regardless of the type of nuclear reaction they represent, the CLOUDY library groups them according to their assignment list number. The reason is that events belonging to the same assignment list are generally similar in character and therefore need to be processed through the same CLOUDY kinematical computations.

The program decides which origins form the chains and identifies the interconnecting tracks. (It should be noted that an interconnecting track is measured and carried along as two separate tracks: the outgoing track from one vertex and the incoming track to another.) It then proceeds to calculate for each track the following parameters: the external errors on angles α and β, the momentum at the vertex and the external error on this estimate, and the momentum from range where appropriate.

CLOUDY Programs

The operations performed so far have been of a very general nature and were of the type necessary for all events, no matter what nuclear reactions they represented. However, the stage is now reached where it is required to carry out calculations such as the reconstruction of lines of flight of neutral particles, the evaluation of the momenta of Λ^0 and θ^0 particles from the kinematics of their decay products, calculations of Q values, centre-of-mass transformations, etc. The set of operations required will depend upon the particular type of nuclear reaction involved. The CLOUDY programs, therefore, consist of several different channels or modes which perform given sets of these operations to given sequences of origin numbers.

The CLOUDY programs are of several types, including those which apply momentum and energy constraints, compute derived quantities (central values), or determine the necessary quantities for variance estimation and assumption testing. Each of these programs reads data from the CLOUDY library, performs its calculations, and writes the results on the CLOUDY library. The programs may be applied in any desired sequence, so that, for example, the derived quantities may be computed either before or after a particular constraint has been applied, or, more commonly, both before and after.

FAIR Program

The primary function of the FAIR program is to control the output of all other programs. It takes the CLOUDY library tape as input. Normally it reads through all events belonging to a particular assignment list and prepares to output information concerning those chains for which a change has occurred since the last run. However, the program can be made to search for specific events satisfying a particular set of criteria. For example, one may require output for only those events in which M^* was less than a certain value, or for which the Q-value lay within defined limits, or certain tracks were a given length, etc. As many as five selection criteria may be specified. The information concerning the events answering the required description is then written onto scratch tape (a temporary storage).

The output may take the form of pages, cards, or CRT displays.

Finally, the program needs to know which items of information it is expected to produce for each event, e.g. FOG momenta and angles, Q-values, M^* values, constrained momenta and angles, the number of points measured on each track, etc. A series of adjustable constants from the System tape supplies these instructions.

Page and card outputs are principally of use in experiments handling only small numbers of events, whereas histograms and scatter diagrams are useful for all classes. With regard to the histograms, the intervals may be required to be a certain definite size, or, alternatively, can represent a given fraction of the experimentally observed range of values. An account is made of the numbers of events with values of the variable lying within the various intervals, and the shape of the histogram is displayed on the CRT unit and photographed. To supplement the histogram, an ordered sequence of the values that have been plotted is also output. Provision is made for printing next to these values, the estimates of other parameters belonging to the same events. For example, an ordered sequence of M^* values can be printed out with the Q-values that corresponded to those events alongside. At a glance one may then see the correlation between these two parameters.

Later it will be possible to plot weighted histograms in which the events are represented as rectangles of equal area, and of width proportional to the errors on the estimate.

The scatter diagrams are organized in a somewhat similar manner to that of the histograms. Once again the CRT display is supplemented by a printed record of the values plotted. This latter information is ordered sequentially according to increasing value of the variable plotted as abscissa.

It can be readily understood that the FAIR system can be elaborated almost indefinitely as the need arises.

DISCUSSION

A number of specific questions concerning the FOG-CLOUDY-FAIR system were asked. Solmitz wondered whether a FOG remeasurement request required remeasurement of fiducial marks; the answer was, in most cases, yes. Taft wondered if the intermediate FOG tape could be dispensed with; there was a considerable amount of discussion at this point, but a sufficient reason for keeping the tape was that the 704 did not contain a large enough core momory. The question arose as to what happened to mis-labeled events. Meissner pointed out that with three independent inputs there was little chance that such an error would go undetected; some of this type of error could be corrected by the program. Berge also noted that automatic labeling would cure many of these difficulties.

Goldschmidt-Clermont posed three questions for all library systems: (a) how easy would it be to add another mass assignment (e.g. the dubnion); (b) how easy would it be to calculate another derived quantity (e.g., a potential path); (c) how easy would it be to add another auxiliary quantity (e.g. a ξ_i such as discussed by Berge in his paper on GUTS)? White said that all three could be done on the FOG-CLOUDY-FAIR System without too much trouble; (a) would be hardest, (c) easiest. The requests would be harder to fulfill in the EXAMIN system. Solmitz voiced the (unfullfillable) plea that physicists decide ahead of time what they want, rather than after the experiment is halfway done.

LOW-BUDGET EFFORTS

Marcello Cresti and Howard White

Whereas large laboratories try to replace people by machines whereever possible, the small laboratories with modest budgets can use facilities such as computers only for humanly impossible jobs. An example of the latter approach was discussed briefly. An exposure of 80,000 pictures (containing about 50,000 interactions total) was made to study the reaction

$$\pi^- + p \rightarrow \pi^+ + \pi^- + n \quad \text{for } T_\pi = 310 \text{ Mev},$$

of which there were expected to be $\leq$ 1,000 examples. It would be theoretically possible to eliminate about 75 to 80% of all the interactions from consideration as desired events by means of scanning rules (applied to angles, curvatures, etc.). An iterative process was used, with scanning criteria tightened up as experience was gained. The last 20 to 25% of events could not be identified on the scanning table; these were measured and then processed on an IBM 650 computer. In an effort to speed up the latter part of the data analysis, the 650 computer is being replaced by an Olivetti computer which is somewhat faster, has a somewhat larger memory, and can be programmed by using FORTRAN. Although the experiment is not yet completed, the data-processing system seems to work; it is not the most elegant but may be the most economical.

As an alternative to the use of small computers by low-budget groups, the collaborative use of large computers was suggested (by White). Small computers such as the IBM 650 are limited in speed, storage, and input and output facilities; in particular, they cannot use magnetic tape. Hence there is a strong motivation to use collaboratively something like an IBM 704. White cited collaboration with Wisconsin on a 1500-event experiment, and with Brookhaven (admittedly not a small-budget operation!) in a 6000-event experiment.

The Wisconsin-UCRL collaboration went roughly as follows. The pictures were taken at UCRL and the first month's analysis done there, while the data-processing routine was worked out. Thereafter all scanning was done at Wisconsin, and all measuring and computing done at UCRL. The added time delay for analysis of any one event due to this split was only one day, i.e. the time for a round-trip airplane flight from Wisconsin to California. Much more than this amount of time was saved by utilizing the experience of an existing computer group. It was emphasized that this kind of "split" in data analysis can be effective only if measuring and computing are treated as an integral process and done at one location only.