CERN Program Library Long Writeups Y250

HBOOK

Reference Manual

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Application Software and Databases

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History

HBOOK is a Fortran[1] callable package for histogramming and fitting. It was originally developed in the 1970s and has since undergone continuous evolution culminating in the current version, HBOOK 4.

Many people have contributed to the design and development of HBOOK, through discussions, comments and suggestions.

For many years and up to November 1994 René Brun has been responsible for the HBOOK program. Paolo Palazzi was involved in the original design. D. Lienart has been in charge of the parametrization part. Fred James is the author of routine `HDIFF` and of the minimization package Minuit, which forms the basis of the fitting routines. The idea of Profile histograms has been taken from the HYDRA system. The Column-wise-Ntuple routines were implemented by Fons Rademakers. The multi-dimensional quadratic fit package `HQUAD` is the work of John Allison. J. Linnemann and his colleagues of the D0 experiment contributed the routine `HDIFFB`. Pierre Aubert is the author of the routines to associate labels with histograms. Roger Barlow and Christine Beeston (OPAL) have developed the `HMCMLL` package.

Preliminary remarks

This manual serves at the same time as a **Reference manual** and as a **User Guide** for the HBOOK system. After a short introductory chapter, where the basic ideas are explained, the following chapters describe in detail the calling sequences for the different user routines.

In this manual examples are in `monotype face` and strings to be input by the user are `underlined`. In the index the page where a routine is defined is in **bold**, page numbers where a routine is referenced are in normal type.

In the description of the routines a * following the name of a parameter indicates that this is an **output** parameter. If another * precedes a parameter in the calling sequence, the parameter in question is both an **input** and **output** parameter.

This document has been produced using LaTeX [1] with the `cernman` style option, developed at CERN. A gzip compressed PostScript file `hbook.ps.gz`, containing a complete printable version of this manual, can be obtained from any CERN machine by anonymous ftp as follows (commands to be typed by the user are underlined):

```
ftp asisftp.cern.ch
Connected to asis00.cern.ch.
220 asis00 FTP server (Version wu-2.4(2)...) ready.
Name (asisftp:username): ftp
Password: your_mailaddress
230 Guest login ok, access restrictions apply.
ftp> cd cernlib/doc/ps.dir
ftp> get hbook.ps.gz    (type get hbook.ps for the uncompressed version)
ftp> quit
```

[1] A C interface is also distributed by the CERN Program Library, created using the tool f2h

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Chapter 1: Introduction

Data processing is an important aspect of particle physics experiments since the volume of data to be handled is quite large, a single LEP experiment producing of the order of a terabyte of data per year. As a result, every particle physics laboratory has a large data processing centre even though more than 50% of the computation is actually carried on in universities or other research establishments. Particle physicists from various countries are in close contact on a continental and world wide basis, the information exchanged being mainly via preprints and conferences. The similarities in experimental devices and problems, and the close collaboration, favour the adoption of common software methodologies that sometimes develop into widely used standard packages. Examples are the histograming, fitting and data presentation package HBOOK, its graphic interface `hplot` [2] and the Physics Analysis Workstation (`paw`) system [3], which have been developed at CERN.

HBOOK is a subroutine package to handle statistical distributions (histograms and Ntuples) in a Fortran scientific computation environment. It presents results graphically on the line printer, and can optionally draw them on graphic output devices via the `hplot` package. `paw` integrates the functionalities of the `hbook` and `hplot` (and other) packages into an interactive workstation environment and provides the user with a coherent and complete working environment, from reading a (mini)DST, via data analysis to preparing the final data presentation.

These packages are available from the CERN Program Library (see the copyright page for conditions). They are presently being used on several hundred different computer installations throughout the world.

1.1 Data processing flow in particle experiments

In the late sixties and early seventies a large fraction of particle physicists were active in bubble chamber physics. The number of events they treated varied between a few hundreds (neutrino) to several tens of thousands (e.g. strong interaction spectroscopy). Normally users would reduce there raw "measurement" tapes after event reconstruction onto Data Summary Tapes (DST) and extract from there mini and micro DSTs, which would then be used for analysis. In those days a statistical analysis program SUMX [4] would read each event and compile information into histograms, two-dimensional scatter diagrams and 'ordered lists'. Facilities were provided (via data cards) to select subset of events according to criteria and the user could add routines for computing, event by event, quantities not immediately available.

Although the idea and formalism of specifying cuts and selection criteria in a formal way were a very nice idea, the computer technology of those days only allowed the data to be analysed in batch mode on the CDC or IBM mainframes. Therefore it was not always very practical to run several times through the data and a more lightweight system HBOOK [5, 6], easier to learn and use, was soon developed.

It was in the middle seventies, when larger proton and electron accelerators became available, that counter experiments definitively superseded bubble chambers and with them the amount of data to be treated was now in the multi megabyte range. Thousands of raw data tapes would be written, huge reconstruction programs would extract interesting data from those tapes and transfer them to DSTs. Then, to make the analysis more manageable, various physicists would write their own mini-DST, with a reduced fraction of the information from the DST. They would run these (m,μ)DSTs through HBOOK, whose functionality had increased substantially in the meantime [7, 8]. Hence various tens of one- or two-dimensional histograms would be booked in the initialization phase and the interesting parameters would be read sequentially from the DST and be binned in the histograms or scatter plots. Doing this was very efficient memory wise (although 2-dim. histograms could still be very costly), but of course all correlations, not explicitly plotted, were lost.

HBOOK in those days still had its own memory management, but with version 4 [9], which became available in 1984, the ZEBRA data memory manager was introduced. This not only allowed the use of all memory managament facilities of ZEBRA, but at the same time it became possible to use the sequential FZ and random access RZ [10] input-output possiblities of that system. This allows “histograms” to be saved and transferred to other systems in an easy way. At about the same time Ntuples, somewhat similar in functionality to “events” as written on a miniDST were implemented. This way the complete correlation matrix between the various Ntuple elements can be reconstructed at will. The last few years multi Mflop machines have become available on the desktop, and “farms” of analysis machines are being set up to “interactively” reconstruct events directly from the raw data as registered in the experimental setup, hence bypassing the “batch” reconstruction step. The first Ntuple implementation can be thought of as a static large two-dimensional array, one dimension representing the number of events and the other a number of characteristics (floating point numbers) stored for each event. With the present version of HBOOK Ntuples can contain complex substructures of different data types, which allow a certain dynamicity. Moreover tools have been developed to dynamically share data between various processes (Unix) or global sections (VMS). This makes it now possible to sample events as they are registered in the experimental setup or, when the computing power is available, to reconstruct, vizualise and analize events in real time as they are recorded in the experimental apparatus. It is expected that this will progressively eliminate the intermediate Batch/DST analysis step and allow, with the help of Monte Carlo events and calibration data, an (almost) immediate response to the data taking needs of a large experiment.

1.2 HBOOK and its output options

The HBOOK system consists of a few hundred Fortran subroutines which enable the user to symbolically define, fill and output one- and two-dimensional density estimators, under the form of **histograms**, **scatter-plots** and **tables** and to handle Ntuples.

Some interesting features of HBOOK are:

- The basic operations require the knowledge of just a few subroutine calls that can be learned in half an hour, reading a few pages of documentation. The internal structure of the package is also such that the options that are not directly called by the user program are not loaded in memory.
- Histograms and plots are represented on the line printer in a standard format that contains the picture and some numerical information. Several options are available to modify the presentation, mainly in the case of one dimensional histograms. By default, one histogram per page is printed, writing a possible common title, date, individual title, drawing the countour of the histogram between the minimum and maximum channel content, with the contents scale adjusted to fit in one page, followed by channel number, contents and scale, and some statistical information (entries, mean value, standard deviation and so on). If the number of channels is greater than 100, the histogram is printed on several pages.
- Printing options permit to add or suppress some information, choose a different graphic presentation and modify the mapping of histograms on output pages. Histograms can also be printed with channels oriented along rows instead of columns, to avoid splitting the ones with many channels. Logarithmic contents scale can be selected. Various alternative output choices are illustrated in the examples.

About 120 subroutines are directly accessible to the user program, via Fortran calls of the type

```
CALL H.....(P1,P2,..)
```

This is the only interface between a Fortran program and the dynamic data structure managed by HBOOK, which thus remains hidden from the average user.

The functionality of HBOOK

The various user routines of HBOOK can be subdivided by functionality as follows:

Booking	Declare a one- or two-dimensional histogram or a Ntuple.
Projections	Project two-dimensional distributions onto both axes.
Ntuples	Way of writing micro data-summary-files for further processing. This allows projections of individual variables or correlation plots. Selection mechanisms may be defined.
Function representation	Associates a real function of 1 or 2 variables to a histogram.
Filling	Enter a data value into a given histogram, table or Ntuple.
Access to information	Transfer of numerical values from HBOOK-managed memory to Fortran variables and back.
Arithmetic operations	On histograms and Ntuples.
Fitting	Least squares and maximum likelihood fits of parametric functions to histogramed data.
Monte Carlo testing	Fitting with finite Monte Carlo statistics.
Differences between histograms	Statistical tests on the compatibility in shape between histograms using the Kolmogorov test.
Parameterization	Expresses relationships between as linear combinations of elementary functions.
Smoothing	Splines or other algorithms.
Random number generation	Based on experimental distributions.
Archiving	Information is stored on mass storage for further reference in subsequent programs.
Editing	Choice of the form of presentation of the histogramed data.

1.3 What you should know before you start

The basic data elements of HBOOK are the **histogram** (one- and two-dimensional) and the **Ntuple**. The user identifies his data elements using a **single integer**. Each of the elements has a number of **attributes** associated with it.

The package is organised as part of a **library**, from which at load time unsatisfied externals are searched and loaded. In this way only those subroutines actually used will be loaded, therefore minimising the space occupied in memory by the code. Unfortunately, given the way Fortran works and although the package is structured as much as possible in the sense of selective loading, some unused subroutines will usually be present.

HBOOK uses the ZEBRA [10] data structure management package to manage its memory (see chapter 8). The working space of HBOOK is an array, allocated to the labelled common /PAWC/. In ZEBRA terms this is a ZEBRA store. It is thus necessary to reserve as many locations as required with a declarative statement in the main program. The actual length of the common is defined most safely via a PARAMETER statement, as shown below:

```
PARAMETER (NWPAWC = 50000)
COMMON /PAWC/ HMEMOR(NWPAWC)
```

Furthermore HBOOK must be informed of the storage limit via a call to HLIMIT. This is discussed in detail in section 8.2 on page 160. In the case above this would correspond to

```
CALL HLIMIT(NWPAWC)
```

At execution time, when histograms are booked, they are accomodated in common /PAWC/ in booking order, up to the maximum size available.

Note that a call to HLIMIT will automatically initialise the ZEBRA system via a call to the routine MZEBRA. If ZEBRA has already been initialised, (MZEBRA has already been called), then HLIMIT should be called with a **negative** number indicating the number of words required, e.g.

```
CALL HLIMIT(-NWPAWC)
```

1.3.1 HBOOK parameter conventions

Histogram or Ntuple Identiers

Histograms and Ntuples in HBOOK are identified by a positive or negative integer. Thus the histogram identifier ID = 0 is illegal at **booking** time. However it is a convenient way to specify that the option or operation applies to **all** known histograms in the current working directory (e.g. output, input, printing). All routines for which a zero identifier is meaningful are mentioned explicitly.

Parameter types

In agreement with the Fortran standard, when calling an HBOOK routine the type of each parameter must correspond to the one described in the routine's calling sequence in this manual. Unless explicitly stated otherwise, parameters whose names start with I, J, K, L, M or N are **integer**, the rest **real**, with the exception of those beginning with the string CH, which correspond to character constants.

Data packing

All booking commands that reserve space for histograms or plots require the "packing" parameter VMX. It corresponds to the estimated maximum population of a single bin, on the basis of which a suitable number of bits per channel will be allocated. This allows several channels to be packed in one machine word, and thus to require less storage space (at the expense of packing and unpacking processing time). A value VMX=0.0 signals that no packing is to be performed and that each histogram channel will occupy one machine word.

1.4 A basic example

Below a simple example is given describing how to use HBOOK for booking, filling and printing simple histograms. After telling HBOOK the length of the `/PAWC/` common block to be `10000` words with a call to `HLIMIT`, a global title to appear on all histograms is specified by calling `HTITLE`. Next a 100 bin one-dimensional histogram with identifier 10 is booked with a call to `HBOOK1`, followed by the booking using a call to `HBOOK2` of a two-dimensional histogram with identifier 20 and consisting of 100 times 40 cells. The `DO`-loop labelled 10 fills the one-dimensional histogram 10, while the nested `DO` loops labelled 20 and 30 look after filling the two-dimensional histogram 20. In both cases a call is made to routine `HFILL`. Finally a call to `HISTDO` writes an index with information about all histograms as well as a lineprinter representation of the histograms on standard output.

Example of how to produce simple histograms

```
      PROGRAM HSIMPLE
*
      PARAMETER (NWPAWC = 10000)
      COMMON/PAWC/H(NWPAWC)
*.___________________________________________
      CALL HLIMIT(NWPAWC)
*                      Set global title
*
      CALL HTITLE('EXAMPLE NO = 1')
*                      Book 1-dim histogram and scatter-plot
*
      CALL HBOOK1(10,'EXAMPLE OF 1-DIM HISTOGRAM',100,1.,101.,0.)
      CALL HBOOK2(20,'EXAMPLE OF SCATTER-PLOT',100,0.,1.,40,1.,41.,30.)
*                      Fill 1-dim histogram
*
      DO 10 I=1,100
         W=10*MOD(I,25)
         CALL HFILL(10,FLOAT(I)+0.5,0.,W)
  10  CONTINUE
*                      Fill scatter-plot
*
      X=-0.005
      DO 30 I=1,100
         X=X+0.01
         DO 20 J=1,40
            Y=J
            IW=MOD(I,25)*MOD(J,10)
            IWMAX=J-MOD(I,25)+10
            IF(IW.GT.IWMAX)IW=0
            CALL HFILL(20,X,Y,FLOAT(IW))
  20     CONTINUE
  30  CONTINUE
*                      Print all histograms with an index
*
      CALL HISTDO
      END
```

Output Generated

```
EXAMPLE NO = 1

............................................................................................................................
.                                                                                                                          .
.   HBOOK   HBOOK  CERN           VERSION   4.13      HISTOGRAM AND PLOT INDEX                             17/12/91        .
.                                                                                                                          .
............................................................................................................................
.                                                                                                                          .
.  NO                     TITLE                          ID  B/C  ENTRIES DIM   NCHA     LOWER       UPPER       ADDRESS LENGTH .
.                                                                                                                          .
............................................................................................................................
.                                                                                                                          .
.                                                                                                                          .
.   1  EXAMPLE OF 1-DIM HISTOGRAM                        10  32      100  1  X   100   0.100E+01   0.101E+03       79369    149 .
.                                                                                                                          .
.                                                                                                                          .
.   2  EXAMPLE OF SCATTER-PLOT                           20   5     4000  2  X   100   0.000E+00   0.100E+01       79217    760 .
.                                                                    Y    40   0.100E+01   0.410E+02       78482    726 .
.                                                                                                                          .
............................................................................................................................

MEMORY UTILISATION

     MAXIMUM TOTAL SIZE OF COMMON /PAWC/           80000

EXAMPLE NO = 1
--------------
EXAMPLE OF 1-DIM HISTOGRAM

HBOOK     ID =        10                                    DATE  17/12/91             NO =   1

     250
     240                              -                        -                        -                        -
     230                             -I                       -I                       -I                       -I
     220                            -II                      -II                      -II                      -II
     210                           -I I                     -I I                     -I I                     -I I
     200                          -I  I                    -I  I                    -I  I                    -I  I
     190                         -I   I                   -I   I                   -I   I                   -I   I
     180                        -I    I                  -I    I                  -I    I                  -I    I
     170                       -I     I                 -I     I                 -I     I                 -I     I
     160                      -I      I                -I      I                -I      I                -I      I
     150                     -I       I               -I       I               -I       I               -I       I
     140                    -I        I              -I        I              -I        I              -I        I
     130                   -I         I             -I         I             -I         I             -I         I
     120                  -I          I            -I          I            -I          I            -I          I
     110                 -I           I           -I           I           -I           I           -I           I
     100                -I            I          -I            I          -I            I          -I            I
      90               -I             I         -I             I         -I             I         -I             I
      80              -I              I        -I              I        -I              I        -I              I
      70             -I               I       -I               I       -I               I       -I               I
      60            -I                I      -I                I      -I                I      -I                I
      50           -I                 I     -I                 I     -I                 I     -I                 I
      40          -I                  I    -I                  I    -I                  I    -I                  I
      30         -I                   I   -I                   I   -I                   I   -I                   I
      20        -I                    I  -I                    I  -I                    I  -I                    I
      10       -I                     I -I                     I -I                     I -I                     I

CHANNELS 100   0                                                                                                   1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100            111111111122222          111111111122222          111111111122222          111111111122222
          10   123456789012345678901234 123456789012345678901234 123456789012345678901234 123456789012345678901234
          1.   000000000000000000000000 000000000000000000000000 000000000000000000000000 000000000000000000000000

LOW-EDGE 100                                                                                                       1
          10            11111111112222222222333333333344444444445555555555666666666677777777778888888888999999999990
          1.   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

* ENTRIES =        100      * ALL CHANNELS = 0.1200E+05      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E+01      * MEAN VALUE   = 0.5433E+02      * R . M . S = 0.2854E+02
```

```
EXAMPLE NO = 1
--------------

EXAMPLE OF SCATTER-PLOT

HBOOK     ID =        20                                         DATE  17/12/91            NO =   2

CHANNELS 100 U 0                                                                                                  1 O
          10 N 0         1         2         3         4         5         6         7         8         9         0 V
           1 D 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 E
           ************************************************************************************************************
  OVE      *                                                                                                      * OVE
   40      *                                                                                                      *  40
   39      *   9IR*                     9IR*                     9IR*                     9IR*                        *  39
   38      *   8GO**                    8GO**                    8GO**                    8GO**                       *  38
   37      *   7ELS*                    7ELS*                    7ELS*                    7ELS*                       *  37
   36      *   6CIOU*                   6CIOU*                   6CIOU*                   6CIOU*                      *  36
   35      *   5AFKPU*                  5AFKPU*                  5AFKPU*                  5AFKPU*                     *  35
   34      *   48CGKOS*                 48CGKOS*                 48CGKOS*                 48CGKOS*                    *  34
   33      *   369CFILORU               369CFILORU               369CFILORU               369CFILORU                  *  33
   32      *   2468ACEGIKMOQS           2468ACEGIKMOQS           2468ACEGIKMOQS           2468ACEGIKMOQS              *  32
   31      *   +23456789ABCDEFGHIJK     +23456789ABCDEFGHIJK     +23456789ABCDEFGHIJK     +23456789ABCDEFGHIJK        *  31
   30      *                                                                                                      *  30
   29      *   9IR                      9IR                      9IR                      9IR                         *  29
   28      *   8GO*                     8GO*                     8GO*                     8GO*                        *  28
   27      *   7ELS                     7ELS                     7ELS                     7ELS                        *  27
   26      *   6CIOU                    6CIOU                    6CIOU                    6CIOU                       *  26
   25      *   5AFKP                    5AFKP                    5AFKP                    5AFKP                       *  25
   24      *   48CGKO                   48CGKO                   48CGKO                   48CGKO                      *  24
   23      *   369CFILO                 369CFILO                 369CFILO                 369CFILO                    *  23
   22      *   2468ACEGIK               2468ACEGIK               2468ACEGIK               2468ACEGIK                  *  22
   21      *   +23456789ABCDEF          +23456789ABCDEF          +23456789ABCDEF          +23456789ABCDEF             *  21
   20      *                                                                                                      *  20
   19      *   9I                       9I                       9I                       9I                          *  19
   18      *   8GO                      8GO                      8GO                      8GO                         *  18
   17      *   7EL                      7EL                      7EL                      7EL                         *  17
   16      *   6CI                      6CI                      6CI                      6CI                         *  16
   15      *   5AFK                     5AFK                     5AFK                     5AFK                        *  15
   14      *   48CG                     48CG                     48CG                     48CG                        *  14
   13      *   369CF                    369CF                    369CF                    369CF                       *  13
   12      *   2468ACE                  2468ACE                  2468ACE                  2468ACE                     *  12
   11      *   +23456789A               +23456789A               +23456789A               +23456789A                  *  11
   10      *                                                                                                      *  10
    9      *   9                        9                        9                        9                           *   9
    8      *   8G                       8G                       8G                       8G                          *   8
    7      *   7E                       7E                       7E                       7E                          *   7
    6      *   6C                       6C                       6C                       6C                          *   6
    5      *   5A                       5A                       5A                       5A                          *   5
    4      *   48                       48                       48                       48                          *   4
    3      *   369                      369                      369                      369                         *   3
    2      *   2468                     2468                     2468                     2468                        *   2
    1      *   +2345                    +2345                    +2345                    +2345                       *   1
  UND      *                                                                                                      * UND
           ************************************************************************************************************
LOW-EDGE   0   0000000000111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
           0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

 *                                                          I         I
 * ENTRIES =     4000                 PLOT       ---------I---------I---------
 * SATURATION  AT=          31                            I    10488I
 * SCALE  .,+,2,3,.,., A,B,         STATISTICS   ---------I---------I---------
 * STEP = 1.00     * MINIMUM=0.000                        I         I
```

1.5 HBOOK batch as the first step of the analysis

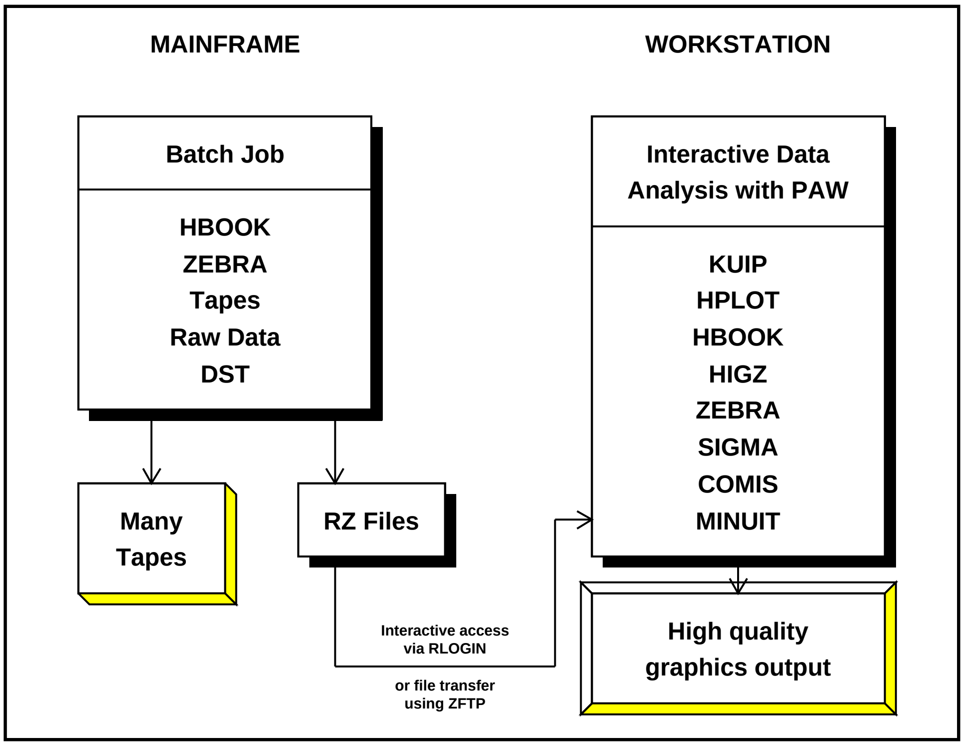


Figure 1.1: Schematic presentation of the various steps in the data analysis chain

Although it is possible to define histograms interactively in a PAW session, and then read the (many thousands of) events, in general for large data samples the relevant variables are extracted from the **Data Summary Files** or **DST**s and stored in **histograms** or an **Ntuple**. Histograms require to make a certain choice as to the range of values for the plotted parameter, because the **binning**, or the coarseness, of the distribution has to be specified when the histogram is defined (**booked**). Also only one- and two-dimensional histograms are possible, hence the correlations between various parameters can be difficult to study. Hence in many cases it is more appropriate to store the value of the important parameters for each event in an **Ntuple**. This approach preserves the correlation between the parameters and allows selection criteria to be applied on the (reduced) data sample at a later stage.

In general, the time consuming job of analysing all events available on tape is run on a mainframe or CPU server, and the important event parameters are stored in a Ntuple to allow further detailed study. For convenience the Ntuple can be output to disk for each run, and then at a later stage the Ntuples can be **merged** in order to allow a global interactive analysis of the complete data sample (see Figure 1.1).

A typical batch job in which data are analysed offline and some characteristics are stored in HBOOK is shown in Figure 1.2. HBOOK is initialised by a call to `HLIMIT`, which declares a length of 20000 words for the length of the `/PAWC/` dynamic store. Then the one- and two- dimensional histograms 110 and 210 are filled respectively according to the functions `HTFUN1` and `HTFUN2` and the histograms are output to a newly created file `HTEST.DAT`. The output generated by the program is shown in Figure 1.3.

```
      PROGRAM HTEST
      PARAMETER (NWPAWC=20000)
      COMMON/PAWC/H(NWPAWC)
      EXTERNAL HTFUN1,HTFUN2
*.------------------------------------------------------------
      CALL HLIMIT(NWPAWC)
*             Book histograms and declare functions
      CALL HBFUN1(100,'Test of HRNDM1',100,0.,1.,HTFUN1)
      CALL HBOOK1(110,'Filled according to HTFUN1',100,0.,1.,1000.)
      CALL HBFUN2(200,'Test of HRNDM2',100,0.,1.,40,0.,1.,HTFUN2)
      CALL HSCALE(200,0.)
      CALL HBOOK2(210,'Filled according to HTFUN2',100,0.,1.,40,0.,1.,30.)
*             Fill histograms
      DO 10 I=1,10000
         X=HRNDM1(100)
         CALL HFILL(110,X,0.,1.)
         CALL HRNDM2(200,X,Y)
         CALL HFILL(210,X,Y,1.)
  10  CONTINUE
*             Save all histograms on file HTEST.DAT
      CALL HRPUT(0,'HTEST.DAT','N')
      CALL HDELET(100)
      CALL HDELET(200)
      CALL HPRINT(0)
      END
      FUNCTION HTFUN2(X,Y)
*             Two-dimensional gaussian
      HTFUN2=HTFUN1(X)*HTFUN1(Y)
      RETURN
      END
      FUNCTION HTFUN1(X)
*             Constants for gaussians
      DATA C1,C2/1.,0.5/
      DATA XM1,XM2/0.3,0.7/
      DATA XS1,XS2/0.07,0.12/
*             Calculate the gaussians
      A1=-0.5*((X-XM1)/XS1)**2
      A2=-0.5*((X-XM2)/XS2)**2
      X1=C1
      X2=C2
      IF(ABS(A1).GT.0.0001)X1=C1*EXP(A1)
      IF(ABS(A2).GT.0.0001)X2=C2*EXP(A2)
*             Return function value
      HTFUN1=X1+X2
      RETURN
      END
```

Figure 1.2: Writing data to HBOOK with the creation of a HBOOK RZ file

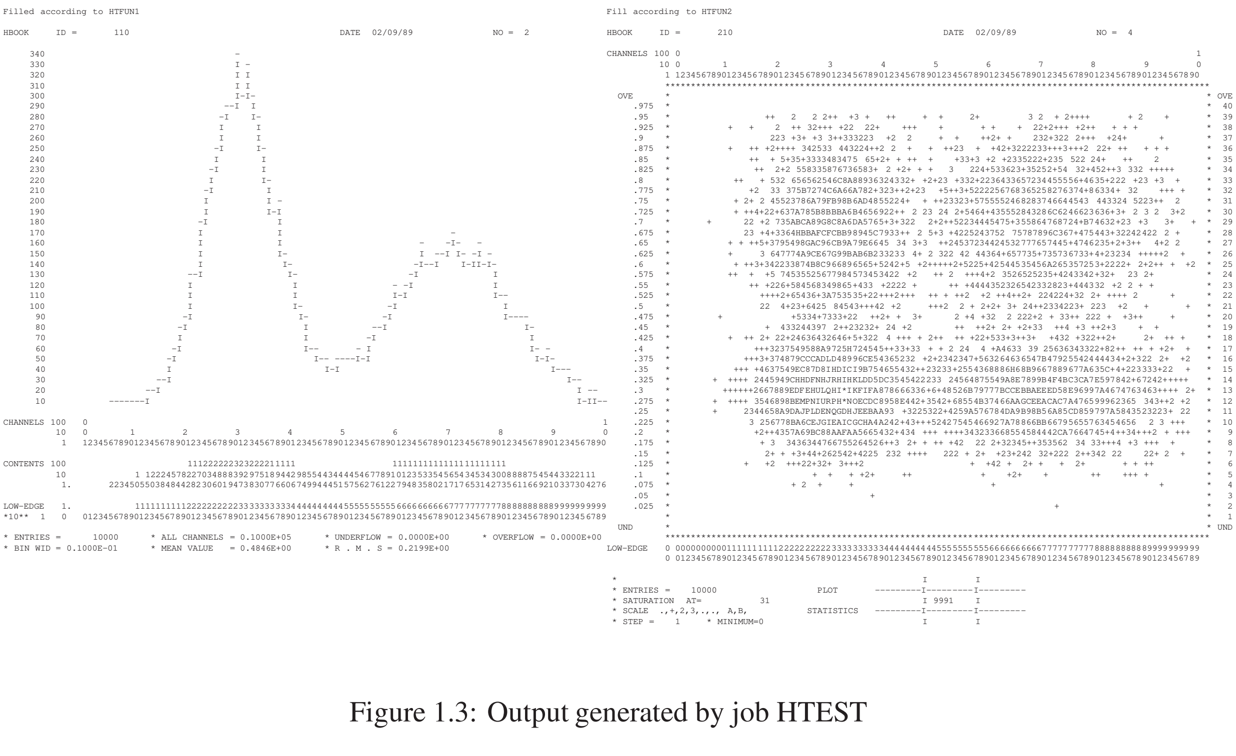


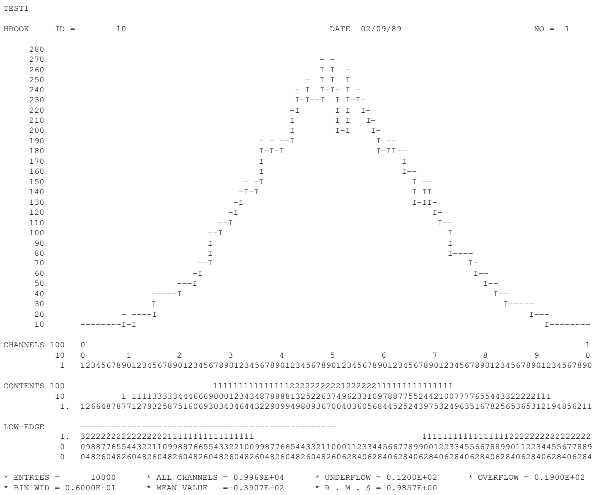
Figure 1.3: Output generated by job HTEST

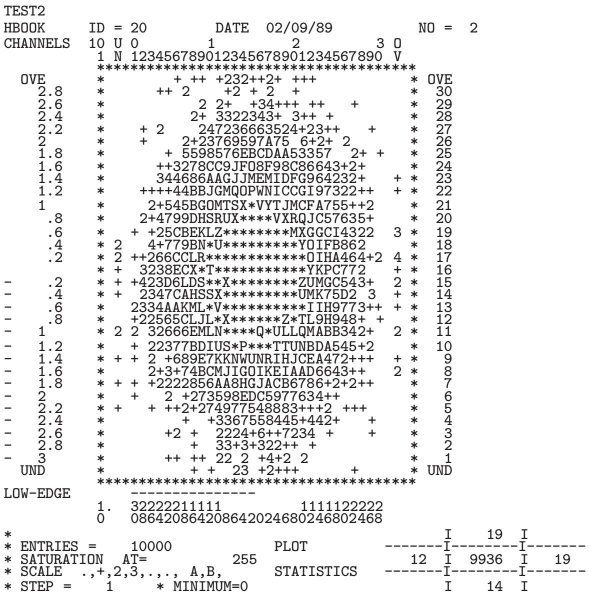
1.5.1 Adding some data to the RZ file

A second run using program HTEST1 below shows how to add some data to the HBOOK RZ file created in the job HTEST (Figure 1.2). After opening the file HTEST.DAT, created in the previous run, in update mode ('U' option) with the name EXAM2, a new directory NTUPLE is created, known as //EXAM2/NTUPLE as seen in the output of HLDIR command at the end of the output. One-dimensional (10) and two-dimensional (20) histograms and an Ntuple (30) are booked. Each Ntuple element or "event" is characterised by three **variables** (labelled 'X', 'Y' and 'Z'). The Ntuple data, when the initial size of 1000 words is exhausted, will be written to the directory on disk specified in the call to HBOOKN, i.e. //EXAM2/NTUPLE, and the data in memory are replaced with those newly read. A one- and a two-dimensional projection of X and X/Y are then made onto histograms 10 and 20 respectively, before they are printed and written on the HBOOK RZ file. At the end the **current** and **parent** directories are listed. The contents of the latter shows that the data written in the first job (HTEST) are indeed still present in the file under the top directory //EXAM2. The call to RZSTAT shows usage statistics about the RZ file.

Example of adding data to a HBOOK RZ file

```
      PROGRAM HTEST1
      PARAMETER (NWPAWC=20000)
      COMMON/PAWC/H(NWPAWC)
      DIMENSION X(3)
      CHARACTER*8 CHTAGS(3)
      DATA CHTAGS/'   X    ','   Y    ','   Z    '/
*.------------------------------------------------------
      CALL HLIMIT(NWPAWC)
*             Reopen data base
      LRECL = 0
      CALL HROPEN(1,'EXAM2','HTEST.DAT','U',LRECL,ISTAT)
      CALL HMDIR('NTUPLE','S')
      CALL HBOOK1(10,'TEST1',100,-3.,3.,0.)
      CALL HBOOK2(20,'TEST2',30,-3.,3.,30,-3.,3.,250.)
      CALL HBOOKN(30,'N-TUPLE',3,'//EXAM2/NTUPLE',
     +            1000,CHTAGS)
*
      DO 10 I=1,10000
         CALL RANNOR(A,B)
         X(1)=A
         X(2)=B
         X(3)=A*A+B*B
         CALL HFN(30,X)
  10  CONTINUE
*
      CALL HPROJ1(10,30,0,0,1,999999,1)
      CALL HPROJ2(20,30,0,0,1,999999,1,2)
      CALL HPRINT(0)
      CALL HROUT(0,ICYCLE,' ')
      CALL HLDIR(' ',' ')
      CALL HCDIR('\',' ')
      CALL HLDIR(' ',' ')
      CALL RZSTAT(' ',999,' ')
      CALL HREND('EXAM2')
      END
```






```
********************************************************
* NTUPLE ID=   30  ENTRIES=  10000   N-TUPLE           *
********************************************************
*  Var numb  *   Name    *    Lower     *    Upper     *
********************************************************
*      1     *    X      * -.422027E+01 * 0.386411E+01 *
*      2     *    Y      * -.411076E+01 * 0.378366E+01 *
*      3     *    Z      * 0.485187E-04 * 0.179518E+02 *
********************************************************


===> Directory : //EXAM2/NTUPLE
        30 (N)   N-TUPLE
        10 (1)   TEST1
        20 (2)   TEST2

===> Directory : //EXAM2
       100 (1)   Test of HRNDM1
       110 (1)   Filled according to HTFUN1
       200 (2)   Test of HRNDM2
       210 (2)   Fill according to HTFUN2


      NREC    NWORDS    QUOTA(%)  FILE(%)   DIR. NAME
       34      34066       .21       .21   //EXAM2/NTUPLE
       41      40438       .26       .26   //EXAM2
```

Figure 1.4: Adding data to a HBOOK RZ file

1.6 HPLOT interface for high quality graphics

hplot is a package of Fortran subroutines for producing hbook output suitable for graphic devices or in PostScript. It is designed to produce drawings and slides of a quality suitable for presentations at conferences and scientific publications. It does not produce all the numerical information of the HBOOK output routines. It is not restricted by the line printer's poor resolution and unique character sets but it uses the full graphics capabilities of the targeted output device.

HPLOT can access an HBOOK data structure and transform it into drawings using the HIGZ graphics package. Some of the available options are :

- Predefined ISO standard paper size (A4, A3, etc.), horizontal or vertical orientation, with suitable margins. Other sizes are also possible.
- Combination of several plots on the same page, either by windowing or superimposition, or both, with different symbols to distinguish them.
- Titles on the axes and text anywhere on the picture, using various fonts, containing, e.g., Greek or special characters.
- Three-dimensional surface representations for two-dimensional histograms (with hidden-line and hidden-surface removal).
- Colour (if the hardware allows it), hatching, grey levels,....

As a simple example of the use of HPLOT let us consider a program similar to the one in Figure 1.4. After opening a file on unit 10 to write the metafile output (Fortran OPEN statement), we book, then fill the Ntuple projections, and finally plot them. The call to HPLINT initialises HPLOT and HPLCAP redirects the metafile output to unit 10. The parameters given to HPLOT instruct the program to output all histograms in the current working directory to the metafile using "standard" option, while HPLEND closes the metafile. See the HPLOT user's guide [2] for more details. The result of the job and the resulting PostScript file can be compared to the "lineprinter" output in Figure 1.4.

Example of a simple HPLOT program

```
      PROGRAM HPTEST
      COMMON/PAWC/H(80000)
      DIMENSION X(3)
      CHARACTER*8 CHTAGS(3)
      DATA CHTAGS/'   X    ','   Y    ','   Z    '/
*.------------------------------------------------------------
      CALL HLIMIT(80000)
*             Reopen data base
      OPEN(UNIT=10,file='hplot.meta',form='formatted',status='unknown')
      CALL HBOOK1(10,'TEST1',100,-3.,3.,0.)
      CALL HBOOK2(20,'TEST2',30,-3.,3.,30,-3.,3.,250.)
      CALL HBOOKN(30,'N-TUPLE',3,' ',1000,CHTAGS)
*
      DO 10 I=1,10000
         CALL RANNOR(A,B)
         X(1)=A
         X(2)=B
         X(3)=A*A+B*B
         CALL HFN(30,X)
  10  CONTINUE
*
```

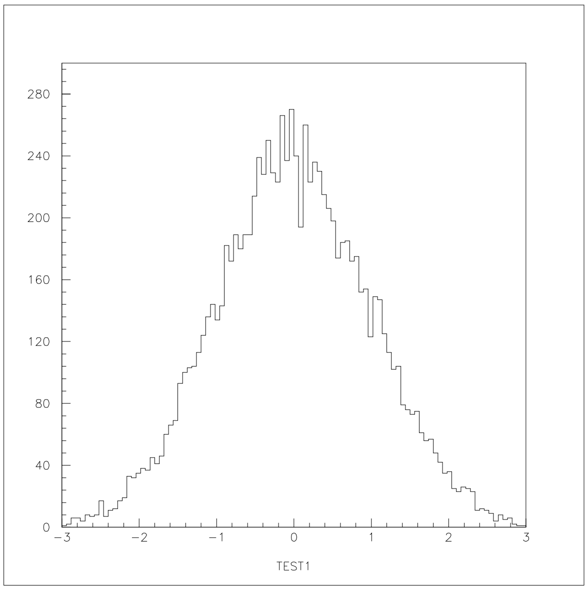
```
      CALL HPROJ1(10,30,0,0,1,999999,1)
      CALL HPROJ2(20,30,0,0,1,999999,1,2)
      CALL HPLINT(0)
      CALL HPLCAP(-10)
      CALL HPLOT(0,' ',' ',0)
      CALL HPLEND
      CALL HINDEX
      END
```

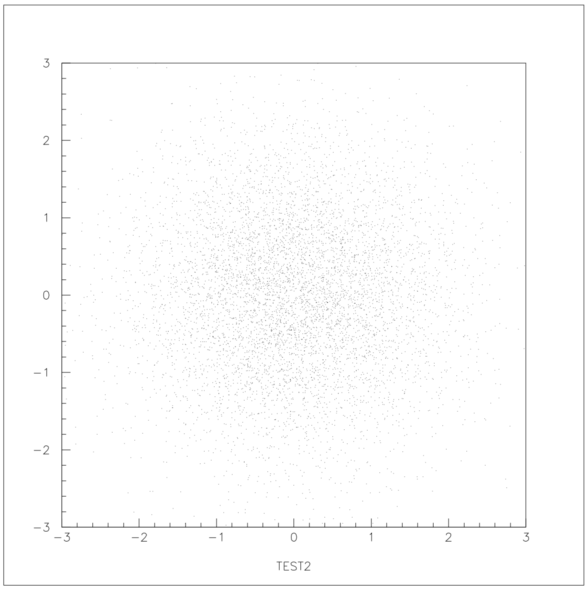
Output Generated

```
Version 1.13/05 of HIGZ started
..........................................................................................................
.                                                                                                        .
.   HBOOK   HBOOK  CERN    VERSION   4.13     HISTOGRAM AND PLOT INDEX                     06/02/92      .
.                                                                                                        .
..........................................................................................................
.                                                                                                        .
.  NO           TITLE             ID  B/C  ENTRIES DIM   NCHA     LOWER       UPPER       ADDRESS LENGTH .
.                                                                                                        .
..........................................................................................................
.                                                                                                        .
.                                                                                                        .
.   1  TEST1                      10  32    10000  1  X   100  -0.300E+01   0.300E+01       78388    144 .
.                                                                                                        .
.                                                                                                        .
.   2  TEST2                      20   8    10000  2  X    30  -0.300E+01   0.300E+01       78240    298 .
.                                                     Y    30  -0.300E+01   0.300E+01       77963    268 .
.                                                                                                        .
.   3  N-TUPLE                    30              N                                         77914     39 .
.                                                                                                        .
.                                                                                                        .
..........................................................................................................

 MEMORY UTILISATION
      MAXIMUM TOTAL SIZE OF COMMON /PAWC/           80000
```

Output generated by HPLOT on printer with graphics capabilities





Chapter 2: One and two dimensional histograms – Basics

2.1 Booking

2.1.1 One-dimensional case

```
CALL HBOOK1 (ID,CHTITL,NX,XMI,XMA,VMX)
```

Action: Books a one-dimensional histogram.

Input parameter description:

`ID`	histogram identifier, integer non zero
`CHTITL`	histogram title (character variable or constant up to 80 characters)
`NX`	number of channels
`XMI`	lower edge of first channel
`XMA`	upper edge of last channel
`VMX`	upper limit of single channel content (see below). `VMX=0.` means 1 word per channel (no packing).

Special values:

- If `XMA`≤`XMI`, origin and binwidth are calculated automatically, and one word is reserved per channel.
- Zero (0) is an illegal histogram identifier.
- If the histogram `ID` already exists it will be deleted and recreated with the new specifications. A warning message is printed.
- `VMX` is used to compute the number of bits to be allocated per histogram channel. If `VMX<1.` then one full word is reserved per channel. When filling a histogram with weights the latter are truncated to the nearest integer unless one full word is reserved per channel (i.e. `VMX = 0.`). Filling with negative weights will give meaningless results unless one word per channel has been allocated. Automatic calculation of limits (`XMA`≤`XMI`) forces one word per channel.

2.1.2 Two-dimensional case

```
CALL HBOOK2 (ID,CHTITL,NX,XMI,XMA,NY,YMI,YMA,VMX)
```

Action: Books a two-dimensional histogram.

Input parameter description:

`ID`	histogram identifier, integer
`CHTITL`	histogram title (character variable or constant up to 80 characters)
`NX`	number of channels in X

XMI	lower edge of first X channel
XMA	upper edge of last X channel
NY	number of channels in Y
YMI	lower edge of first Y channel
YMA	upper edge of last Y channel
VMX	maximum population to store in 1 cell.

Remarks:

- Similar to HBOOK1, apart from automatic binning.
- By default, a 2-dimensional histogram will be printed as a scatterplot.
- If the option `TABL` is selected via `CALL HIDOPT(ID,'TABL')` the 2-dimensional histogram will be printed as a table.
- When editing the table, the number of columns `NCOL` used to write the content of one cell depends on the value of `VMX` as follows `NCOL = ALOG10(VMX) + 2`. When `VMX` is zero, the contents is printed in 10 columns in floating point format (including sign). If necessary, all contents are multiplied by a power of 10, this number being reported at the bottom of the table.

2.2 Filling

```
CALL HFILL (ID,X,Y,WEIGHT)
```

Action: Fills a 1-dimensional or a 2-dimensional histogram. The channel which contains the value X and for two-dimensionals the cell that contains the point `(X,Y)`, gets its contents increased by `WEIGHT`. All booked projections, slices, bands, are filled as well.

Input parameter description:

ID	histogram identifier
X	value of the abscissa
Y	value of the ordinate
WEIGHT	event weight (positive or negative)

Remarks:

- If one full word per channel is reserved at booking time, `WEIGHT` is taken with its floating point value. In case of packing (i.e. more than one channel per word), `WEIGHT` must be positive and will be truncated to the nearest integer (`WEIGHT<0` will give meaningless results)
- See section 4.2 on page 59 for alternative filling routines.

2.3 Editing

CALL **HISTDO**

Action: Outputs all booked histograms to the line printer. An index is printed at the beginning specifying the characteristics and storage use of each histogram.

Remark:

- If a histogram is empty, a message declares this condition, and the histogram is not printed.

CALL **HPRINT** (ID)

Action: Outputs a given histogram to the line printer.

`ID`	Histogram identifier.

Remarks:

- `CALL HPRINT(0)` is equivalent to `CALL HISTDO` apart from not printing the index
- When a histogram is empty a message declares this condition and the histogram is not printed.

Some available booking options are shortly listed below. For a full description see chapter 4.

- Creation of histograms with non-equidistant bins
- Creation of profile histograms
- Rounded scale
- Projections and slices of 2-dimensional histograms
- More statistical information
- Comprehensive booking and filling with user-supplied functions of one or two real variables.
- Dynamic creation of ordinary Fortran arrays (`HARRAY`)

2.4 Copy, rename, reset and delete

CALL **HCOPY** (ID1,ID2,CHTITL)

Action: Generates histogram `ID2` as a copy of `ID1`, apart from the title.

Input parameter description:

`ID1`	existing identifier
`ID2`	non existing identifier
`CHTITL`	new title. `CHTITL=' '` means that the old title is kept.

```
CALL HCOPYR (ID1,ID2,CHTITL,IBINX1,IBINX2,IBINY1,IBINY2,CHOPT)
```

Action: Generates histogram ID2 as a copy of a range of the channels of ID1, and optionally copies the stored errors on the channels. If ID2 already exists, it is deleted and re-created.

The new histogram is created with the same bin width in X (and Y, for 2-D histograms) as in the original histogram. The bin number range is allowed to exceed the range of the original histogram, in which case the new histogram will contain bins with zero contents. This possibility is to allow users to copy a histogram into one of a larger scale.

Input parameter description:

ID1	Existing identifier.
ID2	New identifier.
CHTITL	New title. CHTITL=' ' means that the old title is kept.
IBINX1	Bin in X from which to start the channel copy.
IBINX2	Bin in X on which to end the channel copy.
IBINY1	Bin in Y from which to start the channel copy (2-D histograms only).
IBINY2	Bin in Y on which to end the channel copy (2-D histograms only).
CHOPT	CHOPT='E' causes the stored errors on each bin to be be copied as well.

```
CALL HRENID (IDOLD,IDNEW)
```

Action: Renames a histogram or Ntuple.

Input parameter description:

IDOLD	Old histogram identifier.
IDNEW	New histogram identifier.

```
CALL HRESET (ID,CHTITL)
```

Action: Resets the contents of all channels of a histogram (and its projections) or Ntuple to zero and changes optionally the title.

Input parameter description:

ID	identifier of a histogram. ID=0 resets all existing histogram contents.
CHTITL	new title. CHTITL=' ' means that the old title is kept.

```
CALL HDELET (ID)
```

Action: Deletes a histogram and releases the corresponding storage space.

Input parameter description:

ID	identifier of a histogram. ID=0 deletes all existing histograms.

See section 1.4 in the introductory chapter for a simple example of how to book, fill and print histograms.

Chapter 3: Ntuples

To introduce the concept of Ntuples, let us consider the following example. A Data Summary Tape (DST) contains 10000 events. Each event consists of many variables (say `NVAR=200`) for which we would like to make some distributions according to various selection criteria.

One possibility is to create and fill 200 histograms on an event-by-event basis while reading the DST. An alternative solution, particularly interesting during interactive data analysis with the data presentation system `paw` [3], is to create one Ntuple. Instead of histograming the 200 variables directly, and therefore losing the exact values of the variables for each event and their correlations, the variables are first stored in an Ntuple. (One can of course fill the histograms at the same time!) An Ntuple is like a table where the 200 variables mentioned above are the columns and each event is a row. The storage requirement is proportional to the number of columns in one event and can become significant for large event samples. An Ntuple can thus be regarded as a standard way of storing a DST.

Once the events are stored in this form, it becomes easy, in particular with `paw`, to make 1- or more-dimensional projections of any of the `NVAR` variables of the events and to change the selection mechanisms, or the binning and so on. Before running the system on a large number of events, the selection mechanisms can be rapidly tested on a small sample.

3.1 CWN and RWN – Two kinds of Ntuples

In a *Row-Wise-Ntuple* (**RWN**) the elements of each row, usually corresponding to an individual event, are stored contiguously in an HBOOK RZ file. This storage method is similar to that of a conventional DST, where events are stored sequentially and it is particularly suited for small Ntuples (up to a few Mbytes), with only a few columns. You can even use an RWN for larger Ntuples (up to about 20 Mbytes) when you know you want to reference almost all columns in your query commands. A RWN should not be used if there are more than about 100 columns, or when your queries only references a small number of columns. A RWN can only contain floating point data. It is created with `HBOOKN` and filled with `HFN`. Routines `HGN`, `HGNF` are used to retrieve information about one row.

Figure 3.1 shows schematically how a RWN is laid out in memory, row after row. The buffer size in memory `NWBUFF` is specified as the primary allocation parameter `NWBUFF` of the `HBOOKN` routine. Of course, you must have reserved sufficient space in the `/PAWC/` common when calling the HBOOK initialization routine `HLIMIT`. The lower line shows how the information is written to an RZ file. The length of the input/output buffer `LRECL` is specified as an argument of the routine `HROPEN`. It is evident that, if you have a small Ntuple and a lot of memory, you can fit the complete Ntuple in memory, thus speeding up the Ntuple operations.

In a *Column-Wise-Ntuple* (**CWN**) the elements of each column are stored sequentially. Data in such an Ntuple can be accessed in a much more flexible and powerful manner than for a RWN. The CWN storage mechanism has been designed to substantially improve access time and facilitate compression of the data, thereby permitting much larger event samples (several hundreds of Mbytes) to be interactively processed, e.g. using `paw`. Substantial gains in processing time can be obtained, especially if your queries only reference a few columns. A CWN is not limited to floating point data, but can contain all basic data types (real, integer, unsigned integer, logical or character). A CWN is created with routines `HBNT`, `HBNAME` or `HBNAMC` and filled with `HFNT` and `HFNTB`. Information about one row/block/column can be retrieved with routines `HGNT`, `HGNTB`, `HGNTV` and `HGNTF`.

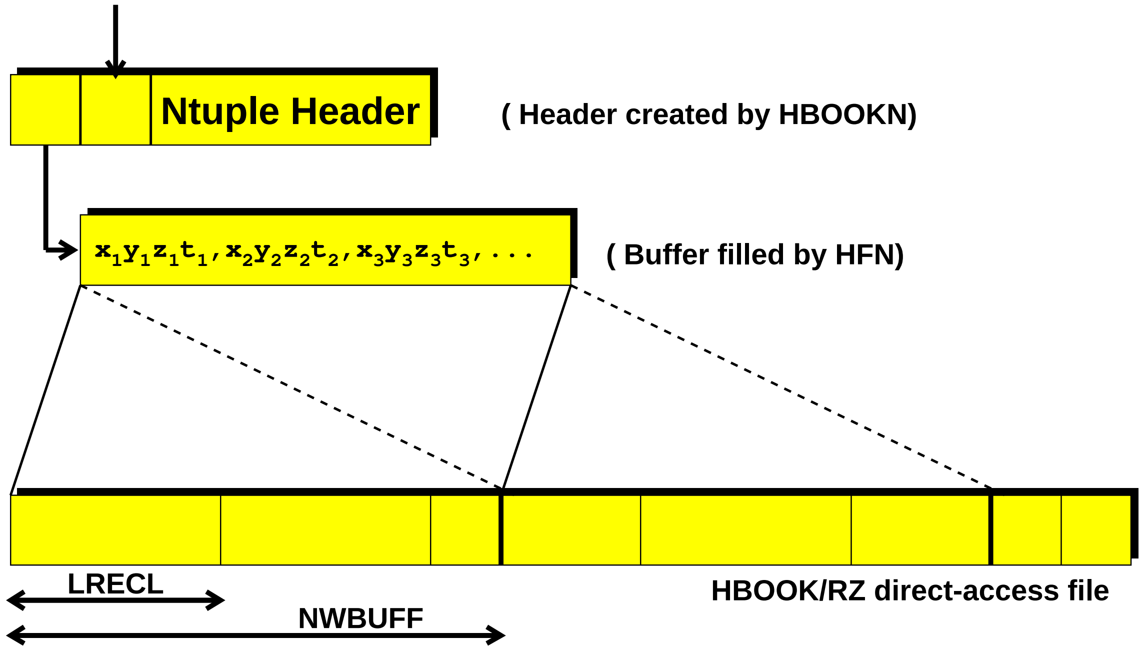


Figure 3.1: Schematic structure of a RWN Ntuple

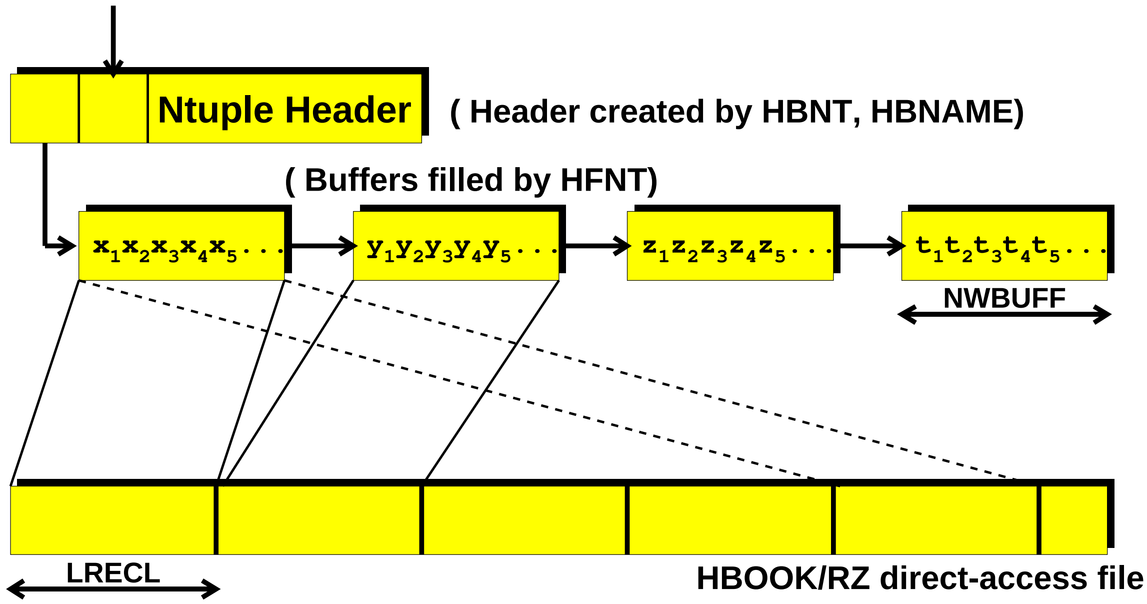


Figure 3.2: Schematic structure of a CWN Ntuple

Figure 3.2 shows the layout of a CWN Ntuple. The buffer size for each of the columns NWBUFF was set equal to the record length LRECL (defined with routine HROPEN). A CWN requires a large value for the length of the common /PAWC/, in any case larger than the number of columns times the value NWBUFF, i.e. NWPAWC>NWBUFF*NCOL. You can, however, expect important performance improvements by setting the buffer size NWBUFF equal to a multiple of the record length LRECL (via routine HBSET).
In both figures, x_i, y_i, z_i, t_i, etc. represent the columns of event i.

3.2 Row-Wise-Ntuples (RWN)

3.2.1 Booking a RWN

`CALL` **HBOOKN** `(ID,CHTITL,NVAR,CHRZPA,NWBUFF,CHTAGS)`

Action: Books a RWN in memory or with automatic overflow on an `RZ` file. Only single precision floating point numbers (`REAL*4` on 32 bit machines) can be stored, no data compression is provided.

Input parameters:

`ID` Identifier of the Ntuple.

`CHTITL` Character variable containing the title associated with the Ntuple.

`NVAR` Number of variables per event (`NVAR`≤`512`)

`CHRZPA` Character variable containing the path name of a RZ file onto which the contents of the Ntuple can overflow.

- `' '` **Memory resident Ntuples:**
  A bank of `NWBUFF` words is created. Further banks of the same size are added in a linear chain should additional space be required at filling time.
- `'RZTOP'` **Disk resident Ntuples:** (recommended)
  A disk resident Ntuple is created if the `CHRZPA` argument specifies the top directory name of an existing RZ file that has already been opened with `HROPEN` or `HRFILE`. A bank of length `NWBUFF` is created, as in the case of memory resident Ntuples. However, each time the bank becomes full it is automatically flushed to the RZ file, rather than creating additional banks in memory.

`NWBUFF` Number of words for the primary allocation for the Ntuple.

`CHTAGS` Character array of length `NVAR`, providing a short name (up to eight characters) tagging scheme for each variable.

Example of the declaration of a memory resident RWN

```
      CHARACTER*2 CHTAGS(5)
      DATA CHTAGS/'Px','Py','Pz','Q2','NU'/
*
      CALL HBOOKN(10,'My first Ntuple',5,' ',1000,CHTAGS)
```

3.2.2 Filling a RWN

`CALL` **HFN** `(ID,X)`

Action: Fills a RWN.

Input parameters:

`ID` Identifier of the Ntuple.

`X` Array of dimension `NVAR` containing the values for the current event.

Memory resident Ntuples

When a RWN is booked, HBOOK reserves space in memory in which to store the data, as specified by the NWBUFF argument of routine HBOOKN. As the RWN is filled by a call to HFN, this space will be successively used until full. At that time, a new memory allocation will be made and the process continues.

If this data is then written to disk, it appears as one enormous logical record. In addition, it most cases the last block of data will not be completely filled thus wasting space.

If one tries to reprocess this RWN at a later date, e.g. with paw, there must be enough space in memory to store the entire Ntuple. This often gives rise to problems and so the following alternative method is recommended.

Circular buffer

In an online environment you often want to have the last N events inside a buffer, so that the experiment can be monitored continuously. To make it easier to handle this case, you can use routine HFNOV, which fills a circular buffer in memory with RWN events, and when the buffer is full, overwrites the oldest Ntuple.

```
CALL HFNOV (ID,X)
```

Action: Fills a circular buffer with RWNs.

Input parameters:

ID Identifier of the Ntuple.

X Array of dimension NVAR containing the values for the current event.

Disk resident Ntuples

Prior to booking the RWN, a new HBOOK RZ file is created using HROPEN. The top directory name of this file is passed to routine HBOOKN when the Ntuple is booked.

Filling proceeds as before but now, when the buffer in memory is full, it is written to the HBOOK file and then reused for the next elements of the Ntuple. This normally results in a more efficient utilisation of the memory, both when the Ntuple is created and when it is reprocessed.

Recommended way of creating a RWN

```
      PROGRAM TEST
      PARAMETER (NWPAWC = 15000)
      COMMON/PAWC/PAW(NWPAWC)
      CHARACTER*8 CHTAGS(5)
      DIMENSION EVENT(5)
      EQUIVALENCE (EVENT(1),X),(EVENT(2),Y),(EVENT(3),Z)
      EQUIVALENCE (EVENT(4),ENERGY),(EVENT(5),ELOSS)
      DATA CHTAGS/'X','Y','Z','Energy','Eloss'/
*
      CALL HLIMIT(NWPAWC)
      CALL HROPEN(1,'EXAMPLE','EXAMPLE.DAT','N',1024,ISTAT)
      IF(ISTAT.NE.0)GO TO 99
*
      CALL HBOOKN(10,'A Row-Wise-Ntuple',5,'//EXAMPLE',5000,CHTAGS)
```

```
      CALL HBOOK1(100,'Energy distribution',100,0.,100.,0.)
*
      DO 10 I=1,10000
         CALL RANNOR(X,Y)
         Z=SQRT(X*X+Y*Y)
         ENERGY=50. + 10.*X
         ELOSS=10.*ABS(Y)
         CALL HFN(10,EVENT)
         CALL HFILL(100,ENERGY,0.,1.)
 10   CONTINUE
*
      CALL HROUT(0,ICYCLE,' ')
      CALL HREND('EXAMPLE')
*
 99   CONTINUE
      END
```

When the Ntuple is filled, routine HFN will automatically write the buffer to the directory in the RZ file, which was specified in the call to HBOOKN (the top directory //EXAMPLE in the example above). If the current directory (CD) is different, HFN will save and later automatically restore the CD.

The Ntuple created by the program shown above can be processed by paw as follows.

Reading an RWN in a PAW session

```
PAW > Histo/file  1  example.dat
PAW > Histo/plot 100
PAW > Ntuple/plot 10.energy
PAW > Ntuple/plot 10.eloss  energy<50
PAW > Ntuple/plot 10.eloss%energy  x<2.and.sqrt(z)>1
```

By default HROPEN creates a file that can be extended up to 32000 blocks, i.e. 128 Mbytes for a record length LREC of 1024 words. If one wishes to create very large Ntuples, one should make two changes to the above procedure.

- A large value should be used for the record length of the file, e.g. 8192 words (the maximum on most machines). **N.B. the maximum record length on VMS systems is 8191 words. If access mode RELATIVE is used, the maximum is 4095 words.** This remark does not apply to a CWN, as described later.
- Option Q on HROPEN should be used to override the default number of records allowed.

This can be achieved as by changing the previous call to HROPEN as follows:

Writing very large Ntuple files

```
              COMMON/QUEST/IQUEST(100)
              CALL HLIMIT(150000)
*
*     Create HBOOK file with the maximum record length (32756 bytes)
*     and maximum number of records (65000)
*
              IQUEST(10) = 65000
              CALL HROPEN(1,'EXAMPLE','EXAMPLE.DAT','NQ',8192,ISTAT)
              IF(ISTAT.NE.0)GO TO 99
```

3.3 More general Ntuples: Column-Wise-Ntuples (CWN)

A CWN supports the storage of the following data types: floating point numbers (`REAL*4` and `REAL*8`), integers, bit patterns (unsigned integers), booleans and character strings.

Data Compression

Floating point numbers, integers and bit patterns can be packed by specifying a range of values or by explicitly specifying the number of bits that should be used to store the data. Booleans are always stored using one bit. Unused trailing array elements will not be stored when an array depends on an index variable. In that case only as many array elements will be stored as specified by the index variable.

For example, the array definition `NHITS(NTRACK)` defines `NHITS` to depend on the index variable `NTRACK`. When `NTRACK` is 16, the elements `NHITS(1..16)` are stored, when `NTRACK` is 3, only the elements one to three (`NHITS(1..3)`) are stored, etc.

Storage Model

Column wise storage allows direct access to any column in the Ntuple. Histogramming one column from a 300 column CWN requires reading only 1/300 of the total data set. However, this storage scheme requires one memory buffer per column as opposed to only one buffer in total for an RWN. By default the buffer length is 1024 words, in which case a 100 column Ntuple requires 409600 bytes of buffer space. In general, performance increases with buffer size. Therefore, one should tune the buffer size (using routine `HBSET`) as a function of the number of columns and the amount of available memory. Highest efficiency is obtained when setting the buffer size equal to the record length of the RZ HBOOK file (as specified in the call to `HROPEN`). A further advantage of column wise storage is that a CWN can easily be extended with one or more new columns.

Columns are logically grouped into blocks (physically, however, all columns are independent). Blocks allow users to extend a CWN with private columns or to group relevant columns together. New blocks can even be defined after a CWN has been filled. The newly created blocks can be filled using routine `HFNTB`. For example, a given experiment might define a number of standard Ntuples. These would be booked in a section of the code that would not normally be touched by an individual physicist. However, with a CWN a user may easily add one or more blocks of information as required for their particular analysis.

Note that arrays are treated as a single column. This means that a CWN will behave like a RWN, with the addition of data typing and compression, if only one array of `NVAR` elements is declared. This is not recommended as one thereby loses the direct column access capabilities of a CWN.

Performance

Accessing a relatively small number of the total number of defined columns results in a huge increase in performance compared to a RWN. However, reading a complete CWN will take slightly longer than reading a RWN due to the overhead introduced by the type checking and compression mechanisms and because the data is not stored sequentially on disk. The performance increase with a CWN will most clearly show up when using `paw`, where one typically histograms one column with cuts on a few other columns. The advantages of having different data types and data compression generally outweighs the performance penalty incurred when reading a complete CWN.

3.3.1 Booking a CWN

The booking is performed in two stages. Firstly, a call to `HBNT` is made to declare the Ntuple identifier and title. Secondly, one or more calls are made to `HBNAME` or `HBNAMC` to describe the variables that are to be stored in the Ntuple. Routine `HBNAMC` is used to define `CHARACTER` variables, while all other variable types are defined with routine `HBNAME`.

```
CALL HBNT (ID,CHTITL,CHOPT)
```

Action: Books a CWN.

Input parameters:

`ID` Identifier of the Ntuple.

`CHTITL` Character variable specifying the title associated to the Ntuple.

`CHOPT` Character variable specifying the desired options.

- `' '` for disk resident Ntuples (default).
- `'D'` idem as `' '`.
- `'M'` for memory resident Ntuples.

The CWN will be stored in the current HBOOK directory. The variables to be stored in the Ntuple will be specified with routine `HBNAME` or `HBNAMC` described below.

When the CWN will be filled with `HFNT`, the memory buffers associated with each column will be written to the file and directory corresponding to the current working directory when `HBNT` was called. Remember that when routine `HROPEN` is called, the current working directory is automatically set to the top directory of that file. It is therefore convenient to call `HBNT` immediately after `HROPEN`. If this was not the case, routine `HCDIR` must be called prior to `HBNT` to set the current working directory. When the Ntuple has been filled (via calls to `HFNT`) the resident buffers in memory as well as the Ntuple header must be written to the file with a call to `HROUT`. Before calling `HROUT`, the current working directory must be set to the current directory when `HBNT` was called.

```
CALL HBSET (CHOPT,IVAL,IERR*)
```

Action: Set global Ntuple options.

Input parameters:

`CHOPT` Character variable specifying the parameter to set.

- `'BSIZE'` Set the buffer size. For each variable (i.e. column) a buffer of `BSIZE` words is created in memory. The default for `BSIZE` is 1024.

`IVAL` Value for the parameter specified with `CHOPT`.

Output parameters:

`IERR` Error return code (=0 means no errors).

If the total memory in /PAWC/, allocated via HLIMIT is not sufficient to accomodate all the column buffers of BSIZE words, then HBNT will automatically reduce the buffer size in such a way that all buffers can fit into memory. It is strongly recommended to allocate enough memory to /PAWC/ in such a way that each column buffer is at least equal to the block size of the file. A simple rule of thumb in the case of no data compression is to have NWPAWC>NCOL*LREC, where NWPAWC is the total number of words allocated by HLIMIT, LREC is the block size of the file in machine words as given in the call to HROPEN and NCOL is the number of columns.

3.3.2 Describing the columns of a CWN

```
CALL HBNAME  (ID, CHBLOK, VARIABLE, CHFORM)
```

```
CALL HBNAMC  (ID, CHBLOK, VARIABLE, CHFORM)
```

Action: Describe the variables to be stored in a CWN (non-character and character variables, respectively).

Input parameters:

ID	Identifier of the Ntuple as in the call to HBNT.
CHBLOK	Character variable of maximum length 8 characters specifying the name by which the block of variables described by CHFORM is identified.
VARIABLE	The first variable that is described in CHFORM. Variables must be in common blocks but may not be in a ZEBRA bank. For example, given the common block CEXAM described below, one would call HBNAME with the argument IEVENT. In the case of character variables, the routine HBNAMC must be used. In all other cases one should use HBNAME.
CHFORM	Can be either a character string describing the variables to be stored in block CHBLOK or: '$CLEAR' To clear the addresses of all variables in the Ntuple. '$SET' To set the addresses in which to write the values of all variables in block CHBLOK. The last two forms are used before reading back the Ntuple data using HGNT, HGNTB, HGNTV or HGNTF. See also HUWFUN.

With CHFORM the variables, their type, size and, possibly, range (or packing bits) can all be specified at the same time. **Note however that variable names should be unique, even when they are in different blocks**.

The routine HNFORM (see below) can be used to ease the task of generating the CHFORM character string.

In the simplest case CHFORM corresponds to the COMMON declaration. For example:

```
COMMON /CEXAM/ IEVENT, ISWIT(10), IFINIT(20), NEVENT, NRNDM(2)
```

can be described by the following CHFORM:

```
CHFORM = 'IEVENT, ISWIT(10), IFINIT(20), NEVENT, NRNDM(2)'
```

in this case the Fortran type conventions are followed and the default sizes are taken. Note that to get a nice one-to-one correspondance between the COMMON and the CHFORM statements the dimensions of the variables are specified in the COMMON and not in a DIMENSION statement.

The default type and size of a variable can be overridden by extending the variable name with :<t>*<s>:

<t>	type of variable	<s> values	default	routine
R	floating-point	4, 8	4	HBNAME
I	integer	4, 8	4	HBNAME
U	unsigned integer	4, 8	4	HBNAME
L	logical	4	4	HBNAME
C	character	[4≤s≤32] (multiple of 4)	4	HBNAMC

Packing variables in a CWN

Significant data storage savings can be achieved in the Ntuple when the range of a type U, I or R variable is known. In such cases the number of bits required to store all possible values of the variable is calculated by HBOOK, and the data suitably packed. For example, an integer run number, IRUN, which takes values from 8000 to 8007 should be specified as IRUN[8000,8007], and HBOOK will automatically use 3 bits to store the variable in the resulting Ntuple. By the same token, if the variable is known to only require a certain number of bits, then this should also be indicated in CHFORM by adding that number after the type specification using :<b> for types U and I and :<b>:[<min>,<max>] for type R. For example, if IRUN takes values between 0 and 10, then the declaration should be IRUN:I*4:4 (4 bits are allocated). Note that the type declaration simply describes how the variable is stored in memory when the HBOOK program is run, and is not necessarily a description of its size in the resulting Ntuple.

Floating-points are packed into an integer using:

```
IPACK = ((R - <min>)/(<max> - <min>)*(2**<b> - 1) + 0.5
```

When the bit-packing specifier :<b>... is not given, HBOOK will store the variable using the number of bytes given by <s> or the default (see the table above for a list of defaults for each type).

In case the default type and size of a variable should be used, the packing bits can be specified as ::<b>....

If the bit-packing specifier is given, then it must be in the range 1≤b≤8*<s>, where <s> either appears in the CHFORM declaration, or is the assumed default.

Logical variables are always stored in 1 bit by HBOOK.

Alignment of variables declared in CHFORM

Variables declared in CHFORM must always be aligned on a word boundary. In other words, all variables (including character strings) must be declared in the calling program with alength that is a multiple of 4 bytes. Character variable *names* (not their contents) are limited to a maximum of 32 characters.

Variable length Ntuple rows

Variable-length Ntuple rows and looping over array components are also supported to optimize Ntuple storage and Ntuple plotting. Variable row length occurs when arrays in the Ntuple depend on an index variable which varies.

Example of a variable row length CWN definition

```
      PARAMETER (MAXTRK = 100, MAXHIT = 300)
      COMMON /CMTRK/ NTRACK, NHITS(MAXTRK), PX(MAXTRK), PY(MAXTRK),
     +               PZ(MAXTRK), XHITS(MAXHIT,MAXTRK), YHITS(MAXHIT,MAXTRK),
     +               ZHITS(MAXHIT,MAXTRK)
      CALL HBNAME(ID,'VARBLOK2',NTRACK,
     +           'NTRACK[0,100], NHITS(NTRACK)[0,300],'//
     +           'PX(NTRACK), PY(NTRACK), PZ(NTRACK), XHITS(300,NTRACK),'//
     +           'YHITS(300,NTRACK), ZHITS(300,NTRACK)')
```

In this example the number of elements to store in one Ntuple row depends on the number of tracks, `NTRACK`. The call to `HBNAME` declares `NTRACK` to be an index variable and that the size of the Ntuple row depends on the value of this index variable.

Ranges of index variables in a CWN

The range of an index variable is specified using `[<l>,<u>]`, where `<l>` is the lower and `<u>` the upper limit of the arrays using this index variable. In the above example the lower limit of `NTRACK` is 0 and the upper limit is 100 (`= MAXTRK`). While filling a CWN HBOOK can also easily test for array out-of-bound errors since it knows the range of `NTRACK`.

Only the last dimension of a multi-dimensional array may be variable and the index variable must be specified in the block where it is used. Array lower bounds must, just like the lower range of the index variable, be 0.

Multiple calls to `HBNAME`

`HBNAME` may be called more than once per block as long as no data has been stored in the block. New blocks can be added to an Ntuple at any time, even after filling has started, whereas existing blocks may only be extended before filling has started.

3.3.3 Creating `CHFORM` dynamically

CALL **HNFORM** (CHFORM,CHNAME,LDIM,CHTYPE,XLOW,XHIGH)

Action: Assists with the formation of the character string `CHFORM`.

Input parameters:

`CHFORM` The character string to be started or appended to. The string should be declared of sufficient length in the calling routine such that it can hold the fully expanded specifications of the Ntuple variables.

`CHNAME` Character variable specifying the name of the variable to be added to `CHFORM`. If the variable is dimensioned then `CHNAME` should contain the dimension specification in brackets, as usual. For dimension spcifications that are to be computed at run time, the `LDIM` argument is used, and a `*` used as a placeholder in the dimension specification for replacement by `HNFORM` at run time. See the examples.

LDIM Dimension(s) of the variable. If the variable in CHNAME is not dimensioned, or its dimensions are hard-coded in CHNAME, then LDIM should be set to 0. If there is one * placeholder in the dimension specification in CHNAME then LDIM should be set to the value of that dimension. For more than one placeholder, LDIM should be an integer array of appropriate size. See the examples.

CHTYPE A character variable specifying the type and bit-packing to be used for the variable in CHNAME. Possible values for the type are [R,I,U,L,C][*[4..32]]. The bit-packing number should appear after a ":".

XLOW The lowest value that the variable in CHNAME may take. This may be specified as either a real or integer value.

XHIGH The highest value that the variable in CHNAME may take. If XHIGH is less than or equal to XLOW, then no limits will be encoded by CHFORM.

The following example shows how HNFORM may be used to aid the creation of an Ntuple:

Example of booking an Ntuple with HNFORM and HBNAME

```
      PARAMETER (MAXTRK = 100, MAXHIT = 300)
      COMMON /CMTRK/ NTRACK, NHITS(MAXTRK), PX(MAXTRK), PY(MAXTRK),
     +               PZ(MAXTRK), XHITS(MAXHIT,MAXTRK), YHITS(MAXHIT,MAXTRK),
     +               ZHITS(MAXHIT,MAXTRK)
      CHARACTER*500 CHFORM

      CHFORM(:) = ' '
      CALL HNFORM(CHFORM,'NTRACK',0,' ',0.,REAL(MAXTRK))
      CALL HNFORM(CHFORM,'NHITS(NTRACK)',0,' ',0.,REAL(MAXHIT))
      CALL HNFORM(CHFORM,'PX(NTRACK)',0,' ',0.,0.)
      CALL HNFORM(CHFORM,'PY(NTRACK)',0,' ',0.,0.)
      CALL HNFORM(CHFORM,'PZ(NTRACK)',0,' ',0.,0.)
      CALL HNFORM(CHFORM,'XHITS(*,NTRACK)',MAXHIT,' ',0.,0.)
      CALL HNFORM(CHFORM,'YHITS(*,NTRACK)',MAXHIT,' ',0.,0.)
      CALL HNFORM(CHFORM,'ZHITS(*,NTRACK)',MAXHIT,' ',0.,0.)

      LFORM = INDEX(CHFORM,' ')-1

      CALL HBNAME(ID,'VARBLOK2',NTRACK,CHFORM(:LFORM))
```

Alternative way of booking a CWN

CALL **HBOOKNC** (ID,CHTITL,NVAR,BLOCK,TUPLE,CHTAGS)

Action: Provides a way to define a CWN similar to HBOOKN for a RWN.

Input parameters:

ID Identifier of the CWN. If it does not already exist, it is created.

CHTITL Character variable specifying the name of the Ntuple (not used if it already exists).

`NVAR` Number of variables per event (maximum 200).

`BLOCK` Name of the block inside the CWN(default is `'Block1'`.

`TUPLE` Array of dimension `NVAR` that will contain values at filling time.

`CHTAGS` Character array of length `NVAR`, providing a short name (up to eight characters) tagging scheme for each variable.

3.3.4 Filling a CWN

```
CALL HFNT (ID)
```

Action: Fill a CWN.

Input parameter:

`ID` Identifier of the CWN.

```
CALL HFNTB (ID,CHBLOK)
```

Action: Fill the named block `CHBLOK` in a CWN.

Input parameters:

`ID` Identifier of the Ntuple.

`CHBLOK` Character variable specifying the block that is to be filled.

```
CALL HPRNT (ID)
```

Action: Print the definition of the CWN `ID` as defined by the calls to `HBNAME` and/or `HBNAMC`.

Input parameter:

`ID` Identifier of the CWN.

Recovery procedure

The Ntuple header, containing the essential definitions associated with an Ntuple, are now written to the output file when the first buffer is written. If the job producing the Ntuple does not terminate in a clean way (i.e. the job crashes or you forgot to call `HROUT`), it is now possible to rebuild the Ntuple header from the information available in the file. Note, however, that the events corresponding to the last Ntuple buffer in memory are lost.

```
CALL HRECOV (ID,CHOPT)
```

Action: Recover the information associated with a CWN.

Input parameters:

`ID` Identifier of the CWN.

`CHOPT` Character variable specifying the option desired. At present Not used at present; `' '` should be specified

Example of saving contents of common variables in an Ntuple

```
      COMMON/GCFLAG/IDEBUG,IDEMIN,IDEMAX,ITEST,IDRUN,IDEVT,IEORUN
     +        ,IEOTRI,IEVENT,ISWIT(10),IFINIT(20),NEVENT,NRNDM(2)

      COMMON/GCTRAK/VECT(7),GETOT,GEKIN,VOUT(7),NMEC,LMEC(MAXMEC)
     + ,NAMEC(MAXMEC),NSTEP ,MAXNST,DESTEP,DESTEL,SAFETY,SLENG
     + ,STEP  ,SNEXT ,SFIELD,TOFG  ,GEKRAT,UPWGHT,IGNEXT,INWVOL
     + ,ISTOP ,IGAUTO,IEKBIN, ILOSL, IMULL,INGOTO,NLDOWN,NLEVIN
     + ,NLVSAV,ISTORY

      COMMON/GCTMED/NUMED,NATMED(5),ISVOL,IFIELD,FIELDM,TMAXFD,DMAXMS
     +      ,DEEMAX,EPSIL,STMIN,CFIELD,PREC,IUPD,ISTPAR,NUMOLD

      CHARACTER*4 TYPE
      COMMON/CMCC/TYPE

*     The code to book and fill the Ntuple would look like this:
*
*   Initialisation phase.
*   The calls to HROPEN, HBNT and HBNAME may be placed in different
*   initialisation routines.
*   In this example example the Ntuple will be stored in directory //MYFILE.
*
      CALL HROPEN(1,'MYFILE','geant.ntup','N',1024,ISTAT)
      CALL HBNT(10,'Geant Ntuple',' ')
*
      CALL HBNAME(10, 'RUN',    IDRUN,  'IDRUN::16,IDEVT::16')
      CALL HBNAME(10, 'RUN',    IEORUN, 'IEORUN::16')
      CALL HBNAME(10, 'VECT',   VECT,   'VECT(6)')
      CALL HBNAME(10, 'GEKIN',  GEKIN,  'GEKIN')
      CALL HBNAME(10, 'INWVOL', INWVOL, 'INWVOL[1,7],ISTOP[1,7]')
      CALL HBNAME(10, 'NUMED',  NUMED,  'NUMED::10')
      CALL HBNAME(10, 'NSTEP',  NSTEP,  'NSTEP::16')
      CALL HBNAMC(10, 'TYPE',   TYPE,   'TYPE:C')
*
*    To fill the Ntuple, when the common blocks are filled just invoke
*    routine HFNT which knows the addresses and the number of variables.
*
      DO 10 I = 1, 1000000
         ...
         CALL HFNT(10)
10    CONTINUE
*
*                    At the end of the job, proceed as usual
*
      CALL HROUT(10, ICYCLE, ' ')
      CALL HREND('MYFILE')
```

Disk resident Ntuples

Histograms are never created directly on a disk file. They are always created in the current directory in memory (`//PAWC` or `//PAWC/subdir`). Histograms are saved on the disk file with a call of type `CALL HROUT` In case of disk-resident Ntuples, it is the same thing. The Ntuple header (data structure containing the column names) is always created in the current directory in memory (`//PAWC` or `//PAWC/subdir`). However, the call to `HBNT` remembers the current directory on disk (in the case below the `CD` on disk is `//K0`). When you fill the Ntuple, `HFNT` fills a buffer in memory. When this buffer is full, `HFNT` knows what is the `CD` on disk. The buffer is written into that directory. Note that your current directory on disk may be somewhere else. `HFNT` will temporarely change the `CD` to `//K0` and will reset the `CD` to what it was before calling `HFNT`. At the end of your job, you have to save the header and the current buffer in memory on the disk file. For that you have to:

- –Change the directory in memory where you book the Ntuple. If you do not have subdirectories, this operation is not necessary.
- –Change the directory on disk where you specified it in `HBNT`. In the case below `//K0`.
- –Issue a call to `HROUT` or `HREND`.

Creating a disk resident Ntuple

```
      call HCDIR('//PAWC',' ')
*--     HROPEN sets the directory to //K0, so no call to HCDIR is needed
      call HROPEN(50,'K0','~/mydir/K0.rz','N',1024,ISTAT)
      if (ISTAT.ne.0) write(6,*) 'Error in HROPEN'
      call HBNT(1000,'Ntuple','D')
      call HLDIR('//PAWC','T') ! Now you can see the header in //PAWC
      call HLDIR('//K0','T')   ! OK, nothing yet on //K0
*--     HBNAME describes the Ntuple
      call HBNAME(1000,'Event',EvtNo,
     +            'RunNo:I,Evtno:I,NPos:I,NNeg:I,'//
     +            ....
....
        call HLDIR('//K0','T') ! Nothing yet on //K0
        call HCDIR('//K0',' ') ! Useless, HFNT remembers that buffers are
 written to //K0
        call HFNT(1000)
        call HLDIR(' ','T')    ! This will not show anything on //K0.
                               ! However if you call HLDIR(' ','TA') you will
 see all Ntuple
                               ! extensions in the case you have many calls to
 HFNT.
                               ! In this particular example everything is still
 in memory.
....
      call HCDIR('//K0',' ')   ! Useless, you are already here
      call HLDIR('//K0',' ')   ! same as call hldir(' ','T')
      call RZLDIR(' ',' ')
      call HROUT(0,icycle,' ')
*-*      If you call HLDIR(' ',' ') here you will see the header
*-*      If you call HLDIR(' ','A') here you will see the header and your Ntuple
 extensions
      call HREND('K0')
```

3.4 Making projections of a RWN

CALL **HPROJ1** (ID,IDN,ISEL,FUN,IFROM,ITO,IVARX)

Action: Fill an existing one-dimensional histogram with data from a RWN.

Input parameters:

`ID` Identifier of 1-dimensional histogram, which must have been previously booked with `HBOOK1`.

`IDN` Identifier of the RWN Ntuple.

`ISEL` Selection flag

- `0` No selection criterion. Events between `IFROM` and `ITO` histogrammed with weight one.
- `<>0` Function `FUN` is called for each event between `IFROM` and `ITP`; they are histogrammed with a weight equal to the value of `FUN`.

`FUN` User function, to be declared `EXTERNAL` in the calling routine. It has as parameters the array of variables `X` and the selection flag `ISEL`. If `FUN=0.`, no filling takes place for that event.

`IFROM` Event number where the histogramming has to start.

`ITO` Event number where the histogramming has to end.

`IVARX` Sequence number in the Ntuple of the variable to be histogrammed.

Example of the use of a one-dimensional Ntuple projection

```
PROGRAM MAIN
EXTERNAL WFUNC
CALL HPROJ1(10,20,1,WFUNC,0,0,4)
.....
FUNCTION WFUNC(X,ISEL)
DIMENSION X(*)
WFUNC=0.
IF(ISEL.EQ.1)     THEN
         IF(X(2)**2 +X(3)**2.LT.0.)WFUNC=1.
ELSEIF(ISEL.EQ.2) THEN
         IF(X(2)**2 +X(3)**2.GT.5.)WFUNC=1.
ELSE     WFUNC=X(5)
ENDIF
END
```

Note that in an interactive session with `paw`, the user function `FUN` can be defined interactively using a Fortran-like syntax without recompilation and relinking.

`CALL` **HPROJ2** `(ID,IDN,ISEL,FUN,IFROM,ITO,IVARX,IVARY)`

Action: Same action as `HPROJ1`, but filling a previously booked 2-dimensional histogram or a profile histogram. Variable `X(IVARX)` will be projected onto the `X` axis and `X(IVARY)` onto the `Y` axis for all entries in the Ntuple between `IFROM` and `ITO` inclusive.
The number of entries in an Ntuple can be obtained by `HNOENT`.

3.5 Get information about an Ntuple

`CALL` **HGIVEN** `(ID,CHTITL*,*NVAR*,CHTAG*,RLOW*,RHIGH*)`

Action: Routine to provide information about an Ntuple.

Input parameters:

`ID`	Identifier of the Ntuple.
`NVAR`	Dimension of arrays `TAGS`, `RLOW` and `RHIGH`.

Output parameters:

`CHTITL`	Character variable containing the title associated with the Ntuple.
`NVAR`	The original contents is overwritten by the actual dimension of the Ntuple. If `ID1` does not exist or is not an Ntuple `NVAR=0` is returned.
`CHTAG`	Character array of dimension `NVAR`, which contains the tag names of the Ntuple elements.
`RLOW`	Array of dimension `NVAR`, which contains the lowest value for each Ntuple element.
`RHIGH`	Array of dimension `NVAR`, which contains the highest value for each Ntuple element.

3.5.1 Retrieve the contents of a RWN into an array

`CALL` **HGN** `(ID,*IDN*,IDNEVT,X*,IERROR*)`

Action: Copy the contents of a RWN event into an array.

Input parameters:

`ID`	Identifier of the Ntuple.
`IDN`	Must be initialized to zero before the first call to `HGN`.
`IDNEVT`	Event number

Output parameters:

`IDN`	Internal HBOOK pointer
`X`	Array to contain variables for the event chosen.
`IERROR`	Error return code.

This routine returns in the vector `X` the contents of the row `IDNEVT` or Ntuple `ID`. The vector `X` must be of size `NVAR`, as specified in the call to `HBOOKN`. If more than one row of the Ntuple is to be processed, it is more efficient to call first `HGNPAR` and then `HGNF`.

`CALL` **HGNPAR** `(ID,CHROUT)`

Action: Obtains the address and parameters of Ntuple ID.

Input parameters:

`ID` Identifier of the Ntuple.

`CHROUT` Character variable containing the name of the calling subroutine (printed in case of errors).

This routine sets some internal pointers and must be called before the first call to `HGNF` for a given RWN. When accessing more than one row of an Ntuple it is more efficient to call `HGNPAR` and then `HGNF` for each row that is required than to call `HGN`.

`CALL` **HGNF** `(ID,IDNEVT,X*,IERROR*)`

Action: Copy the contents of an Ntuple event into an array. The routine `HGNPAR` must have been called prior to the first call to `HGNF` for a given Ntuple.

Input parameters:

`ID` Identifier of the Ntuple.

`IDNEVT` Event number

Output parameters:

`X` Array to contain variables for the event chosen.

`IERROR` Error return code.

This routine returns in the vector `X` the contents of the row `IDNEVT` or Ntuple `ID`. The vector `X` must have be of size `NVAR`, as specified in the call to `HBOOKN`.

Example of access to RWN information

```
      PROGRAM TEST
      INTEGER    NWPAWC
      PARAMETER (NWPAWC=15000, MTUPLE=5)
      COMMON/PAWC/PAW(NWPAWC)
      CHARACTER*80 CHTITL
      CHARACTER*8 CHTAGS(MTUPLE),CHTAGZ(MTUPLE)
      DIMENSION EVENT(MTUPLE),RLOW(MTUPLE),RHIGH(MTUPLE)
      EQUIVALENCE (EVENT(1),X),(EVENT(2),Y),(EVENT(3),Z)
      EQUIVALENCE (EVENT(4),ENERGY),(EVENT(5),ELOSS)
      DATA CHTAGS/'X','Y','Z','Energy','Eloss'/
*-- Tell HBOOK how many words are in PAWC.
      CALL HLIMIT(NWPAWC)
*-- Book Ntuple
      CALL HBOOKN(10,'A Row-Wise-Ntuple',5,' ',5000,CHTAGS)
*-- Fill the Ntuple
      DO 10 I=1,1000
         CALL RANNOR(X,Y)
         Z=SQRT(X*X+Y*Y)
         ENERGY=50. + 10.*X
         ELOSS=10.*ABS(Y)
         CALL HFN(10,EVENT)
 10   CONTINUE
```

```
*--   Obtain the definitions of the Ntuple
      NVAR = MTUPLE
      CALL HGIVEN(10,CHTITL,NVAR,CHTAGZ,RLOW,RHIGH)
      PRINT *,'Definitions of Ntuple # ',10
      PRINT *,'   Title: ',CHTITL(1:LENOCC(CHTITL))
      PRINT *,'   Number of variables: ',NVAR
      DO 20 I=1,NVAR
         PRINT 9001,I,RLOW(I),RHIGH(I)
9001  FORMAT(' Min/Max values for column # ',I3,1X,F10.5,
     +       1X,F10.5)
 20   CONTINUE
*--   Get the contents of 'event' # 333
      CALL HGNPAR(10,'TEST')
      CALL HGNF(10,333,EVENT,IERR)
      PRINT *,IERR,EVENT
*--   Get the number of events in this Ntuple
      CALL HNOENT(10,NEVENT)
      PRINT *,NEVENT
 99   CONTINUE
      END
```

3.5.2 Retrieve the contents of a CWN into a common block

CALL **HGNT** (ID,IDNEVT,IERR*)

Action:

Retrieve information about a CWN row.

Input parameters:

ID Identifier of the Ntuple.

IDNEVT Number of the event about which information is required.

Output parameter:

IERR Error return code (=0 if event was found)

The information is restored at the addresses specified by HBNAME or HBNAMC (for CHARACTER data). If the information is being retrieved by a program other than the one that wrote the Ntuple then HBNAME or HBNAMC must be called as appropriate (see below).

```
      CALL HBNAME(ID,' ',0,'$CLEAR')
      CALL HBNAME(ID,CHBLOK,VARIABLE,'$SET')
```

These calls are required as HBOOK must obtain the location at which the requested information is to be returned which is obviously not valid between programs. The first call clears all the addresses stored by HBOOK for the specified Ntuple and the second one sets the addresses for the variables in block CHBLOK starting at variable VARIABLE. The second call should be repeated for every block of which data has to be retrieved. The routine HUWFUN will generate these calls automatically in the skeleton user function.

```
CALL HGNTB (ID,CHBLOK,IROW,IERR*)
```

Action:
Retrieve information about a named block in an Ntuple row.

Input parameters:

ID Identifier of the Ntuple.

CHBLOK Character variable specifying the block that is to be retrieved.

IROW Number of the row about which information is required.

Output parameter:

IERR Error return code (=0 if row was found)

The information is restored at the addresses specified by HBNAME or HBNAMC (for CHARACTER data).

```
CALL HGNTV (ID,CHVAR,NVAR,IROW,IERR*)
```

Action:
Retrieve information about the named variables in an Ntuple row.

Input parameters:

ID Identifier of the Ntuple.

CHVAR Array of character variables specifying the variables that are to be retrieved.

NVAR Number of character variables specified in CHVAR.

IROW Number of the row about which information is required.

Output parameter:

IERR Error return code (=0 if row was found)

The information is restored at the addresses specified by HBNAME or HBNAMC (for CHARACTER data).

You should only call HBNAME for the blocks that contain variables you want to read using HGNTV. If you call HBNAME for all blocks you should have a PAWC which is at least the same size as the one you used to create the Ntuple. If not you will run out of memory.

Also changing the buffer size will not help because the buffer used for reading will be the same size as the buffer used to write the Ntuple.

There is a special option in HBNAME with which you can tell HBNAME to only set the address for a single variable in a block (this option is used by PAW to reduce memory usage).

To set the address for a single variable call HBNAME (or HBNAMC) as follows:

```
CALL HBNAME(ID, BLOCK, IADDR, '$SET:NTVAR')
```

This will tell HGNTV to restore the Ntuple variable NTVAR in address IADDR. Using this form of HBNAME will only reserve buffer space for the variables you plan to read and not for all variables in the block. However, you have to be careful that when you change the list of variable for HGNTV to also add or remove the correct HBNAME calls.

`CALL` **HGNTF** `(ID,IROW,IERR*)`

Action:
Retrieve information about all variables specified in a previous call to either HGNT, HGNTB or HGNTV, in an Ntuple row. This routine is much faster than either HGNT, HGNTB or HGNTV.

Input parameters:

ID Identifier of the Ntuple.

IROW Number of the row about which information is required.

Output parameter:

IERR Error return code (=0 if row was found)

The information is restored at the addresses specified by HBNAME or HBNAMC (for CHARACTER data).

`CALL` **HNTVDEF** `(ID1,IVAR,CHTAG,BLOCK,ITYPE)`

Action:
Returns the definition as given in HBNAME for the variable with index IVAR in Ntuple ID1. The Ntuple must already be in memory.

3.5.3 Generate a user function

HBOOK can automatically produce a skeleton user selection function, which includes the Ntuple declaration via the calls HBNT, HBNAME and HBNAMC, and can be used in a later run to access the elements of the Ntuple. Two cases are available; one for use in batch and the other for use with paw. In the first case the common block names will be those specifed by the user in the call to HBNAME or HBNAMC. For paw, these common names are /PAWCR4/, /PAWCR8/ and /PAWCCH/ for storing the "single precision" (LOGICAL, INTEGER and REAL*4), "double precision" (REAL*8 and COMPLEX) and CHARACTER data respectively.

`CALL` **HUWFUN** `(LUN,ID,CHFUN,ITRUNC,CHOPT)`

Action:
Write an user function or subroutine to access an Ntuple.

Input parameters:

LUN Logical unit used to write the user routine. LUN must be opened before this call.

ID Identifier of the Ntuple.

CHFUN Character variable specifying the routine name.

ITRUNC All variable names will be truncated to ITRUNC characters. ITRUNC=0 is no truncation.

CHOPT Character variable specifying the desired options.

- 'B' Make an user subroutine for batch usage (i.e. with HBNAME and HBNAMC calls) (default).
- 'P' Make a paw selection function.

A simple example of the two kinds of skeletons generated with routine HUWFUN is given below. Another more complex example can be found on page 49, where the code of a fully worked out subroutine based on such a sketeton can also be studied.
In paw, the command UWFUNC generates a skeleton for the RWN or CWN analysis function automatically.

Example of an Ntuple definition and HUWFUN usage

```
      COMMON /CVECT/ V1, V2, V3, V4, V5, V6, V7, V8, V9, V10,
     +               V11, V12, V13, V14, V15, V16, V17, V18, V19, V20
      ...
      ...
*
*-- book N-tuple 20
*
      CALL HBNT(20,'1 block 20 variable N-tuple', ' ')
      CALL HBNAME(20,'VECT',V1,'V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,
     +                          V12,V13,V14,V15,V16,V17,V18,V19,V20')
*
      ...
      OPEN(11,FILE='nt20.f',STATUS='UNKNOWN')
      OPEN(12,FILE='nt20p.f',STATUS='UNKNOWN')
      CALL HUWFUN(11, 20, 'NT20', 0, 'B')
      CALL HUWFUN(12, 20, 'NT20', 0, 'P')
      ...
```

The HUWFUN output files `nt20.f` and `nt20p.f` look like:

File nt20.f

```
      SUBROUTINE NT20
*********************************************************
*                                                       *
* This file was generated by HUWFUN.                    *
*                                                       *
*********************************************************
*
*     N-tuple Id:     20
*     N-tuple Title:  1 block 20 variable N-tuple
*     Creation:       11/06/92 18.46.10
*
*********************************************************
*
      REAL V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12,V13,V14,V15,V16,V17
     + ,V18,V19,V20
      COMMON /VECT/ V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12,V13,V14,V15
     + ,V16,V17,V18,V19,V20
*
      CALL HBNAME(20,' ',0,'$CLEAR')
      CALL HBNAME(20,'VECT',V1,'$SET')
*
*--   Enter user code here
*

*
      END
```

File nt20p.f

```
      REAL FUNCTION NT20()
*********************************************************
*                                                       *
* This file was generated by HUWFUN.                    *
*                                                       *
*********************************************************
*
*     N-tuple Id:      20
*     N-tuple Title:  1 block 20 variable N-tuple
*     Creation:        11/06/92 18.46.10
*
*********************************************************
*
      COMMON /PAWIDN/ IDNEVT,VIDN1,VIDN2,VIDN3,VIDN(10)
*
      REAL V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12,V13,V14,V15,V16,V17
     + ,V18,V19,V20
      COMMON /PAWCR4/ V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12,V13,V14
     + ,V15,V16,V17,V18,V19,V20
*

*
*--   Enter user code here
*

      NT20 = 1.
*
      END
```

3.5.4 Optimizing event loops

`paw` is able, before starting the loop over the events, to find out which are the columns of the CWN which are actually referenced in any given query (command line selection expression or COMIS routine). Only the columns which are referenced will be read from the file.

If you analyse Ntuple data without `paw`, it is your own responsibility to find out and specify which are the columns referenced via the routines `HGNTV` or `HGNTB` (if all variables in a block are needed).

This optimization can be very important. Assume, for instance, that a 100 Mbyte file contains an Ntuple consisting of 300 columns, and that 3 columns are referenced. Then without optimization the complete 100 Mbyte file will have to be read, while, by specifying the columns used, only 1 Mbyte will be input.

3.6 Ntuple operations

Duplicate Ntuples

```
CALL HNTDUP (ID1,ID2,NEWBUF,CHTITL,CHOPT)
```

Action: Duplicate the definition of an Ntuple into a new Ntuple with the same definitions as the original one, but with 0 entries.

Input parameters:

`ID1` Identifier of original Ntuple

`ID2` Identifier of new Ntuple

`NEWBUF` Buffer size

- `NEWBUF<0` use buffer size of `ID1`
- `NEWBUF=0` use current buffer size(10000 for RWN's)
- `NEWBUF>0` use actually specified value as buffer size

`CHTITL` Character variable specifying the the new title for the duplicate Ntuple. If `CHTITL=' '` use the original title.

`CHOPT` Character variable specifying the desired option

- `CHOPT=' '` use original value (disk or memory resident)
- `CHOPT='M'` make the Ntuple memory resident
- `CHOPT='A'` interactive mode: sets the addresses to `/PAWCR4/`.

Rename a column in an Ntuple

```
CALL HRENAME (ID1,CHOLD,CHNEW)
```

Action: Renames a column in an Ntuple. CHOLD of Ntuple ID into CHNEW. Duplicate the definition of an Ntuple into a new Ntuple with the same definitions as the original one, but with 0 entries.

Input parameters:

`ID1` Identifier of Ntuple

`CHOLD` Character variable with old column name

`CHNEW` Character variable with new column name

One-dimensional convolution of Ntuple

```
CALL HCONVOL (ID1,ID2,ID3,IERROR*)
```

Action: Perform a one-dimensional convolution of the Ntuple with respect to an other[1]. All histograms must pre-exist prior to calling this routine.

[1] Original code written by Per Steinar Iversen (`PerSteinar.Iversen@fi.uib.no`).

Input parameters:

`ID1` Ntuple identifier (this Ntuple can be 1-D or 2-D). It is used as kernel for the convolution of `ID2`.

`ID2` Ntuple to be convoluted

`ID3` Ntuple resulting from the convolution of `ID2` with `ID1`

Output parameters:

`IERROR` error return code.

Discussion

This method scales badly for large histograms. The best general algorithm would be to unpack the histograms, add a suitable number of zeros, do the two FFTs, multiply the transforms, do yet another FFT and stuff the resulting histogram back into HBOOK. However, for small histograms, the naive method is probably faster, especially if recoded in terms of lower level calls. It will also work with 1-D and 2-D kernel-histograms that do not have matched coordinate systems - the FFT method implies equal binsize in `X` and `Y` for the kernel and the histogram to be folded. This simple method uses HBOOK to avoid this in one (`X`) dimension at least, corresponding to folding in a constant resolution term.

Example of use

```
      CALL HBOOK1(1,'Kernel 1 - 1D',100,-5.0,5.0,0.0)
      CALL HBOOK2(2,'Kernel 2 - 2D',100,-5.0,5.0,100,0.0,100.0,0.0)
      CALL HBPRO(2,0.0)
      CALL HBOOK2(3,'Kernel 3 - 2D',100,-5.0,5.0,100,0.0,100.0,0.0)
      CALL HBPRO(3,0.0)
      CALL HBOOK1(4,'Function',100,0.0,100.0,0.0)
      CALL HBOOK1(5,'Result 1',100,-10.0,110.0,0.0)
      CALL HBOOK1(6,'Result 2',100,-10.0,110.0,0.0)
      CALL HBOOK1(7,'Result 3',100,-10.0,110.0,0.0)

      DO 10 I=1,100000
        CALL RANNOR(A,B)
        CALL HFILL(1,A,0.0,1.0)
        CALL HFILL(1,B,0.0,1.0)
        CALL RANNOR(A,B)
        CALL HFILL(2,A,100.0*RNDM(I),1.0)
        CALL HFILL(2,B,100.0*RNDM(I),1.0)
        CALL RANNOR(A,B)
        CALL HFILL(3,A,100.0*SQRT(RNDM(I+1)),1.0)
        CALL HFILL(3,B,100.0*SQRT(RNDM(I+1)),1.0)
        X = 30.0*(RNDM(I)-0.5)+50.0
        CALL HFILL(4,X,0.0,1.0)
   10 CONTINUE

      CALL HCONVOL(1,4,5,IERROR)
      CALL HCONVOL(2,4,6,IERROR)
      CALL HCONVOL(3,4,7,IERROR)
```

3.7 Ntuple examples

The first example shows the use of Row-Wise-Ntuples, containing only floating point data.

Creating and using a RWN

```
      SUBROUTINE HEXAM7
*.==========>
*.           Example of N-tuples.
*..=========>
      DIMENSION X(3)
      CHARACTER*8 CHTAGS(3)
      DATA CHTAGS/'   X   ','   Y   ','   Z   '/
*.___________________________________________
*.
*            Reopen data base
*
      CALL HROPEN(1,'HEXAM7','hexam.dat','U',1024,ISTAT)
*
      CALL HBOOK1(10,'TEST1',100,-3.,3.,0.)
      CALL HBOOK2(20,'TEST2',20,-3.,3.,20,-3.,3.,250.)
      CALL HBOOKN(30,'N-TUPLE',3,'//HEXAM7,1000,CHTAGS)
*
      DO 10 I=1,10000
         CALL RANNOR(A,B)
         X(1)=A
         X(2)=B
         X(3)=A*A+B*B
         CALL HFN(30,X)
  10  CONTINUE
*
      CALL HROUT(30,ICYCLE,' ')
      CALL HPROJ1(10,30,0,0,1,999999,1)
      CALL HPROJ2(20,30,0,0,1,999999,1,2)
      CALL HPRINT(0)
*
      CALL HROUT(10,ICYCLE,' ')
      CALL HROUT(20,ICYCLE,' ')
*
      CALL HLDIR(' ',' ')
*
      CALL HREND('HEXAM7')
      CLOSE (1)
*
      END
```

Output Generated

```
TEST1

HBOOK     ID =        10                                        DATE  17/12/91              NO =  20

     250                                                        -   -  -
     240                                                      --I  -I- I
     230                                                  - - I I  I I-I
     220                                                 -I-I I I--I   I-   -
     210                                                -I  I-I         I---I
     200                                              --I                   I
     190                                           -- I                     I-
     180                                         --II-I                      I-
     170                                        -I                            I
     160                                        I                             I
     150                                       -I                             I
     140                                      -I                              I-- -
     130                                      I                                 I-I- -
     120                                    - I                                    I-I -
     110                                   -I-I                                      I-I
     100                                 --I                                           I
      90                                -I                                             I-
      80                               -I                                              I -
      70                             - I                                               I-I -
      60                            -I-I                                                 I-I
      50                        - --I                                                    I-- -
      40                       -I-I                                                          I-I-
      30                   -- -I                                                                I----
      20          -    ----II-I                                                                     I------
      10       ---I----I                                                                                  I-------

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                               111111111111122222222222222222222211111111111
          10      1    1111221234344665789911044677997990122303341234324100018734232120186756443432222111111
           1.  1591794631142995679730577637087033910061276900757760757337734725809812493999812692748547445127656864

LOW-EDGE       --------------------------------------------------
           1.  3222222222222222211111111111111111                                 1111111111111111122222222222222222
           0   0988776554432211099887665543322100998776654433211000112334456677899001223345566788990112234455677889
           0   0482604826048260482604826048260482604826048260482606284062840628406284062840628406284062840628406284

* ENTRIES =      10000      * ALL CHANNELS = 0.9979E+04      * UNDERFLOW = 0.1000E+02      * OVERFLOW = 0.1100E+02
* BIN WID = 0.6000E-01      * MEAN VALUE   =-0.1499E-01      * R . M . S = 0.9921E+00

%
```

```
TEST2

HBOOK     ID = 20                       DATE  17/12/91              NO =  21

CHANNELS  10 U 0        1         2 O
           1 N 12345678901234567890 V
           ****************************
  OVE      *         ++22 3+  +       * OVE
    2.7    *     + ++233+3+6 ++ +     *  20
    2.4    *      + +396353325+3+ +   *  19
    2.1    *    ++2288EBCB89852 + 2   *  18
    1.8    *   +23+5B7HJIIKC8552++    *  17
    1.5    * + + 525CTJY*WQWUF864+2   *  16
    1.2    *    +78BRX******WMF8532   *  15
     .9    * 2 328DS**********KC72    *  14
     .6    * + 9+6IY**********RGA22 2 *  13
     .3    *   378LU**********VI563 2 *  12
           * + 43ARX**********TPC63 2 *  11
-    .3    * + +3IQZ**********UFB53 3 *  10
-    .6    * + 298PY**********SIB83 + *   9
-    .9    *    65JS**********QKE55   *   8
-   1.2    * + 4358MT********NN863  + *   7
-   1.5    * + 3 3AIS*******QFF7+4+   *   6
-   1.8    *     44ADKQZYX*YPG942++   *   5
-   2.1    *   +4334BELLKCNE7F66+++   *   4
-   2.4    * + ++ 327598C7943672+3    *   3
-   2.7    *      + 23467382+2        *   2
-   3      *      2 ++++332+42        *   1
  UND      *        ++2 +++++ 2       * UND
           ****************************
LOW-EDGE       -----------
           1.  3222111       111222
           0   07418529630369258147
 *                                                        I   11    I
 * ENTRIES =    10000                 PLOT       ---------I---------I---------
 * SATURATION  AT=          255                     10    I 9957    I   11
 * SCALE  .,+,2,3,.,., A,B,         STATISTICS   ---------I---------I---------
 * STEP = 1.00     * MINIMUM=0.000                        I   11    I

********************************************************
* NTUPLE ID=   30  ENTRIES=  10000   N-TUPLE
********************************************************
*  Var numb  *   Name    *    Lower     *    Upper     *
********************************************************
*      1     *    X      * -.359595E+01 * 0.396836E+01 *
*      2     *    Y      * -.398909E+01 * 0.381000E+01 *
*      3     *    Z      * 0.748417E-03 * 0.162475E+02 *
********************************************************

===> Directory :
        30 (N)   N-TUPLE
        10 (1)   TEST1
        20 (2)   TEST2
```

A more complex example - CERN personnel statistics

In order to explain the advantages of the Column-Wise-Ntuple format, we consider a small data sample containing some characteristics of the CERN staff as they were in 1988. For each member of the staff there exists one entry in the file. Each entry consists of 11 values, as described in the following table:

Variable Name	Description and possible values
CATEGORY:	Professional category (integer between 100 and 600)
	100-199: Scientific staff
	200-299: Engineering staff
	300-399: Technical support staff
	400-499: Crafts and trade support staff
	500-529: Supervisory administrative staff
	530-559: Intermediate level administrative staff
	560-599: Lower level administrative staff
DIVISION:	Code for each division (Character variable)
	`'AG', 'DD', 'DG', 'EF', 'EP', 'FI', 'LEP', 'PE',`
	`'PS', 'SPS', 'ST', 'TH', 'TIS'`
FLAG:	A flag where the first four bits have the following significance
	Bit 1 = 0 means **female** otherwise **male**
	Bit 2 = 0 means **resident** otherwise **non-resident**
	Bit 3 = 0 means **single** otherwise **head of family**
	Bit 4 = 0 means **fixed term contract** otherwise **indefinite duration contract**
AGE:	**Age** (in years) of staff member
SERVICE:	Number of **years of service** that the staff member has at CERN
CHILDREN:	Number of **dependent children**
GRADE:	Staff member 's position in **Grade** scale (integer between 3 and 14)
STEP:	Staff member 's position (step) **inside** given grade (integer between 0 and 15)
NATION:	Code for staff member's **nationality** (character variable)
	`'AT', 'BE', 'CH', 'DE', 'DK', 'ES', 'FR', 'GB',`
	`'GR', 'IT', 'NL', 'NO', 'PT', 'SE', 'ZZ'`
HRWEEK:	Number of contractual **hours worked per week** (between 20 and 44)
COST:	**Cost** of the staff member to CERN (in CHF)

Note how the constraints on the various variables shown in the table are expressed in the job when creating the Ntuple.

On the next pages we show first the creation run, together with its output and the automatically generated analysis skeleton, and then the analysis program created based on the skeleton.

Creating the Ntuple

```
      PROGRAM CERN

      PARAMETER (NWPAWC = 30000)
      PARAMETER (LRECL  = 1024)

      COMMON /PAWC/ IPAW(NWPAWC)

      REAL    RDATA(11)
      INTEGER CATEGORY, FLAG, AGE, SERVICE, CHILDREN, GRADE, STEP,
     +        HRWEEK, COST
      CHARACTER*4   DIVISION, NATION
      COMMON /CERN/ CATEGORY, FLAG, AGE, SERVICE, CHILDREN, GRADE,
     +              STEP, HRWEEK, COST
      COMMON /CERNC/ DIVISION, NATION

      CHARACTER*4 DIVS(13), NATS(15)
      DATA DIVS /'AG', 'DD', 'DG', 'EF', 'EP', 'FI', 'LEP', 'PE',
     +           'PS', 'SPS', 'ST', 'TH', 'TIS'/
      DATA NATS /'AT', 'BE', 'CH', 'DE', 'DK', 'ES', 'FR', 'GB',
     +           'GR', 'IT', 'NL', 'NO', 'PT', 'SE', 'ZZ'/

      CALL HLIMIT(NWPAWC)

*
*-- open a new RZ file
*
      CALL HROPEN(1,'MYFILE','cern.hbook','N',LRECL,ISTAT)

*
*-- book Ntuple
*
      CALL HBNT(10,'CERN Population',' ')

*
*-- define Ntuple (1 block with 11 columns)
*
      CALL HBNAME(10, 'CERN', CATEGORY, 'CATEGORY[100,600]:I,
     +            FLAG:U:4, AGE[1,100]:I, SERVICE[0,60]:I,
     +            CHILDREN[0,10]:I, GRADE[3,14]:I, STEP[0,15]:I,
     +            HRWEEK[20,44]:I, COST:I')
      CALL HBNAMC(10, 'CERN', DIVISION, 'DIVISION:C, NATION:C')

*
*-- open data file with staff information
*
      OPEN(2,FILE='aptuple.dat', STATUS='OLD')
```

```
*
*-- read data and store in Ntuple
*
10    READ(2, '(10F4.0, F7.0)', END=20) RDATA
*
      CATEGORY = RDATA(1)
      DIVISION = DIVS(INT(RDATA(2)))
      FLAG     = RDATA(3)
      AGE      = RDATA(4)
      SERVICE  = RDATA(5)
      CHILDREN = RDATA(6)
      GRADE    = RDATA(7)
      STEP     = RDATA(8)
      NATION   = NATS(INT(RDATA(9)))
      HRWEEK   = RDATA(10)
      COST     = RDATA(11)
      CALL HFNT(10)
      GOTO 10

*
*-- read data of person #100
*
20    I = 100
      CALL HGNT(10, I, IER)
      IF (IER .NE. 0) THEN
         PRINT *, 'Error reading row ',I
      ENDIF
      PRINT *,'Person 100',' ',CATEGORY,' ',DIVISION,' ',AGE,' ',NATION

*
*-- print Ntuple definition
*
      CALL HPRNT(10)

*
*-- write batch version of analysis routine to file staff.f
*
      OPEN(3, FILE='staff.f', STATUS='UNKNOWN')
      CALL HUWFUN(3, 10, 'STAFF', 0, 'B')

*
*-- write Ntuple buffer to disk and close RZ file
*
      CALL HROUT(10, ICYCLE, ' ')
      CALL HREND('MYFILE')
*
      END
```

Output generated by running the above program

```
 ***** ERROR in HFNT : HRWEEK: Value out of range, event     2668 : ID=      10
 ***** ERROR in HFNT : HRWEEK: Value out of range, event     2673 : ID=      10
 ***** ERROR in HFNT : HRWEEK: Value out of range, event     2710 : ID=      10
 ***** ERROR in HFNT : HRWEEK: Value out of range, event     2711 : ID=      10
 ***** ERROR in HFNT : HRWEEK: Value out of range, event     2833 : ID=      10
 Person 100 415 PS    55 FR

 ******************************************************************
 * Ntuple ID = 10     Entries = 3354      CERN Population         *
 ******************************************************************
 * Var numb * Type * Packing *    Range     *  Block   *  Name    *
 ******************************************************************
 *      1   * I*4  *    11   * [100,600]    * CERN     * CATEGORY *
 *      2   * U*4  *    4    *              * CERN     * FLAG     *
 *      3   * I*4  *    8    * [1,100]      * CERN     * AGE      *
 *      4   * I*4  *    7    * [0,60]       * CERN     * SERVICE  *
 *      5   * I*4  *    5    * [0,10]       * CERN     * CHILDREN *
 *      6   * I*4  *    5    * [3,14]       * CERN     * GRADE    *
 *      7   * I*4  *    5    * [0,15]       * CERN     * STEP     *
 *      8   * I*4  *    7    * [20,44]      * CERN     * HRWEEK   *
 *      9   * I*4  *         *              * CERN     * COST     *
 *     10   * C*4  *         *              * CERN     * DIVISION *
 *     11   * C*4  *         *              * CERN     * NATION   *
 ******************************************************************
 *  Block   * Unpacked Bytes * Packed Bytes *   Packing Factor    *
 ******************************************************************
 * CERN     *    44          *    19        *    2.316            *
 * Total    *    44          *    19        *    2.316            *
 ******************************************************************
 * Number of blocks = 1     Number of columns = 11                *
 ******************************************************************
```

Note the HFNT error messages, which report that out-of-range data were read in the input file. This is an example of the error checking performed by the CWN routines.

Analysis skeleton generated for above example

```
      SUBROUTINE STAFF
*********************************************************
*                                                       *
* This file was generated by HUWFUN.                    *
*                                                       *
*********************************************************
*
*     N-tuple Id:      10
*     N-tuple Title:  CERN Population
*     Creation:       12/06/92 11.46.34
*
*********************************************************
*
      INTEGER CATEGORY,FLAG,AGE,SERVICE,CHILDREN,GRADE,STEP,HRWEEK,COST
      CHARACTER DIVISION*4,NATION*4
      COMMON /CERN/ CATEGORY,FLAG,AGE,SERVICE,CHILDREN,GRADE,STEP,HRWEEK
```

```
     + ,COST
      COMMON /CERN1/ DIVISION,NATION
*
      CALL HBNAME(10,' ',0,'$CLEAR')
      CALL HBNAME(10,'CERN',CATEGORY,'$SET')
      CALL HBNAMC(10,'CERN',DIVISION,'$SET')
*
*--   Enter user code here
*

*
      END
```

This skeleton is used in the example below to prepare a job for analysing the Ntuple data sample.

Example of Fortran code based on skeleton

```
      PROGRAM NEWNTUP

      PARAMETER (NWPAWC = 30000)
      PARAMETER (LRECL  = 1024)
      COMMON /PAWC/ IPAW(NWPAWC)

      CALL HLIMIT(NWPAWC)
      CALL HROPEN(1,'MYFILE','cern.hbook',' ',LRECL,ISTAT)
      CALL HRIN(10,9999,0)
      CALL STAFF
      CALL HREND('MYFILE')
      END
      SUBROUTINE STAFF
********************************************************
*                                                      *
* This file was generated by HUWFUN.                   *
*                                                      *
********************************************************
*
*     N-tuple Id:     10
*     N-tuple Title:  CERN Population
*     Creation:       12/06/92 11.46.34
*
********************************************************
*
      INTEGER CATEGORY,FLAG,AGE,SERVICE,CHILDREN,GRADE,STEP,HRWEEK,COST
      COMMON /CERN/ CATEGORY,FLAG,AGE,SERVICE,CHILDREN,GRADE,STEP,HRWEEK
     + ,COST

      CHARACTER DIVISION*4,NATION*4
      COMMON /CERN1/ DIVISION,NATION
*
      CHARACTER*8 VAR(4)
*
      CALL HBNAME(10,' ',0,'$CLEAR')         ! Clear addresses in Ntuple
      CALL HBNAME(10,'CERN',CATEGORY,'$SET') ! Set addresses for variables
 CATEGORY...
      CALL HBNAMC(10,'CERN',DIVISION,'$SET') ! Set addresses for variables
```

```
 DIVISION...
*
*--   Enter user code here
*
*-- book the histograms
*
      CALL HBOOK1(101, 'Staff Age', 45, 20., 65., 0.)
      CALL HBOOK1(102, 'Number of years at CERN', 35, 0., 35., 0.)
      CALL HBOOK2(103, 'Grade vs. Step', 12, 3., 15., 16, 0., 16., 0.)
      CALL HBIGBI(101,2)
      CALL HBIGBI(102,2)
*
*-- get number of entries
*
      CALL HNOENT(10, NLOOP)
*
*-- read only the four desired columns
*
      VAR(1) = 'AGE'
      VAR(2) = 'SERVICE'
      VAR(3) = 'GRADE'
      VAR(4) = 'STEP'
      CALL HGNTV(10, VAR, 4, 1, IER)
      DO 10 I = 1, NLOOP
         IF (I.NE.1) CALL HGNTF(10, I, IER)
         IF (IER .NE. 0) THEN
            PRINT *, 'Error reading row ', I
         ENDIF
         CALL HFILL(101, FLOAT(AGE), 0., 1.)
         CALL HFILL(102, FLOAT(SERVICE), 0., 1.)
         CALL HFILL(103, FLOAT(GRADE), FLOAT(STEP), 1.)
10    CONTINUE
*
      CALL HISTDO
*
      END
```

The summary table about the Ntuple shown below, as obtained by running the program above on the CERN Ntuple, should be compared with the table obtained during the creation run, as shown on page 48.

Output Generated

```
 ...........................................................................................................................
 .                                                                                                                         .
 .  HBOOK   HBOOK  CERN           VERSION   4.17       HISTOGRAM AND PLOT INDEX                            09/03/93        .
 .                                                                                                                         .
 ...........................................................................................................................
 .                                                                                                                         .
 . NO                    TITLE                        ID  B/C  ENTRIES DIM   NCHA     LOWER       UPPER       ADDRESS LENGTH .
 .                                                                                                                         .
 ...........................................................................................................................
 .                                                                                                                         .
 .                                                                                                                         .
 .  1  CERN Population                                 10                N                                      27174     37 .
 .                                                                                                                         .
 .                                                                                                                         .
 .  2  Staff Age                                      101  32     3354  1  X     45    .200E+02    .650E+02       26527     90 .
 .                                                                                                                         .
 .                                                                                                                         .
 .  3  Number of years at CERN                        102  32     3354  1  X     35    .000E+00    .350E+02       26432     83 .
 .                                                                                                                         .
 .                                                                                                                         .
 .  4  Grade vs. Step                                 103  32     3354  2  X     12    .300E+01    .150E+02       26347    298 .
 .                                                                       Y     16    .000E+00    .160E+02       26074    264 .
 .                                                                                                                         .
 ...........................................................................................................................

 MEMORY UTILISATION

      MAXIMUM TOTAL SIZE OF COMMON /PAWC/           30000
```

```
******************************************************************
* Ntuple ID = 10     Entries = 3354      CERN Population         *
******************************************************************
* Var numb * Type * Packing *    Range     *  Block   *  Name    *
******************************************************************
*      1   * I*4  *    11   * [100,600]    * CERN     * CATEGORY *
*      2   * U*4  *    4    *              * CERN     * FLAG     *
*      3   * I*4  *    8    * [1,100]      * CERN     * AGE      *
*      4   * I*4  *    7    * [0,60]       * CERN     * SERVICE  *
*      5   * I*4  *    5    * [0,10]       * CERN     * CHILDREN *
*      6   * I*4  *    5    * [3,14]       * CERN     * GRADE    *
*      7   * I*4  *    5    * [0,15]       * CERN     * STEP     *
*      8   * I*4  *    7    * [20,44]      * CERN     * HRWEEK   *
*      9   * I*4  *         *              * CERN     * COST     *
*     10   * C*4  *         *              * CERN     * DIVISION *
*     11   * C*4  *         *              * CERN     * NATION   *
******************************************************************
*  Block   * Unpacked Bytes * Packed Bytes *   Packing Factor    *
******************************************************************
* CERN     *    44          *    19        *    2.316            *
* Total    *    44          *    19        *    2.316            *
******************************************************************
* Blocks = 1            Variables = 11          Columns = 11     *
******************************************************************

Staff Age

HBOOK     ID =       101                                        DATE  09/03/93             NO =     1

     180                                                                   --
     176                                                                   II
     172                                                                   II--
     168                                                               --  I  I
     164                                                               II  I  I--
     160                                                           --  II  I    I
     156                                                           II  II--I    I
     152                                                           II--I        I--
     148                                                           I              I
     144                                                           I              I
     140                                                           I              I
     136                                                           I              I
     132                                                           I              I    --
     128                                                         --I              I    II
     124                                                         I                I  --II
     120                                                         I                I--I  I
     116                                                   --  --I                      I
     112                                                   II  I                        I--
     108                                                   II  I                          I
     104                                                   II  I                          I
     100                                                 --II  I                          I
      96                                                 I  I--I                          I
      92                                                 I                                I----
      88                                                 I                                    I
      84                                                 I                                    I
      80                                               --I                                    I
      76                                               I                                      I
      72                                               I                                      I
      68                                               I                                      I
      64                                           ----I                                      I
      60                                           I                                          I
      56                                           I                                          I
      52                           --              I                                          I  --
      48                           II--    --  ----I                                          I  II
      44                           I  I  --II  I                                              I--II
      40                       --  I  I--I  I  I                                              I
      36                       II--I        I--I                                              I   I
      32                       I                                                                  I--
      28                       I                                                                    I--
      24                       I                                                                      I
      20                   ----I                                                                      I
      16                 --I                                                                          I
      12                 I                                                                            I--
       8             ----I                                                                              I
       4         ----I                                                                                  I

CHANNELS  10    0                   1                   2                   3                   4
           1    1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5

CONTENTS 100                                            1 1   1 1 1 1 1 1 1 1 1 1 1 1 1 1
          10              1 1 1 3 3 4 4 3 4 4 3 4 4 6 6 7 0 1 9 1 2 5 5 6 5 7 7 6 5 1 2 3 1 9 8 4 5 2 2 1
           1.     1 1 7 6 5 8 8 8 3 9 5 9 2 5 3 7 6 4 4 9 0 4 3 3 8 8 1 8 4 9 2 2 2 7 2 0 2 2 9 1 1 9 5 2

LOW-EDGE  10    2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 6 6 6 6 6
           1.   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4

* ENTRIES =       3354      * ALL CHANNELS =  .3354E+04      * UNDERFLOW =  .0000E+00      * OVERFLOW =  .0000E+00
* BIN WID =  .1000E+01      * MEAN VALUE   =  .4765E+02      * R . M . S =  .8643E+01
```

```
Number of years at CERN

HBOOK     ID =       102                                     DATE  09/03/93              NO =     2

     200                                                 --
     195                                             --  II--
     190                                             II  I  I
     185                                             II  I  I
     180                                     --      II--I  I
     175                                     II      I      I
     170                                     II      I      I
     165                                     II  --  I      I--
     160                                     II  II  I        I
     155                                     II  II  I        I    --
     150                                     II  II  I        I--  II
     145                                     II  II  I          I  II
     140                                     II--II  I          I--II
     135                                     I    I  I              I
     130                                     I    I--I              I  --
     125                                     I                      I  II
     120                                   --I                      I--II
     115                                   I                            I
     110                 --                I                            I--
     105                 II                I                              I
     100                 II                I                              I
      95                 II                I                              I
      90                 II    --          I                              I
      85                 II    II          I                              I
      80                 II    II          I                              I
      75                 II    II          I                              I      --
      70                 II    II          I                              I      II
      65         --      II    II          I                              I      II
      60         II      II    II          I                              I      II
      55         II    --II    II    --    I                              I----  II
      50         II    I  I    II    II    I                                  I--II
      45       --II----I  I    II  --II    I                                      I
      40       I          I  --II  I  I    I                                      I
      35       I          I  I  I  I  I  --I                                      I
      30       I          I  I  I  I  I  I                                        I
      25       I          I--I  I--I  I  I                                        I
      20       I                      I  I                                        I
      15       I                      I  I                                        I--
      10       I                      I--I                                          I

CHANNELS  10    0                 1                   2                   3
           1    1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5

CONTENTS 100              1                 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
          10    4 6 4 4 5 0 2 4 8 2 4 5   3 1 7 3 6 2 9 7 9 9 6 4 3 5 2 2 1 5 5 4 7 1
           1.   3 5 2 1 4 9 1 0 9 3 5 5 7 2 8 8 6 5 9 5 7 8 2 4 6 7 2 0 9 0 2 2 7 2 4

LOW-EDGE  10                       1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3
           1.    1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4

* ENTRIES =       3354      * ALL CHANNELS =  .3349E+04      * UNDERFLOW =  .0000E+00      * OVERFLOW =  .5000E+01
* BIN WID =  .1000E+01      * MEAN VALUE   =  .1943E+02      * R . M . S =  .8124E+01

Grade vs. Step

HBOOK     ID =       103                                     DATE  09/03/93              NO =     3

CHANNELS  10 U 0        1   O
           1 N 123456789012 V
           ********************
  OVE      *                  * OVE
   15      *   4*             *  16
   14      *    7             *  15
   13      *   22********     *  14
   12      *    +J*YFB23G     *  13
   11      *    39**QJ6H8     *  12
   10      *    3C*YTL6JE*    *  11
    9      *    36E**N9HD3    *  10
    8      *     2K**VEN85    *   9
    7      *   +38D***NRB25   *   8
    6      *    2GQ***TD8     *   7
    5      *    3S9***UM7+    *   6
    4      *    5I9P*QKG44    *   5
    3      *    298WW*QK72    *   4
    2      *    +9J*S*NK5 +   *   3
    1      *     7EJMYQM6+    *   2
           *    32A9GMNM2     *   1
  UND      *                  * UND
           ********************
LOW-EDGE  10          11111
           1.  345678901234

 *                                                           I         I
 * ENTRIES =     3354                    PLOT       ---------I---------I---------
 * SATURATION  AT=     INFINITY                              I 3354    I
 * SCALE  .,+,2,3,.,.,  A,B,           STATISTICS   ---------I---------I---------
 * STEP = 1.00     * MINIMUM=0.000E+00                       I         I
```

Chapter 4: Advanced features for booking and editing operations

4.1 Overview of booking options

4.1.1 Histograms with non-equidistant bins

```
CALL HBOOKB (ID,CHTITL,NCX,XBINS,VMX)
```

Action: As `HBOOK1`, but instead of giving the lower and upper limits, an array `XBINS` of `NCX+1` elements is provided.

`XBINS(1)`	contains the lower edge of the first bin.
`XBINS(2)`	contains the lower edge of the second bin.
`...`	and so on.
`XBINS(NCX+1)`	contains the upper edge of the last bin.

4.1.2 Profile histograms

```
CALL HBPROF (ID,CHTITL,NCX,XLOW,XUP,YMIN,YMAX,CHOPT)
```

Action: Create a profile histogram. Profile histograms are used to display the mean value of Y and its RMS for each bin in X. Profile histograms are in many cases an elegant replacement of two-dimensional histograms : the inter-relation of two measured quantities X and Y can always be visualized by a two-dimensional histogram or scatter-plot; its representation on the line-printer is not particularly satisfactory, except for sparse data. If Y is an unknown (but single-valued) approximate function of X, this function is displayed by a profile histogram with much better precision than by a scatter-plot.

The following formulae show the cumulated contents (capital letters) and the values displayed by the printing or plotting routines (small letters) of the elements for bin `J`.

$$
\begin{array}{rclrcl}
H(\mathtt{J}) & = & \sum Y & E(\mathtt{J}) & = & \sum Y^2 \\
l(\mathtt{J}) & = & \sum l & L(\mathtt{J}) & = & \sum l \\
h(\mathtt{J}) & = & H(\mathtt{J})/L(\mathtt{J}) & s(\mathtt{J}) & = & \sqrt{E(\mathtt{J})/L(\mathtt{J}) - h(\mathtt{J}) * *2} \\
e(\mathtt{J}) & = & s(\mathtt{J})/\sqrt{L(\mathtt{J})} & & &
\end{array}
$$

The first five parameters are similar to `HBOOK1`. Only the values of Y between `YMIN` and `YMAX` will be considered. To fill a profile histogram, one must use `CALL HFILL (ID,X,Y,1.)`.

$H(\mathtt{J})$ is printed as the channel contents. The errors displayed are $s(\mathtt{J})$ if `CHOPT='S'` (spread option), or $e(\mathtt{J})$ if `CHOPT=' '` (error on mean).

Profile histograms can be filled with weights.

The computation of the errors and the text below is based on a proposal by Stephane Coutu[1].

If a bin has `N` data points all with the same value `Y` (especially possible when dealing with integers), the spread in `Y` for that bin is zero, and the uncertainty assigned is also zero, and the bin is ignored in making subsequent fits. This is a problem. If $\sqrt{\mathtt{Y}}$ was the correct error in the case above, then $\sqrt{\mathtt{Y}}/\sqrt{\mathtt{N}}$ would be

[1] Stephane Coutu, `coutu@roo.physics.lsa.umich.edu`

the correct error here. In fact, any bin with non-zero number of entries `N` but with zero spread should have an uncertainty $\sqrt{\mathtt{Y}}/\sqrt{\mathtt{N}}$.

Yet, is $\sqrt{\mathtt{Y}}/\sqrt{\mathtt{N}}$ really the correct uncertainty? Probably it is only true in the case where the variable `Y` is some sort of counting statistics, following a Poisson distribution. This should probably correspond to the default case. However, `Y` can be any variable from an original Nntuple, not necessarily distributed according to a Poisson distribution. Therefore several settings for the option variable `CHOPT` are possible to determine how errors should be calculated (S stands for the spread in the formulae below):

		Errors are	$S/\sqrt{\mathtt{N}}$	for $S \neq 0.$,
`' '`	(Default)	" "	$\sqrt{\mathtt{Y}}/\sqrt{\mathtt{N}}$	for $S = 0, \mathtt{N} > 0$,
		" "	$0.$	for $\mathtt{N} = 0.$

	Errors are	S	for $S \neq 0.$,
`'S'`	" "	$\sqrt{\mathtt{Y}}$	for $S = 0, \mathtt{N} > 0$,
	" "	$0.$	for $\mathtt{N} = 0.$

	Errors are	$S/\sqrt{\mathtt{N}}$	for $S \neq 0.$,
`'I'`	" "	$1./\sqrt{12.\mathtt{N}}$	for $S = 0, \mathtt{N} > 0$,
	" "	$0.$	for $\mathtt{N} = 0.$

The third case above corresponds to integer `Y` values for which the uncertainty is ± 0.5, with the assumption that the probability that `Y` takes any value between $\mathtt{Y} - 0.5$ and $\mathtt{Y} + 0.5$ is uniform (the same argument goes for `Y` uniformly distributed between `Y` and $\mathtt{Y} + 1$); this could be useful, for instance, for the case where `Y` are ADC measurements.

4.1.3 Rounding

```
CALL HBINSZ  ('YES'/'NO')
```

Action: Round the bin size for bookings of subsequent histograms to a reasonable value, i.e.: `1.,1.5,2.,2.5,4.,5.` times an integer power of 10. `HBINSZ` controls a switch that, when on, rounds the binsize, still respecting the number of bins. The switch is initially off.

Input parameters:

`'YES'` enable the 'reasonable rounding' feature.

`'NO'` disable the 'reasonable rounding' feature.

4.1.4 Projections, Slices, Bands

```
CALL HBPRO  (ID,VMX)
```

Action: Books the projections of a 2-dimensional histogram as two 1-dimensional histograms.

Input parameters:

`ID` identifier of an existing 2-dimensional histogram
`ID=0` means book projections for all existing 2-dimensional histograms.

`VMX` upper limit of single channel content.

Remark:

- if `ID` does not exist, or is a 1-dimensional histogram, the call does nothing
- see `HBOOK1` for details about `VMX`
- booking of projections can be executed only after the 2-dimensional histogram with identifier `ID` has been booked.

`CALL` **HBPROX** `(ID,VMX)` and `CALL` **HBPROY** `(ID,VMX)`

Action: Books projection onto X or Y only. See `HBPRO` for more details.

`CALL` **HBANDX** `(ID,YMI,YMA,VMX)`

Action: Books a projection onto X, restricted to the Y interval (`YMI,YMA`).

Input parameters:

`ID` identifier of an existing 2-dimensional histogram

`YMI` lower limit of Y interval

`YMA` upper limit of Y interval

`VMX` maximum value to be stored in 1 channel.

The same remarks as for `HBPRO` apply.

`CALL` **HBANDY** `(ID,XMI,XMA,VMX)`

Action: As `HBANDX` but the projection is onto Y.

`CALL` **HBSLIX** `(ID,NSLI,VMX)`

Action: Books slices along Y of 2-dimensional histograms as `NSLI` 1-dimensional histograms. Each slice is a projection onto X restricted to an interval along the Y axis.

Input parameters:

`ID` identifier of an existing 2-dimensional histogram

`NSLI` number of slices

`VMX` maximum value to be stored in 1 channel.

The same remarks as for `HBPRO` apply.

`CALL` **HBSLIY** `(ID,NSLI,VMX)`

Action: As `HBSLIX` but slices are projected onto Y.

4.1.5 Statistics

Mean value and standard deviation of 1-dimensional histograms are calculated at editing time, using the channel contents. If a more accurate calculation is desired, or if more statistical information is needed, the following option will provide it : `CALL HIDOPT (ID,'STAT')`

`CALL` **HBARX** `(ID)`

Action: Store the errors for 1-dimensional histograms, X-projections, etc., in memory and superimpose them on the plot during output. This routine must be called after booking **but before filling**.

Input parameter:

`ID` identifier of an existing histogram. `ID=0` means all histograms already booked.

If `ID` corresponds to a 2-dimensional histogram, `HBARX` acts on all X projections, slices, bands.

$$\text{Error}(i) = \sqrt{\sum_{j=1}^{n^i} W_{ji}^2}$$

where :

i	bin number
n^i	number of entries in bin i
$W_{j\,i}$	weight of event j in bin i

It is clear that the sum of the squares of weights in each bin must also be stored to perform this calculation. However when filling with weight always equal to 1, errors can be calculated from bin contents only, and `HBARX`, `HBARY` need not be called. The superimposition of error bars can be selected at output time, using `HIDOPT(ID,'ERRO')` In both cases the values of errors can be printed under the contents, via the editing option `HIDOPT(ID,'PERR')` The entry `HPAKE` permits user-defined error bar setting.

`CALL` **HBARY** `(ID)`

Action: As `HBARX`, it is used to act on Y projections of 2-dimensional histograms.

`CALL` **HBAR2** `(ID)`

Action: This routine can be used to create the data structure to store errors for 2-D histograms (like `HBARX` for 1-Ds). By default, the errors are set to the sqrt(contents).

Input parameter:

`ID` identifier of an existing 2-D histogram. `ID=0` means all histograms already booked.

The routine `HPAKE` (or the `paw` command `PUT/ERR`) may be used to fill errors. If `HBAR2` is not called before `HPAKE`, then `HPAKE` invokes `HBAR2` automatically. When `HBAR2` is called, routines `HFILL` or `HF2` will accumulate the sum of the squares of the weights. The errors for 2-D histograms are used by the fit routines or the `Histo/FIT` command. The error bars are not drawn by the `hplot` routines.

4.1.6 Function Representation

```
CALL HBFUN1 (ID,CHTITL,NX,XMI,XMA,FUN)
```

Action: Books 1-dimensional histogram and fills it with the values of the external function `FUN(X)` computed at the centre of each bin. One computer word per channel is used.

The first five parameters are as for `HBOOK1`.

Input parameters:

`ID`	histogram identifier, integer non zero
`CHTITL`	histogram title (character variable or constant up to 80 characters)
`NX`	number of channels
`XMI`	lower edge of first channel
`XMA`	upper edge of last channel
`FUN`	real function of one variable, to be declared `EXTERNAL` in the calling subroutine, and to be supplied by the user.

```
CALL HBFUN2 (ID,CHTITL,NX,XMI,XMA,NY,YMI,YMA,FUN)
```

Action: Books a 2-dimensional histogram and fills it with the values of the external function `FUN(X,Y)`, computed at the centre of each bin. One computer word per channel is used.

The first eight parameters are as for `HBOOK2`.

Input parameters:

`ID`	histogram identifier, integer
`CHTITL`	histogram title (character variable or constant up to 80 characters)
`NX`	number of channels in X
`XMI`	lower edge of first X channel
`XMA`	upper edge of last X channel
`NY`	number of channels in Y
`YMI`	lower edge of first Y channel
`YMA`	upper edge of last Y channel
`FUN`	real function of two variables, to be declared `EXTERNAL` in the calling subroutine, and to be supplied by the user.

```
CALL HFUNC (ID,FUN)
```

Action: Samples the function `FUN`, which must have been declared `EXTERNAL`, at the centre of the bins of a histogram. The function will be superimposed onto the histogram at editing time and its values optionally printed out (see `HIDOPT(ID,'PFUN')`)

Input parameters:

`ID` identifier of an existing 1-dimensional histogram.
`ID=0` signals that the function should be calculated for all existing 1-dimensional histograms.

`FUN` External real function, e.g. `REAL FUNCTION FUN(X).`
The function parameter `X` will be the central value of a histogram bin. The user must return the corresponding function at that point as a value in `FUN`.

Remark:

- Not existing for 2-dimensional histograms.
- Function `FUN` cannot contain any call to an entry of the HBOOK package.
- `HFUNC` can be called several times for the same histogram identifier `ID`. If the latter case, the values of the old function will be overwritten by the new one.
- The chi-squared χ^2, as defined below, will be printed along with the statistical information at the bottom of the histogram.

$$\chi^2 = \sum_{i=1}^{n_{ch}} \frac{(C(i) - F(i))^2}{\sum_{j=1}^{n^i} W_{ji}{}^2}$$

with:

n_{ch}	number of channels of histogram
$C(i)$	contents of channel i
$F(i)$	value of function at centre of channel i
n^i	number of entries in channel ii
W_{ji}	weight of event j in channel i, i.e. square root of contents $C(i)$ or as given by `HBARX/HPAKE`

4.1.7 Reserve array in memory

```
CALL HARRAY (ID,NWORDS,LOC*)
```

Action: Reserves an array in the memory storage area managed by HBOOK.

Input parameters:

`ID` identifier of the array (pseudo-histogram)

`NWORDS` length of the array.

Output Parameters

`LOC` Address minus one in the internal `hbook` common block `/PAWC/` of the 1st element of the array, i.e.

```
COMMON/PAWC/NWPAW,IXPAWC,IHDIV,IXHIGZ,IXKU,FENC(5),LMAIN,HCV(9989)
DIMENSION IQ(2),Q(2),LQ(8000)
EQUIVALENCE (LQ(1),LMAIN),(IQ(1),LQ(9)),(Q(1),IQ(1))

IADDR = Q(LOC+1)
```

Remark:

At any time the address of preudo-histogram `ID` can be obtained with `HLOCAT(ID,LOC)`

4.1.8 Axis labels and histograms

A set of routines, `HLABEL`, `HFC1` and `HFC2`, allows one to associate labels with histogram channels. This association can be made before or after a histogram is filled, but it has the advantage that the label information get stored in the histogram data structure, so that it is available for all future plots in an automatic way in the HPLOT and PAW packages. Printing histograms with associated alphanumeric labels is not implemented in the line-printer oriented routines of HBOOK.

`CALL` **HLABEL** `(ID,NLAB,*CLAB*,CHOPT)`

Action: Associates alphanumeric labels with a histogram. This routine can be called for a histogram after it has been filled, and then the labels specified will be shown on the respective axes. The routine can also be called before a histogram is filled , and in this case, when filling, a certain order can be imposed. By default the entries will be automatically ordered.

Input parameters:

`ID` Histogram identifier.

`NLAB` Number of labels.

`CHOPT` Character variable specifying the option desired.

- `' '` As `'N'` below.
- `'N'` Add `NLAB` new labels read in `CLAB` to histogram `ID`.
- `'R'` Read `NLAB` labels into in `CLAB` from histogram `ID`.
- `'X'` X-axis is being treated (default).
- `'Y'` Y-axis is being treated.
- `'Z'` Z-axis is being treated.
- `'S'` Sorting order of the labels:
  - `'S'` default, as `'SA'`;
  - `'SA'` alphabetically;
  - `'SE'` reverse alphabetical order;
  - `'SD'` by increasing channel contents (after filling);
  - `'SV'` by decreasing channel contents (after filling).
- `'T'` Modify (replace) `NLAB` existing labels read from `CLAB` in histogram `ID`.

Input/Output parameter:

`*CLAB*` Character variable array with `NLAB` elements (input and output).

Notes:

- For one-dimensional histograms `HLABEL` can be called at any time.
- For two-dimensional histograms one **must** call `HLABEL` with option `'N'` for each axis between the call to `HBOOK2` and the first call to `HFC2`.

4.2 Filling Operations

It is possible to speed up the filling process with the loss of some protection, and to globally transfer an array or a matrix to a histogram.

4.2.1 Fast Filling Entries

If the program that is using HBOOK fills many histograms several times a substantial fraction of time can be spent by HFILL in searching for the histogram it has to fill, deciding which type of histogram it is and unpacking and packing bits if more than one channel is to be stored in one computer word. To reduce the overall filling time, there are several actions that can be taken

- Bypass part of the logic that finds out the characteristics of the histogram to fill. This can be achieved by using, instead of HFILL the special filling entries described in this section.
- Avoid packing more than one channel in a computer word.

For these reasons it is recommended to use always HFILL at the development stage, and replace it later with HF1, HF2, etc. only when a rather stable program is going to be used extensively.

Calls to HFILL and HF1 or HF2 cannot be mixed on the same ID.

`CALL` **HF1** `(ID,X,WEIGHT)`

Action: Analogous to HFILL on a 1-dimensional histogram but HBARX and HIDOPT(ID,'STAT') are ignored.

Input parameters:

ID	histogram identifier
X	value of the abscissa
WEIGHT	event weight

`CALL` **HF1E** `(ID,X,WEIGHT,ERRORS)`

Action: Analogous to HF1, but also the errors are accumulated.

Input parameters:

ID	histogram identifier.
X	value of the abscissa.
WEIGHT	the content is incremented by WEIGHT.
ERROR	the error is incremented by ERROR**2.

===¿ HF1E Fills a 1-D histogram

SUBROUTINE HF1E(ID,X,W,E)

- ID : Histogram identifier. - X : Value of the abscissa - W : Content is incremented by W - E : Errors is incremented by E**2

`CALL` **HF2** `(ID,X,Y,WEIGHT)`

Action: Analogous to `HFILL` on a 2-dimensional histogram except that projections, bands, slices are not filled. `HBARY` is ignored as well.

Input parameters:

`ID`	histogram identifier
`X`	value of the abscissa
`Y`	value of the ordinate
`WEIGHT`	event weight

`CALL` **HFF1** `(ID,*NID*,X,WEIGHT)`

Action: Analogous to `HF1` with the same restrictions. Cannot be used for variable-bin-width histograms.

Input parameters:

`ID`	histogram identifier
`NID`	is a histogram-specific variable that has to be provided by the user. Before the first call, `NID` must be initialized to 0. In subsequent calls to `HFF1` the constant `NID` must then be used in order to skip the calculation of the histogram address.
`X`	value of the abscissa
`WEIGHT`	event weight

Output parameter:

`NID`	After the first call to `HFF1`, `NID` will contain the current address of histogram `ID`.

`CALL` **HFF2** `(ID,*NID*,X,Y,W)`

Action: Analogous to `HF2` with the use of the parameter `NID` as explained for `HFF1`.

`CALL` **HFPAK1** `(ID,NID,V,N)`

Action: Fill an histogram using the contents of a vector.

Input parameters:

`ID`	histogram identifier
`V`	array containing the values to be entered into the histogram.
`N`	length (dimension) of the array `V`

Input/output parameter:

`*NID*`	address of histogram (see `HFF1`)

This subroutine has the same effect as

```
   DO 10 I=1,N
10 CALL HFF1(ID,NID,V(I),1.)
```

where the array `V` of `N` words must have been filled previously by the user.

```
CALL HIPAK1 (ID,NID,IV,N)
```

Action: Analogous to HFPAK1, except that the user vector contains now integers instead of real numbers.

4.2.2 Global Filling

A vector or matrix can be transferred into a histogram with a single call.

```
CALL HPAK (ID,CONTEN)
```

Action: Transfer the contents of an array as channel contents into an histogram. The original contents of the histogram are overwritten.

Input parameters:

ID an existing histogram identifier

CONTEN a user array, suitably dimensioned

Remark:

- In the case of a **1-dimensional** histogram, the dimension of the array must at least be equal to the number of histogram channels (NCHAN), i.e. DIMENSION CONTEN(NX) with NX>NCHAN
- In the case of a **2-dimensional** histogram, the dimensions of the array must exactly be equal to the number of histogram channels (NCHANX and NCHANY),
  i.e. DIMENSION CONTEN(NX,NY) with NX=NCHAN and NY=NCHANY
  Projections and slices, if present for the given histogram, are **not** filled.

```
CALL HPAKAD (ID,CONTEN)
```

Action: Similar to HPAK, but instead of overwriting the channel contents, the array values are **added** to the respective channel contents.

```
CALL HPAKE (ID,ERRORS)
```

Action: Store the contents of an array as the errors for the bins of the 1-dimensional histogram for which the option HBARX has been invoked.

Input parameters:

ID histogram identifier

ERRORS user array containing the errors to be assigned to the histogram bin contents. Its dimension should be at least equal to the number of channels in histogram ID.

Remark:

If the HBARX option was not set for the given histogram, then it is activited by a call to HPAKE.

4.2.3 Filling histograms using character variables

Routines for which, using routine HLABEL, alphanumeric labels were associated with the histogram channels, are filled with the routines HFC1 and HFC2. These allow, on top of by bin number, to fill an histogram by specifying a alphanumeric channel identifier.

```
CALL HFC1 (ID,IBIN,CLAB,W,CHOPT)
```

Action: Fills a channel in a one-dimensional histogram.

ID	One-dimensional histogram identifier.
IBIN	Number of the bin to be filled (if $\neq 0$).
CLAB	Character variable containing the label describing the bin (if IBIN=0).
CHOPT	Character variable specifying the option desired.

- ' ' default, as 'S';
- 'N' filling order, i.e. the order of the labels on the plot is given by the sequence in which they are presented in the successive calls to the routine (this method can be very time consuming since all channels must be scanned at each call);
- 'S' automatic sort;
- 'U' if the channel does not exist then the underflow channel is incremented (by default a new channel is created for each new label).

Remarks:

- If IBIN$\neq$0, then the channel IBIN is filled; CLAB may then be undefined.
- When a label is encountered, which is not yet known, then for options 'N' and 'S' a new channel is added dynamically, while for option 'U' the underflow channel is incremented.
- Routine HLABEL can be called before or after HFC1.

```
CALL HFC2 (ID,IBINX,CLABX,IBINY,CLABY,W,CHOPT)
```

Action: Fills for a two-dimensional histogram the channel identified by position IBINX or label CLABX and position IBINY or label CLABY with weight W.

ID	Two-dimensional histogram identifier.
IBINX	Number of the X-bin to be filled (if $\neq 0$).
CLABX	Character variable containing the label describing the X-bin (if IBINX=0).
IBINY	Number of the Y-bin to be filled (if $\neq 0$).
CLABY	Character variable containing the label describing the Y-bin (if IBINY=0).
W	Weight of the event to be entered into the histogram.
CHOPT	Character variable specifying the option desired.

- ' ' default, as 'S';

- `'N'` filling order (see `HFC1`;
- `'S'` automatic sort (default)
- `'U'` if the channel does not exist then the underflow channel is incremented (by default a new channel is created for each new label).

Remarks:

- For efficiency reasons, routine `HLABEL` must be called **before** `HFC2`.
- If `IBINX`$\neq$`0`, then the channel described by `IBINX` is filled; `CLABX` may then be undefined.
- If `IBINY`$\neq$`0`, then the channel described by `IBINY` is filled; `CLABY` may then be undefined.
- If the channel described by `IBINX` or `CLABX` does not exist, the underflow channel is incremented. Idem for `IBINY` and `CLABY`.

The example below shows different uses of the label routines. The input data are the same as those used for building the Ntuple on page 45. Three histograms are booked. For the first one (`11`), the number of channels (`13`) is given explicitly, and a call to `HLABEL` declares all the labels for that histogram. Then a second histogram (`12`) is booked with one pre-declared channel. In fact this latter histogram will be filled with `HFC1`, in a way completely identical to histogram `11`, but channels will be dynamically added as new labels are encountered. We also create a 2-D histogram (`21`), where for the y-axis we again pre-declare labels and we fill it with a call to `HFC2`. After the loop, where the histograms are filled, we tell HBOOK to order the labels in the second histogram (`12`) according to decreasing bin contents. This shows that it is not necessary, in the 1-D case, to pre-declare the labels of a histogram, but that they can be added to a histogram "on the fly", i.e. while filling. The sorting order can be specified after the histogram is filled. As stated earlier, labels are only printed on graphical output devices, so that one must use HPLOT/HIGZ to see the effect of the label routines. The calls to the HPLOT/HIGZ routines, used to generate the PostScript picture shown in Fig. 4.1, are described in the HIGZ/HPLOT manual.

Example of the use of the histogram label routines

```
      PROGRAM CERN

      PARAMETER (NWPAWC = 30000)
      COMMON /PAWC/ IPAW(NWPAWC)
      REAL        RDATA(11)
      CHARACTER*4 CHDIV,CHDIVS(13), CHNAT,CHNATS(15)

      DATA CHDIVS /'AG', 'DD', 'DG', 'EF', 'EP', 'FI', 'LEP', 'PE',
     +           'PS', 'SPS', 'ST', 'TH', 'TIS'/
      DATA CHNATS /'AT', 'BE', 'CH', 'DE', 'DK', 'ES', 'FR', 'GB',
     +           'GR', 'IT', 'NL', 'NO', 'PT', 'SE', 'ZZ'/

      CALL HLIMIT(NWPAWC)
*
      OPEN(11,FILE='aptuple.dat', STATUS='OLD')
      OPEN(12,file='hlabexa.ps',form='formatted',status='unknown')

      CALL HBOOK1(11,'Example HLABEL explicit list',13,1.,14.,0.)
      CALL HBOOK1(12,'Example HLABEL implicit list',1 ,0.,1. ,0.)
      CALL HBOOK2(21,'Example HLABEL 2-D',13,2.,15.,13,1.,14.,0.)
*
      CALL HLABEL(11,13,CHDIVS,'N')
      CALL HLABEL(21,13,CHDIVS,'NY')
*
*-- Loop over input data
*
      DO 10 IEVENT = 1, 99999
         READ(11, '(10F4.0, F7.0)', END=20) RDATA
         CHDIV    = CHDIVS(INT(RDATA(2)))
         IGRADE   = RDATA(7)
         CALL HFC1(11,0,CHDIV,1.,' ')
         CALL HFC1(12,0,CHDIV,1.,' ')
         CALL HFC2(21,IGRADE,' ',0,CHDIV,1.,' ')
   10 CONTINUE

   20 CALL HLABEL(12,0,' ','SV')
*
*-- Call the HPLOT/HIGZ routines to print the histos showing the labels
*
      CALL HPLINT(0)
      CALL HPLCAP(-12)
      CALL HPLSET('VSIZ',0.20)
      CALL HPLSET('NDVX',-13.05)
      CALL HPLSET('HCOL',1105)
      CALL HPLSET('BCOL',1.5)
      CALL HPLSET('*FON',-60.)
      CALL HPLOPT('NBOX',1)
      CALL HPLZON(2,2,1,' ')
      CALL HPLOT(11,' ',' ',0)
      CALL HPLOT(12,' ',' ',0)
      CALL HPLZON(1,2,2,'S')
      CALL HPLOPT('GRID',1)
      CALL HPLOT(21,'BOX',' ',0)
      CALL HPLEND
*
      END
```

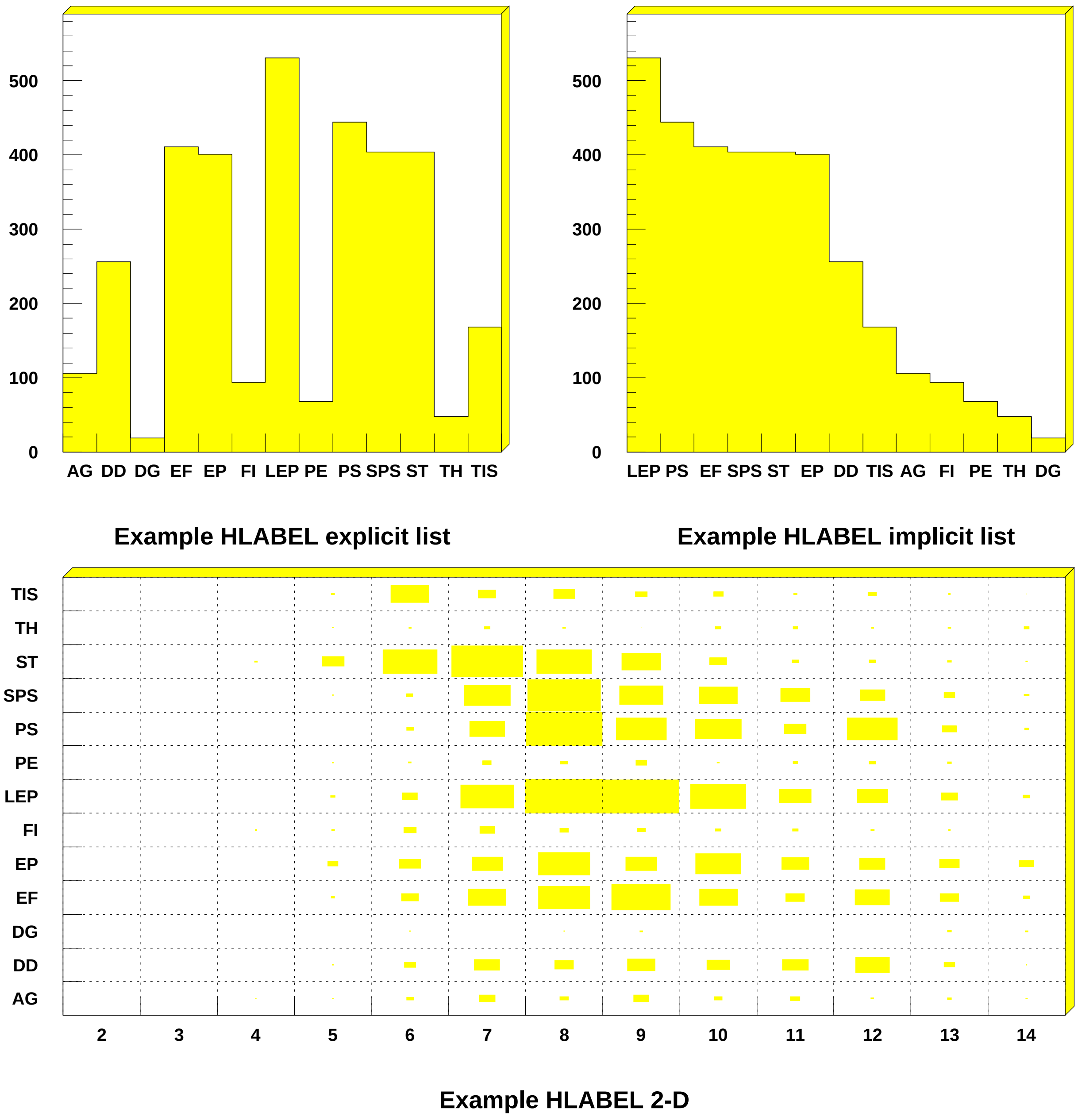


Figure 4.1: Example of the use of `HLABEL`

- The top left picture shows the contents of the histogram ordered alphabetically by label.
- The top right picture shows the same histogram, but with the bins ordered by decreasing contents, irrespective of their label.
- The lower picture shows a two-dimensional histogram, where the ordinate (Y-axis) ordered alphabetically.

Example of booking options

```
      SUBROUTINE HEXAM2
*.==========>
*.           TEST OF SOME BOOKING OPTIONS USING HBOOK RANDOM
*.           NUMBER GENERATORS.
*..=========> ( R.Brun )
      COMMON/HDEXF/C1,C2,XM1,XM2,XS1,XS2
      DOUBLE PRECISION C1,C2,XM1,XM2,XS1,XS2
      EXTERNAL HTFUN1,HTFUN2
*.___________________________________________
*.
*             Booking
*
      C1=1.
      C2=0.5
      XM1=0.3
      XM2=0.7
      XS1=0.07
      XS2=0.12
*
      CALL HBFUN1(100,'TEST OF HRNDM1',100,0.,1.,HTFUN1)
      CALL HIDOPT(100,'STAR')
      CALL HCOPY(100,10,' ')
*
      CALL HBOOK1(110,  'THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCT
     +ION HTFUN1'
     +  ,100,0.,1.,1000.)
*
      CALL HBFUN2(200,'TEST OF HRNDM2',100,0.,1.,40,0.,1.,HTFUN2)
      CALL HSCALE(200,0.)
      CALL HCOPY(200,20,' ')
*
      CALL HBOOK2(210,'HIST FILLED WITH HFILL AND HRNDM2' ,100,0.,1.,
     +  40,0.,1.,30.)
*
*             Filling
*
      DO 10 I=1,5000
         X=HRNDM1(100)
         CALL HFILL(110,X,0.,1.)
         CALL HRNDM2(200,X,Y)
         CALL HFILL(210,X,Y,1.)
  10  CONTINUE
*
*             Save all histograms on file 'hexam.dat'
*
      CALL HRPUT(0,'hexam.dat','N')
*
      CALL HDELET(100)
      CALL HDELET(200)
*
*             Printing
*
      CALL HPRINT(0)
      END
      FUNCTION HTFUN1(X)
      DOUBLE PRECISION HDFUN1
```

```
      HTFUN1=HDFUN1(X)
      END
      FUNCTION HTFUN2(X,Y)
      HTFUN2=HTFUN1(X)*HTFUN1(Y)
      END
      DOUBLE PRECISION FUNCTION HDFUN1(X)
      COMMON/HDEXF/C1,C2,XM1,XM2,XS1,XS2
      DOUBLE PRECISION C1,C2,XM1,XM2,XS1,XS2,A1,A2,X1,X2
*
      A1=-0.5*((X-XM1)/XS1)**2
      A2=-0.5*((X-XM2)/XS2)**2
      IF(A1.LT.-20.)THEN
         X1=0.
      ELSEIF(A1.GT.20.)THEN
         X1=1.E5
      ELSE
         X1=C1*EXP(A1)
      ENDIF
      IF(A2.LT.-20.)THEN
         X2=0.
      ELSEIF(A2.GT.20.)THEN
         X2=1.E5
      ELSE
         X2=C2*EXP(A2)
      ENDIF
      HDFUN1=X1+X2
      END
```

Output Generated

```
TEST OF HRNDM1

HBOOK     ID =        10                                        DATE  17/12/91              NO =   4

      10                                   ****
       9.75
       9.5                                *    *
       9.25
       9                                 *      *
       8.75
       8.5
       8.25                             *        *
       8
       7.75
       7.5                             *          *
       7.25
       7
       6.75                           *            *
       6.5
       6.25
       6                                            *
       5.75                          *
       5.5
       5.25
       5                            *                *                           ********
       4.75                                                                    **        **
       4.5                                                                    *            *
       4.25                                        *                      *              *
       4                           *                                        *                *
       3.75                                                                *                  *
       3.5                                          *                  *                    *
       3.25                       *                                      *                      *
       3                                                *               *                        *
       2.75                      *                                     *                          *
       2.5                                               *            *                            *
       2.25                     *                                    *                              *
       2                                                  *        **                                *
       1.75                    *                           *      *                                   **
       1.5                                                  ******                                      *
       1.25                   *                                                                          **
       1                     *                                                                             *
        .75                 *                                                                               ***
        .5                **                                                                                   ***
        .25    ***********                                                                                        *

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS   1.                 1122334567889999998876544322111111111122223333444444444444444443333222111111
*10**  1   0   0000000001234681505297653183799848145791483964333346791469146813567899998765318641964197531087654322
           0   0000123583003267539488304339899027929647999998500671879261615911069969969960119505050742236063223694
           0   1247315797649110704725408821516203649039012333618823383230115137101215512101720499659126352424226173
           0   4557197143534774472257850306737109143583172717457650550628417019558717717855896970455185631419095996

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        100      * ALL CHANNELS = 0.3249E+02      * UNDERFLOW = 0.0000E+00       * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4830E+00      * R . M . S = 0.2198E+00
```

```
THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCTION HTFUN1

HBOOK     ID =       110                                        DATE  17/12/91              NO =   5

     172                                    -
     168                                    I
     164                                    I
     160                                   -I
     156                                   II -
     152                                   II-I
     148                                   I  I-
     144                                 --I   I
     140                                 I     I-
     136                                 I      I
     132                                 I      I
     128                                 I      I-
     124                                -I       I
     120                               -I        I
     116                               I         I
     112                               I         I
     108                               I         I
     104                              -I         I-
     100                              I           I
      96                              I           I -
      92                              I           I-I
      88                             -I             I
      84                             I              I -                              - -
      80                             I              I I                        -     I I  -
      76                             I              I I                        I--  -I I  I
      72                             I              I I-                       I I- II I  I -
      68                             I              I-II                    -  I  I-II-I--I-I
      64                             I                 I                  --I  I            I-
      60                           - I                 I                  I I -I             I
      56                           I-I                 I                  I I-I              I -
      52                           I                   I-               --I                  I-I
      48                          -I                    I-              I                      I
      44                          I                      I             -I                      I-  -
      40                          I                      I-           -I                        I  I
      36                          I                       I           I                         I--I-
      32                          I                       I    -     -I                             I
      28                         -I                       I- - I -  -I                              I- -
      24                       --I                         I-I I I- I                                I I--
      20                      -I                             I I-II-I                                I-I I -
      16                      I                              I-I                                         I-I
      12                     -I                                                                            I--
       8                 - --I                                                                               I----
       4            -----I-I                                                                                     I-

CHANNELS 100   0                                                                                                  1
          10   0         1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                          1111111111111
          10                 112224658012445755432099687543222121221233455666557776678686676664543343222221111
           1.       21124626818147606828212710478511552225771649871850922032539736953183588893942434650812591167574

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =       5000      * ALL CHANNELS = 0.5000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4834E+00      * R . M . S = 0.2184E+00
```

```
TEST OF HRNDM2

HBOOK     ID =        20                                            DATE  17/12/91              NO =   6

CHANNELS 100 U 0                                                                                                  1 0
          10 N 0        1         2         3         4         5         6         7         8         9         0 V
           1 D 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 E
           ************************************************************************************************************
  OVE      *                                                                                                      * OVE
     .975  *             ..........................................................................................   *  40
     .95   *           .................++++++++...................................................................   *  39
     .925  *          ................+++++++++++++++..............................................................   *  38
     .9    *          .............+++++2222222222+++++.....................++++++++++++++++++.....................   *  37
     .875  *         .............+++2223333333333222++++...............++++++++++++++++++++++++++.................   *  36
     .85   *        ............++++2233444444444433222+++...........++++++++2222222222222222++++++++..............   *  35
     .825  *        ...........+++2233445566666655443322++++.....+++++++222222233333333332222222++++++.............   *  34
     .8    *       ............++223345567778877765543322++++++++++++++2222333333333443333333322222++++++..........   *  33
     .775  *       ...........+++23345677889999998776544322+++++++++++22223333344444444444444333332222+++++........   *  32
     .75   *       ...........++2234567889AAAAAA98876543322+++++++++222233344445555555555444433332222+++++.........   *  31
     .725  *       ..........+++233456789ABBBBBBA98765443222+++++++222233344445555555555555544443332222+++++.......   *  30
     .7    *       ..........+++23445789AABCCCBBA9876543222++++++22223333444555556666666555554443332222+++++.......   *  29
     .675  *       ..........+++23445789AABCCCBBA9876543222++++++22223333444555556666666555554443332222+++++.......   *  28
     .65   *       ..........+++233456789ABBBBBBA98765443222+++++++222233344445555555555555544443332222+++++.......   *  27
     .625  *       ...........++2234567889AAAAAA98876543322+++++++++222233344445555555555444433332222+++++.........   *  26
     .6    *       ...........+++23345677889999998776544322+++++++++++22223333344444444444444333332222+++++........   *  25
     .575  *       ............++223345567778877765543322++++++++++++++2222333333333443333333322222++++++..........   *  24
     .55   *        ...........+++2233445566666655443322++++.....+++++++222222233333333332222222++++++.............   *  23
     .525  *        ............+++2223344455444433222++++..........+++++++++2222222222222222++++++++..............   *  22
     .5    *         ............++++2223333333333222++++..............++++++++++++++++++++++++++++................   *  21
     .475  *         .............++++22223333332222++++.................++++++++++++++++++++++++..................   *  20
     .45   *         .............++++22233333333222++++................++++++++++++++++++++++++++.................   *  19
     .425  *        .............+++223334444444433322++++...........+++++++++22222222222222+++++++++..............   *  18
     .4    *        ...........+++23344566777777665543322+++++..+++++++2222233333333333333333322222++++++..........   *  17
     .375  *       ..........+++233456789ABBBBBBA98765443222+++++++222233344445555555555555544443332222+++++.......   *  16
     .35   *      ..........+++2345689BCDFFGHHGGFDCB98754432222222333444556677778888888887777665544433222+++++.....   *  15
     .325  *      ..........++234578ACEGHJKLLLLKJHGECA97654332222333445566778899AAAAAAAAAA99887766554433222++++....   *  14
     .3    *     ..........++2235689BDGIKLNOOOONLKIGECA8754433333334455677899AABBBCCCCCBBBAA998776554433222++++....   *  13
     .275  *     ..........++2235689BDGIKLNOOOONLKIGECA8754433333334455677899AABBBCCCCCBBBAA998776554433222++++....   *  12
     .25   *      ..........++234578ACEFHJKLLLLKJHGECA97654332222333445566778899AAAAAAAAAA99887766554433222++++....   *  11
     .225  *      ..........+++2345689ACDEFGGGGFEDCB98754432222222233444556667778888888887776665544433222+++++.....   *  10
     .2    *       ...........++223456789AABBBBAA9876543322++++++++22223334444555555555555444433332222+++++........   *   9
     .175  *        ...........+++2233455666666665543322+++++....+++++++222222233333333332222222+++++++............   *   8
     .15   *         .............+++2222333333332222++++...............++++++++++++++++++++++++++.................   *   7
     .125  *           ...............++++++++++++++...............................................................   *   6
     .1    *             ..........................................................................................   *   5
     .075  *               .....................................................................................      *   4
     .05   *                   ..........................................................................             *   3
     .025  *                        ..................                          ..........                            *   2
           *                                                                                                          *   1
  UND      *                                                                                                          * UND
           ************************************************************************************************************
LOW-EDGE   0   0000000000111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
           0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

 *                                                          I         I
 * ENTRIES =      4000                 PLOT       ---------I---------I---------
 * SATURATION  AT=     INFINITY                            I  422.327I
 * SCALE  .,+,2,3,.,., A,B,          STATISTICS   ---------I---------I---------
 * STEP =0.400E-01 * MINIMUM=0.000                          I         I
```

```
HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210                                        DATE  17/12/91             NO =   7

CHANNELS 100 U 0                                                                                                  1 0
          10 N 0        1         2         3         4         5         6         7         8         9         0 V
           1 D 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 E
           ************************************************************************************************************
  OVE      *                                                                                                          * OVE
     .975  *                       +         +    +                         +          +     + +     + +  +           *  40
     .95   *                           +  +22+ +++     +  +            2 + 2              +   +     2                 *  39
     .925  *                       2 +  2+ +   + +++ ++     +               +    + +      +  ++     +                 *  38
     .9    *                 +       ++2222 +3  3    +2      + +       + + + +4   +++2 2     ++ +   +  +              *  37
     .875  *                  ++ + +2+ 22 2222+++4 +322  2  +     ++2   ++ +3 2+2    +++    3+ ++ ++   +        +     *  36
     .85   *                 ++   2 +2 23 +33 82++  + +       +      3++ +   +3+ 3+2+3+ +   +      +      ++          *  35
     .825  *                + +  +23++ 227+34724 + 3++++2+++ + +  + 3  +   2++ 32+2+ ++22 +6 +2  22+2     +     +     *  34
     .8    *              +  +2+  +4 +2 + 235565622435+3++    ++ +++2 +2+22243 33++2332+24 3++3+ + 2  +     2         *  33
     .775  *           +     +++2+33222223545235+33333 33 +++  2  +  ++2+544 2+3 732+332+3422 4  +++ ++ ++  + 2+      *  32
     .75   *                    2 +53 4525556865446523 ++223  ++3+23 +2+ 3223+4+3++524 3++ 423243+2 2 ++ +       +    *  31
     .725  *                  + 33+63224226465624664 233++  23 23+ + 23 233++52++5+7++34+33232  ++3+++ +  2 +       *  30
     .7    *             +      +23+85+2478547767234432 2 22++ +++2+++4  34+ +24333+247   3+342+2 +++5 3   ++         *  29
     .675  *               +++ 2++25232+545975576+47A4++32+2++ 2+ 2  ++52 + +24533544223 +65323+2+ 2  +2+  +22+       *  28
     .65   *             +++  2+23++2287533442548B324+++ 2+22++++  2+ 2   3 32+242423 5 +4363+++3  22+ 2  3      +    *  27
     .625  *              + +2  423 255285447559545334 2+3+ + +    + ++22+ 233434+34 3+332+ 2+2+2 2+++2+2+++  + +     *  26
     .6    *                     ++322 6363354545424255++ + +++ 2+ 3++++ ++2+33+2228433+4+32+ +2 2   +  2    ++ + +   *  25
     .575  *              + +  ++ ++3222236+272342322 2  +       + 2++  + 3 +4 + 2+2+3+2+3+ 3+ 22+  +  +  2++         *  24
     .55   *                    +2+3++3+6  665+22+ +5+  ++  3++ 2 ++2+ 3   +2 2 2+ 3+  222++ 2 2    2      +          *  23
     .525  *               ++ +3 + +2+4  35+2+22+22+ 2++ +          +  +2  +   ++2+3222+   +2 + + 2  2  +     +       *  22
     .5    *                       + 2 3+ 3332++22  +2+ + ++ +  +   ++    23+  2+2+ 2+ ++2 3 + +              +   +   *  21
     .475  *                    +  ++2 3 +3  2   2+2 +2 ++  +     +    +2 +    +  +   23   2       23 +       +       *  20
     .45   *                  + 2 + +35+2 2++22+++23     2          +    +  3 2  + 2 +++2 2  +  2   +                 *  19
     .425  *                   +   3 +32+  233+++++++3++  + 2+    + 3 +2+++ + +   ++ + ++2+ +  2++  +                 *  18
     .4    *                    ++2  435263522594 4 +324  + ++++   ++   +3+3+  332 4+22522 + 5+ ++++2    +       +    *  17
     .375  *             ++  ++3+4+2+4578359944+84B53+463+ + +2+ 2222 2423 4 23+5 +65+2+2 2++232 2 +3  ++++   + +    *  16
     .35   *             2  ++  24223763662898869673+234+2++3++2++ 242324 5353935752246553345 ++52+++5232  2+   +     *  15
     .325  *            + + +++224244796897BAGA8B96944546+32  +2   34224422+569642273485454575A3525+  3+42++ +2 +     *  14
     .3    *              + 3+ +6244456768EGABBGBB79A 46245 32+4+4622344424+676772+359C+355286244243332+5 ++++++ +    *  13
     .275  *            +    +32+3463568EACACCBFB7587557+7532  +3 +54 4533423262597856637+73533A37++432 2++ + + +     *  12
     .25   *             ++++2+ 2433654EE686EA863DA57667+  2 2 22 2+22552++25376356364453476246355535233+  +2 +2+     *  11
     .225  *                 +  52425363599874645A66836+2+ 23 ++322+3+22+5262 63643382436242+32+233+232    + +  2     *  10
     .2    *                   + ++ 44625892363A484243+32 +2           3+2 32 54+444++++76254+332 +   +++ + + +  +    *   9
     .175  *               +     2+  2 23332334432352+5++22  +      +2+ +   2++2 5+ ++424+ +3+  3+  +  ++  + +        *   8
     .15   *            +        +  + 2 22+ 22+2++22+2+ 2      +++   +        23 +2+2+ ++2+    +++ 2+      ++ ++      *   7
     .125  *                 +   + +     + 2+  + +  +                     + +++   2      +   ++             +        *   6
     .1    *                                         + +             +       +    +                + +            +   *   5
     .075  *                    +    +     +                                      +                                   *   4
     .05   *                                                                    +                                     *   3
     .025  *                                                                                                          *   2
           *                                                                                                          *   1
  UND      *                                                                                                          * UND
           ************************************************************************************************************
LOW-EDGE   0   0000000000111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
           0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

 *                                                          I         I
 * ENTRIES =     5000                 PLOT        ---------I---------I---------
 * SATURATION  AT=          31                             I 5000    I
 * SCALE  .,+,2,3,.,., A,B,          STATISTICS   ---------I---------I---------
 * STEP = 1.00     * MINIMUM=0.000                          I         I
```

More booking examples

```
      SUBROUTINE HEXAM3
*.==========>
*.           MORE BOOKING OPTIONS
*..=========> ( R.Brun )
*
*             Get all histograms saved in example 2
*
      CALL HROPEN(1,'HEXAM','hexam.dat','U',1024,ISTAT)
      CALL HRIN(0,9999,0)
      CALL HMDIR('HEXAM3','S')
*
*             Print an index of all histograms that are now in memory
*
      CALL HINDEX
*
*             Reset hist 110 and 210.  adds more options
*
      CALL HRESET(110,' ')
      CALL HRESET(210,' ')
      CALL HIDOPT(110,'STAT')
      CALL HBARX(210)
      CALL HBPROX(210,0.)
      CALL HBSLIX(210,3,1000.)
      CALL HBANDY(210,0.1,0.5,0.)
      CALL HIDOPT(0,'1EVL')
*
*             New filling
*
      DO 10 I=1,2000
         CALL HFILL(110,HRNDM1(10),0.,1.)
         CALL HRNDM2(20,X,Y)
         CALL HFILL(210,X,Y,1.)
  10  CONTINUE
*
*             Print new contents using specialized printing routines
*             Same result could be obtained using HISTDO/HPRINT(0)/HPHS.
*
      CALL HPHIST(110,'HIST',1)
      CALL HPSCAT(210)
      CALL HPHIST(210,'PROX',1)
      CALL HPHIST(210,'BANY',1)
      CALL HPHIST(210,'SLIX',0)
*
*             Save all histograms in new directory HEXAM3
*
      CALL HROUT(0,ICYCLE,' ')
      CALL HREND('HEXAM')
      CLOSE (1)
*
      END
```

Output Generated

```
 ...............................................................................................................................
 .                                                                                                                             .
 .  HBOOK   HBOOK  CERN           VERSION   4.13       HISTOGRAM AND PLOT INDEX                            17/12/91       .
 .                                                                                                                             .
 ...............................................................................................................................
 .                                                                                                                             .
 . NO                   TITLE                          ID  B/C  ENTRIES DIM   NCHA     LOWER       UPPER       ADDRESS LENGTH .
 .                                                                                                                             .
 ...............................................................................................................................
 .                                                                                                                             .
 .                                                                                                                             .
 .  1  TEST OF HRNDM1                                 100  32       -1  1  X   100   0.000E+00   0.100E+01       64912    146 .
 .                                                                                                                             .
 .                                                                                                                             .
 .  2  TEST OF HRNDM1                                  10  32      100  1  X   100   0.000E+00   0.100E+01       64764    146 .
 .                                                                                                                             .
 .                                                                                                                             .
 .  3  THIS HISTOGRAM IS FILLED ACCORDING TO TH       110  10     5000  1  X   100   0.000E+00   0.100E+01       64605     89 .
 .     E FUNCTION HTFUN1                                                                                                       .
 .                                                                                                                             .
 .  4  TEST OF HRNDM2                                 200  32       -1  2  X   100   0.000E+00   0.100E+01       64523   4328 .
 .                                                                     Y    40   0.000E+00   0.100E+01       60218   4296 .
 .                                                                                                                             .
 .  5  TEST OF HRNDM2                                  20  32     4000  2  X   100   0.000E+00   0.100E+01       60193   4328 .
 .                                                                     Y    40   0.000E+00   0.100E+01       55888   4296 .
 .                                                                                                                             .
 .  6  HIST FILLED WITH HFILL AND HRNDM2              210   5     5000  2  X   100   0.000E+00   0.100E+01       55858    763 .
 .                                                                     Y    40   0.000E+00   0.100E+01       55123    726 .
 .                                                                                                                             .
 ...............................................................................................................................

 MEMORY UTILISATION

      MAXIMUM TOTAL SIZE OF COMMON /PAWC/           80000

 THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCTION HTFUN1

 HBOOK     ID =       110                                      DATE  17/12/91              NO =   1

      68                                  -
      66                                  I  --
      64                                  I  II
      62                                  I -II
      60                                  I I I
      58                                  I I I-
      56                                 -I-I  I
      54                                 I     I
      52                                 I     I
      50                                 I     I
      48                               --I     I
      46                               I       I
      44                               I       I--- -
      42                               I          I I
      40                               I          I I                                -
      38                              -I          I I                          -     I
      36                              I           I I                          I    -I-   -
      34                              I           I-I-                        -I   -I I   I
      32                            - I              I                        II  -I  I  -I
      30                            I I              I                        II  I   I  II
      28                            I I              I-                      -II  I   I  II   -
      26                            I I               I                     -I I  I   I- II  -I
      24                            I I               I                     I  I- I    I II -II -
      22                           -I-I               I                     I   I-I    I II-I I I-
      20                           I                  I                - - -I          I-I    I-II-
      18                         - I                  I -              I I I                      I -
      16                        -I I                  I-I  -       -  -I I-I                      I I
      14                       -II I                    I- I       I -II I                        I-I
      12                       I I-I                     I I  -   -I I I-I                          I--
      10                       I                         I-I- I   II I                                I- - -
       8                       I                            I-I  -II-I                                 I-I-I-
       6                     - I                              I--I                                          I
       4                   - I-I                                                                            I-
       2             -  -- I-I                                                                               I--

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10                   111123234456566654443432111 1  1   11 11211112233223333322332222122111111
           1.        1  11 3154368221187867616584443348583959815682574502969683732245966025146893294712079898422

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        2000      * ALL CHANNELS = 0.2000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4911E+00      * R . M . S = 0.2207E+00      * NEQUIVAL = 0.2000E+04
```

```
HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210                                        DATE  17/12/91              NO =   2

CHANNELS 100 U 0                                                                                                  1 O
          10 N 0        1         2         3         4         5         6         7         8         9         0 V
           1 D 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 E
           ************************************************************************************************************
  OVE      *                                                                                                          * OVE
     .975  *                           +        +                          ++    +                                    *  40
     .95   *                           2+      +   +                                 +                                *  39
     .925  *                               +   + +  ++            +        +2+      +                                 *  38
     .9    *                         +      2 ++     +  +                      2 + +     +                   +        *  37
     .875  *                       +    2+++3 2 +2     +             +           +2   + +   +       2                 *  36
     .85   *                      +    +4+ 2++++++++2  + +    +  ++    +  + +  +          2        +             +    *  35
     .825  *               ++         +++4 +2 +4+ +     +  ++   +    +     ++    2+ ++++ +  ++   2            +  +    *  34
     .8    *                    ++   3  2223223+2++3+   2  + +    ++    + 2   +  +2 +2++2    ++  +   +                *  33
     .775  *                 +   + +3 + 2+2 +2+53+ + 2++  + +   +     +++ +2  2     42 + + +      3 +    2            *  32
     .75   *               +     +  22   +3+3 2+32+3 +      +  + + 2 + +2+  2 +++23  3+2+   +       + +               *  31
     .725  *                  +    +  + 43 325+3+ 2+   ++ +  + + +      +++   ++  2+522 3+  + ++  +++  +    +         *  30
     .7    *             + +  +++ ++4++2++2  +2++552  2 ++ +        2  +22    ++2 +32++  ++23  ++  +    2     +       *  29
     .675  *                    +  342223526+24+ +++++++2  +            + + 2+++ 3++2++3+2+  + +3+ + +2        +     *  28
     .65   *                ++     2223+233+342 2++ 22+     +  ++2 + +++2++   +6 2 +2   ++++ 2++ + ++    + + +        *  27
     .625  *                + ++  ++++2+3++42+2 2+5++2+  + + +     +   +2+ + 2+  22 4+3+2 + + 2 ++ 2 ++ +             *  26
     .6    *                   +  ++ 3+2+32+2 2 2 2 2+ +  +  +     +   +22 ++  + +2  + 2 2 +22 + ++3                 *  25
     .575  *              +     +  +  +  +++2 2 ++2+2+             +    +   2 +22+   2 2+ 2    + +    ++ +            *  24
     .55   *                   ++    2+ 2+ +2 3   ++               2  +    2 2 +   +3   ++2+ +        ++              *  23
     .525  *                      +  ++ ++2++2+2   +            +      + +  +  +    +  + + +  +   +        +          *  22
     .5    *                      2+ ++ + +++   ++++ ++        +                2 2  ++                       ++      *  21
     .475  *                    ++     + +   +     + +2  +         +       ++    ++ +    + 2 +             +          *  20
     .45   *                       +  +        ++ +                +    +         + +   + +    2   +        +         *  19
     .425  *                    2+ ++  +++++++ 3 +    + +     +    + +    ++     + ++ +++          + +  ++    +       *  18
     .4    *               +   +++2+ ++ 2 3 + 242 23+ 3+++ +  ++    2  +3+ 2+   +    ++ 2+3  3     2  ++ +            *  17
     .375  *                 + ++ ++3+   2232 +42++322++  2    ++   3 + 2  +2+22    +++++2+++4+++   ++2+              *  16
     .35   *                 2  3++ 3232 +2+2633+4 +32 +32   +  ++   +   2++  2+++3+2+2 + 3+45 +2 + + 2++   +         *  15
     .325  *                 +    22+322234+443 555+4252 +3 ++++ 2 ++++33+2+ 2+ 42222+2 +4 532+  33  2 +    +     +   *  14
     .3    *                 +++ +42243+46334+475443334++++ +2 +    +2 2+ ++2+ 2 44++2332++2+2+++  22   +2+ +  +      *  13
     .275  *                   ++3  6+255325823646443+2+3+2   2+   23 ++22++ 3+334452 22442 22+ 2+2+2 2 2+++ +        *  12
     .25   *               +   3+22+2+2+95+446335++422++     2    +2 ++++ 2++2223422++242++53++22+++        +         *  11
     .225  *                +  ++ + 22++235347344+45  2 ++  +     + 22+++ 23 33+++++23++++ +3 23++++ +22  +           *  10
     .2    *                      2+ 222++2+4 2++3+ ++ ++++ 22++ + +  + 2 2 222+2+ ++ 2 4+2   + ++ +  ++ +            *   9
     .175  *                    +   +3 +   4++3+ ++  +++    +     +   +  +    +  +    +++   ++++   +3   + +           *   8
     .15   *                     ++    ++ ++++2    + ++  +          ++  + +     + +   + +    ++ 22  +                 *   7
     .125  *                  +   ++ +  2++++  2   +                           +   +         +                        *   6
     .1    *                                       +  +              +                  +                             *   5
     .075  *                               +  +      +                                                                *   4
     .05   *                                                                                                          *   3
     .025  *                                                                                                          *   2
           *                                                                                                          *   1
  UND      *                                                                                                          * UND
           ************************************************************************************************************
LOW-EDGE   0   0000000000111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
           0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

 *                                                          I         I
 * ENTRIES =     2000                   PLOT       ---------I---------I---------
 * SATURATION  AT=           31                             I 2000    I
 * SCALE  .,+,2,3,.,., A,B,           STATISTICS   ---------I---------I---------
 * STEP = 1.00     * MINIMUM=0.000                          I         I
```

```
HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210             PROJECTION X               DATE  17/12/91              NO =   3

      76                                    I
      74                                    I
      72                                    I
      70                                    I  I
      68                                I   0 II
      66                                I  II II
      64                                II II II
      62                                II II I0
      60                                0I II 0II
      58                                II 0 IIII
      56                                I0II IIII I
      54                                IIII IIII II
      52                                IIII I  0III
      50                                 I0I 0  IIII
      48                             I    I  I  II0I                                I
      46                             I    I  I  I0I0                                I
      44                            II    I  I   III                             II I
      42                            II    I      III                             II 0   I
      40                            I0I          I I                             II I   I
      38                            0III            I I                 I      I 00 I I I    I
      36                            IIII            III                 I      I II I I 0    I
      34                            II0I            III                 I      I II  IIIII  II
      32                            I I0            0I0                 0      0 II  I0III  I0
      30                          II  II            I0I                 I     II     IIIIIIIII
      28                          II  II            III                 I  II III  I 0I0 0II0I
      26                          II   I            III                   IIIIIII  I III IIIII
      24                          00                    I          I      IIII0 0  0 I I I00I      II
      22                        I II                    I          I   I  I00II I  I   I  II   II  II
      20                        I II                   I0          II  I I0II0I I  I      II  IIII 00 I
      18                        0I                     III         0II 0 IIIII                IIIIII I
      16                       III                     0III  I     I0I I 0I  I                0II0III 0I
      14                       II0                     I 0I II I   II0II I                    IIII0   II I
      12                       0 I                     I I0 I0 I I  III  I                    I  II   I0II
      10                     I I                         III0II0I0I   0                              I I00
       8                   I 0I                            II 0IIII   I                              0  II  I
       6                   0II0                            0  I 0I0                                  I  I II0II
       4                   I0 I                            I    I I                                        00I00I I
       2                 00 I                                                                              II II0000

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10                   1112234335545656654443331111 11 1   1111131222223233242323222231111111 11 1
           1.            115475274447031969770012586101693260270696854072602204137731817684481677649975290445442121

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =       2000      * ALL CHANNELS = 0.2000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4847E+00      * R . M . S = 0.2204E+00
```

```
HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210             BAND Y                   DATE  17/12/91             NO =   4

BAND Y      NO =   1     XMIN=  0.1000E+00  XMAX=  0.5000E+00

      88                  --
      84                  II
      80                  II
      76                  II
      72                 -II-
      68                 I  I
      64                 I  I
      60                -I  I
      56                I   I-
      52                I    I
      48                I    I            -
      44                I    I           -I-
      40               -I    I--        -I I
      36               I       I        I  I- --
      32               I       I       -I   I-II
      28               I       I       I       I
      24              -I       I       I       I--
      20              I        I-     -I         I
      16            --I         I  ---I          I-
      12            I           I -I              I
       8            I           I-I               I---
       4          --I                                I-

CHANNELS  10   0         1         2         3         4
           1   1234567890123456789012345678901234567890

CONTENTS  10        1123678875431 11111344443233221
           1.     3234280076140895066690028139343257552

LOW-EDGE   1.      111122223333444455556666777788889999
*10**  1   0   0257025702570257025702570257025702570257
           0   0505050505050505050505050505050505050505

* ENTRIES =       1108      * ALL CHANNELS = 0.1108E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.2500E-01      * MEAN VALUE   = 0.4800E+00      * R . M . S = 0.2231E+00

HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210             SLICE X                  DATE  17/12/91             NO =   5

SLICE X     NO =   1     YMIN=  0.0000E+00  YMAX=  0.3333E+00

      34                                    I
      33                                    I
      32                                    I
      31                                    I
      30                                I   I
      29                                I   I  I
      28                                I  IO  I
      27                                I  II II
      26                                I  II III
      25                                OI II III
      24                                II II IOI  I
      23                                II OIIIIII I
      22                                II I IOIIIII
      21                                II I IIIOIII
      20                                IOII IIIIIII                             I      I
      19                             I   III II IIIO                             I      I
      18                            II   II  OI IOII                             I    I I
      17                            II I II  I  IIOI  I                      I   I    I I
      16                            IIII IO  I   III II                      I   OII  I O
      15                          I IOII  I  I   III II                   I  I   III  III   I
      14                          I OIII  I  I   II  II                 I I  I IIIII  OII   I
      13                          I IIIO  I       I  IO                 I I  O IIIII  III   I
      12                          I IIOI  I         IOI                 I I  IIIIIOO  IIII IIII I
      11                          O I II            III                 I O  IIII III IO I IOII I   I
      10                         III  II            III             II  O I  IIOO III  I I IIIIIII II
       9                       I III  I             OI  II  II     III II II  OII IIII I OIOIOOIOI II
       8                       I III                I  IIII II     IIIIII III III   OI I IIIIIIIII IO I
       7                       I O O                I  IIII II     IOOIII  II III   II   III IIOIO OI I
       6                       OII I                I  IOOI OO I   OIIIO   OI I     IO   IOI IIIIIIII I III
       5                       III I                   OIIO IIII  IIIIOI I IO        I    I    I III  OIIII
       4                     IIIO                      IIII IIIO III  II I II        I    I       O  IIIOOO  I
       3                     II I                      I  I   OI IO   I  O  I                     I  IIOIII  I
       2                   IIOO I                             II OI      I                        I  O IIIIIIO I
       1                   OOII                                  I                                   I     OOI O

CHANNELS 100   0                                                                                                  1
          10   0         1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10                      1 1111221221222111 11                 1 1  1 11111  111   1
           1.              11226471745235063882418799235665 6634 236775603165390062286416969199797478253444112 1

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        751      * ALL CHANNELS = 0.7510E+03      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4820E+00      * R . M . S = 0.2188E+00
```

```
HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210             SLICE X                    DATE  17/12/91              NO =   6

SLICE X     NO =   2     YMIN=  0.3333E+00  YMAX=  0.6667E+00

      25                                  I I
      24                                  I I I   I                                          I
      23                                  I III   I                                          I
      22                                  I IIIII I I                                        I
      21                                  I IIIII I I                                        I
      20                                 IO OIIII I I                                        I
      19                             II  IIIIIOII O I                               I        O
      18                             II  IIIIOIII III                               I     I  I
      17                             II IIIIIIIOOIIIO I                 I         I I     I  I
      16                             II IOIIIIIIIIIII I                 I      I  I I    II  I
      15                          I  OO II O IIIIIIIIII                 I  I   I  I O   IIII I
      14                        I IIIII II I I III OIII                 I  I   IIII I   IIOII
      13                        I IIIII OI I   IIO IIIO                 O  I   IIIO I   IIIII
      12                        I IIIIIIII I     I I II            I    I  I   OIII III IOIII
      11                        I OII  II        I I OI            I    II OI IIIII  IIIOIIOI      I  I
      10                        O IOO  II        I   II            I   III II IIOOI  IIIII IO      I  I
       9                        I III  O             I I           OI  I I II IIII   OOIII II  I  III II
       8                       II III  I             I IIII        II  I O IOIO II I IIOI  II  I IIOI OI
       7                       II  II  I               IIII        II  O I  III II I III    I  I IIII II
       6                     I I I     I               OIII  I  II IO II I  III    I III      IOIIOIOIIO I
       5                     I O I                     IOOO  IIIII  IIII     O     O          IIIOI II III  I
       4                    IO I O                     IIIII OIIOO  IIO   I  I     I          OIOII IO IIO II I
       3                    II I I                      IIII IOOII   OI   I  I     I          I II   I  OI IO I
       2                  IIOII  I                         OIIIIII   II   O                   I I    I  II OI OI  I
       1                  OOI O                            IO             I                                I  IO  O

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10                    1 11111 112121111111111                 1  1   1111 1   111111
           1.             1124150410055936050897739471365552143344 963473821858200355998124109464568648634 23 21  1

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        707      * ALL CHANNELS = 0.7070E+03      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4943E+00      * R . M . S = 0.2244E+00

HIST FILLED WITH HFILL AND HRNDM2

HBOOK     ID =       210             SLICE X                    DATE  17/12/91              NO =   7

SLICE X     NO =   3     YMIN=  0.6667E+00  YMAX=  0.1000E+01

      26                                I
      25                                II     I
      24                                II II II
      23                                II II II                                    I
      22                                II II II                                    I
      21                                OI II II                                    I
      20                                IO II IO                                    I
      19                                II OO OI                                    I
      18                                II IIIIIII                                  O
      17                            I   IIIIIIIIII I                                II
      16                            I    IIIIIIIIIII                              I II
      15                            I     IIIII IIII                             II II
      14                            II    I  O  OOII                             II II
      13                            OI    O  I  IIIO                             II  O
      12                            II I  I  I  IIOI                    I   I  I IO  I  I
      11                            II I  I  I  IIII    I               I   I  I OI  IIII
      10                           IIO I  I       II I  I               I I I II II  IIIII  I
       9                           I IIO          I  I  I               O I O IO III  IIOI  I
       8                           I III            IIIIO               IIIII II I I  OOII  I       I
       7                           O III            IOIII               IIOII OI   I  IIIO  O       I
       6                           I  OI            IIIII  I         I IIIIII II   O  IIIIIII  IIIII
       5                     I    II I  I             OIOO   II  I III I I OIO  I I  I     IIIIIIIIIIO   I
       4                     I  I III   I             I II IIOII IIIIIIO O I I I  I  I      OO IIOOOOOI IIII   II  I
       3                     O  I OOI                 I II IIIOI OIOOOII I I I I  O         II OOIIIIII IOII   II  I
       2                 I IIIOIIIO                       OOIIOIIOIIIOIII     O  I         II IIIIIII IOIOO IIOO IO
       1                 O  OOIO  I                       II  IO I   I O      I                       OI II OOII OI

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10                        11  221111121111                             11 11
           1.            1 3112133273069103994904423575582243213233324149575927931268388974473344444512322 1122 12

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        542      * ALL CHANNELS = 0.5420E+03      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4760E+00      * R . M . S = 0.2167E+00
```

4.3 Editing operations

Histograms are output on the line printer by calling `HISTDO` or `HPRINT`, according to the following specifications:

One-dimensional histograms

One histogram per page is printed, writing the global title, date, title, drawing the contour of the histogram in the range between the minimum and the maximum content, with the contents scale adjusted to fit on one page, followed by channel number, contents, and low edge of each channel, plus some statistics about the histogram itself (entries, mean value, standard deviation and so on). If the number of channels is greater than 100, the histogram is printed on several pages.

Two-dimensional histograms

They can use more than one page, according to the number of channels in X and Y, and in X and Y both channel number and lower edge of each channel are printed.

The plot statistics reported at the bottom consists of a table of 9 numbers, corresponding to the total contents in each of the following classes:

N1	N2	N3
N4	N5	N6
N7	N8	N9

N1	=	underflow X	,	overflow Y
N2	=	X inside range	,	overflow Y
N3	=	overflow X	,	overflow Y
N4	=	underflow X	,	Y inside range
N5	=	X inside range	,	Y inside range
N6	=	overflow X	,	Y inside range
N7	=	underflow X	,	underflow Y
N8	=	X inside range	,	underflow Y
N9	=	overflow X	,	underflow Y

Any of these numbers can in fact be smaller than the real sum of the contents, in the case of saturation of a cell.

For information on how to suppress the plot statistics, see `HIDOPT(ID,'NPST')`

All projections, bands and slices follow the plot they refer to as 1-dimensional histograms in the order in which they were booked.

Histograms are printed with the channels oriented along computer printer output columns, so if they extend to more than 100 channels they will be chopped into pieces of 100 channels each and printed one after the other on separate pages. The same is true for 2-dimensional histograms, the limit for tables being related to the maximum value that has to be stored in each channel (see remarks about `HTABLE`).

Using the entries described in this chapter, it is possible to modify the standard output format, adding or suppressing some information, choosing a different printed presentation, and modifying the mapping of histograms onto computer output pages.

One-dimensional histograms can also be printed with channels oriented along rows instead of columns, to avoid chopping up those having more than 100 channels.

All editing entries must be executed **before** calling `HISTDO` or `HPRINT`. Some of them can be executed any time after the booking, others require that the histogram is already full, so it is good practice to group them (perhaps in one single subroutine) and execute them just before printing.

4.3.1 Index and General Title

It is sometimes convenient to print just the index of plots without printing all the plots themselves.

```
CALL HINDEX
```

Action: Prints the index.

Remark:

Routine `HISTDO` generates the index automatically.

```
CALL HTITLE (CHGTIT)
```

Action: Defines a general title to be printed as the header line of each histogram.

Input parameter:

`CHGTIT` general title (character variable of up to 80 characters).

Remark:

- See `HBOOK1` about passing the title
- A call to this routine does not destroy any given individual histogram titles.

4.3.2 What to Print (1-dimensional histogram)

Each 1-dimensional histogram output consists of several parts, some compulsory and some optional:

general title	compulsory (if defined)
identifier, date and title	compulsory
the histogram itself	default = yes
channel numbers	default = yes
channel contents	default = yes
error values	default = no
value of the superimposed function (if any)	default = no
integrated contents	default = no
low edge of channels	default = yes
statistical information	default = yes

Routine `HIDOPT` can be used to change the above defaults.

```
CALL HIDOPT (ID,CHOPT)
```

Action: Select an option for a given histogram.

Input parameters:

`ID` Histogram identifier. If `ID=0` the option is set for all histograms.

`CHOPT` Character variable specifying the option chosen (see table 4.1.)

Option	**Action**
SETD*	Set all options to the default values
SHOW	Print all the options currently set
BLAC	1 Dim histogram printed with X characters (see HPCHAR)
CONT*	1 Dim histogram is printed with the contour option
STAR	1 Dim histogram is printed with a * at the Y value (see HPCHAR)
SCAT*	Print a 2 Dim histogram as a scatter-plot
TABL	Print a 2 Dim histogram as a table
PROS*	Plot errors as the Spread of each bin in Y for profile histograms
PROE	Plot errors as the mean of each bin in Y for profile histograms
STAT	Mean value and RMS computed at filling time (double precision)
NSTA*	Mean value and RMS computed from bin contents only
ERRO	Errors bars printed as SQRT(contents)
NERR*	Do not print print error bars
INTE	Print the values of integrated contents bin by bin
NINT*	Do not print integrated contents
LOGY	1 Dim histogram is printed in Log scale in Y
LINY*	1 Dim histogram is printed in linear scale in Y
PCHA*	Print channel numbers
NPCH	Do not print channel numbers
PCON*	Print bin contents
NPCO	Do not print bin contents
PLOW*	Print values of low edge of the bins
NPLO	Do not print the low edge
PERR	Print the values of the errors for each bin
NPER*	Do not print the values of the errors
PFUN	Print the values of the associated function bin by bin
NPFU*	Do not print the values of the associated function
PHIS*	Print the histogram profile
NPHI	Do not print the histogram profile
PSTA*	Print the values of statistics (entries,mean,RMS,etc.)
NPST	Do not print values of statistics
ROTA	Print histogram rotated by 90 degrees
NROT*	Print histogram vertically
1EVL	Force an integer value for the steps in the Y axis
AEVL*	Steps for the Y axis are automatically computed
2PAG	Histogram is printed over two pages
1PAG*	Histogram is printed in one single page

A star `'*'` indicates that the option is the default setting.

Table 4.1: List of available HBOOK options, which can be set by `HIDOPT`

CALL **HSTAF** (CHOPT)

If CHOPT='YES' statistics are computed at filling time. All the histograms created (via HBOOK1 or HBOOK2) after a CALL HSTAF('YES'), will have the IDOPT option 'STAT' automatically activated. This is very useful when histograms are created in an indirect way like in the command NT/PLOT. The way to activate this option in paw is:

```
PAW > OPTION HSTA
PAW > NT/PLOT 10.x IDH=100
```

4.3.3 Graphic Choices (1-dimensional histogram)

A histogram is normally represented by drawing its contour, with a channel being represented by one character along the printed line at a displacement corresponding to the bin contents, but alternative graphic presentations are available. If some contents are negative a dotted line is drawn at Y=0.

CALL **HPCHAR** (CHOPT,CHAR)

Action: Selects a printing character different from the default for histograms that are not drawn contour only, or for superimposed functions.

Input parameters:

CHOPT Printing option for which the character applies. It can be:

'BLAC'	when HIDOPT(ID,'BLAC') is called
'FUNC'	when HBFUN1, HFUNC or HIDOPT(ID,'STAR') have been called.
'STAR'	when HBFUN1, HFUNC or HIDOPT(ID,'STAR') have been called.

CHAR Character chosen.

Example:

```
CALL HPCHAR ('STAR','.')
```

Replaces the asterisk with a dot in all histograms with the HIDOPT(ID,'STAR') option selected.

CALL **HBIGBI** (ID,NCOL)

Action: For a given 1-dimensional histogram prints one channel over a certain number of columns.

Input parameters:

ID Histogram identifier

NCOL Number of columns to be used per bin.
NCOL=0 meams use the full width of the page.

Remark:

- HBIGBI will be applied to histograms output across the page only, i.e. if NCHAN*NCOL$\leq$100.
  If this relation is not fulfilled, then the value of NCOL will be reduced till it obeys the inequality. No restrictions if the histogram is printed down the page (HIDOPT(ID,'ROTA')).
- If the histogram is 2-dimensional, the "bigbin" option is selected on all its projections, etc.
- It can be redefined at any time.

4.3.4 Scale Definition and Normalization

Note that, whenever a multiplication by a power of ten appears in the output, it means that the quantity it refers to has been multiplied by that **factor** before being printed.

The scaling of the contents while outputing a 1-dimensional histogram is chosen by default to be linear and to span the interval between the minimum and the maximum of the contents of the channels.

The options described below allow:

- the choice of a logarithmic contents scale
- the definition of the limits of the scale
- the choice of the minimum step of the scale to be an integer
- the choice of the same scale for several histograms so that they can be compared more easily
- the normalisation of the total contents to a given value

If the identifier corresponds to a 2-dimensional histogram, they act on projections, slices, bands if any.

`CALL` **HMAXIM** `(ID,FMAX)` and `CALL` **HMINIM** `(ID,FMIN)`

Action: The scale limits for a histogram are not calculated automatically, but they as **set** to the specified values. The histogram contents are left intact.

Input parameters:

`ID`	Histogram identifier. `ID=0` Meams apply limit to **all** existing histograms.
`FMAX(FMIN)`	Maximum (minimum) for contents scale of given histogram. When `FMAX`$\leq$`FMIN` then the maximum and minimum values of the scale are computed automatically.

These routines can be called as often as desired for a given histogram.

`CALL` **HCOMPA** `(IDVECT,N)`

Action: Compare the contents of all histograms whose identifiers are contained in array `IDVECT` and assign them the same vertical scale. The comparison is made on the basis of the contents at the time routine is called.

Input parameters:

`IDVECT`	Array of `N` elements that contain the identifiers of the histograms to be compared The array must be dimensioned in the calling program to a length larger or equal to `N`.
`N`	Number of histograms to be compared `N=0` Means compare all existing 1-dimensional histograms.

Remark:

This routine can be called as often as desired to recompute the histogram scales.

`CALL` **HNORMA** `(ID,XNORM)`

Action: Normalizes the total contents of a 1-dimensional histogram when printing it. Original contents are left intact.

Input parameters:

`ID` Histogram identifier
`ID=0` Meams apply normalization factor to **all** existing histograms

`XNORM` Normalization factor to be applied to histogram when printing.
`XNORM=0` is illegal.

Remarks:

- If a function is superimposed, it is not affected by the normalization
- The histogram can have error bars
- The normalization factor can be redefined at any time.

`CALL` **HSCALE** `(ID,FACTOR)`

Action: The contents scale for a scatter plot is multiplied by a given factor.

Input parameters:

`ID` Histogram identifier
`ID=0` Means apply scaling factor to to **all** existing 2-dimensional histograms.

`FACTOR` Scaling factor to be applied to the contents scale.
`FACTOR=0` means automatic scaling. The range will be from the minimum to the maximum of the actual contents.

In a scatter-plot the contents scale starts at `0.` and increases in steps of `1.` The content of each channel is represented by one character, using the following scheme:

Value	Character	Range
	`.`	$0 < x < 1$
`1`	`+`	$1 \leq x < 2$
`2`	`2`	$2 \leq x < 3$
`3`	`3`	$3 \leq x < 4$
⋮	⋮	⋮
`9`	`9`	$9 \leq x < 10$
`10`	`A`	$10 \leq x < 11$
`11`	`B`	$11 \leq x < 12$
`12`	`C`	$12 \leq x < 13$
⋮	⋮	⋮
overflow	`*`	`VMX` $\leq x$

Remarks:

- The call has no effect on the projection of histogram `ID`.
- The scale can be redefined several times.

4.3.5 Page Control

Plots are output on the line printer file, each of them starting at the beginning of a new page. The page size is an installation default. One dimensional histograms take one page, and are printed across the page.

All those defaults can be overwritten as follows.

```
CALL HSQUEZ  ('YES'/'NO')
```

Action: Suppres / reestablish page eject.

```
CALL HPAGSZ  (NLINES)
```

Action: Changes the number of lines per page.

Input parameter:

`NLINES` Number of lines per page. The initial value of this parameter is system dependent (generally 56).

4.3.6 Selective Editing

Editing routines that draw histograms use a considerable amount of core, due to the complexity of the tasks they have to perform.

If the editing is performed by `HISTDO` or `HPRINT`, all the routines that deal with 1-dimensional histograms, rotated 1-dimensional histograms, 2-dimensional histograms, get loaded even if not used (e.g. even in the case where only 1-dimensional in standard format are required).

In such cases, selective editing options for different classes can be used to replace `HISTDO` or `HPRINT`.

```
CALL HPHIST  (ID,CHOICE,NUM)
```

Action: Edits 1-dimensional histogram or projection, slice or band of a 2-dimensional histogram on the line printer, in the standard representation.

Input parameters:

`ID` Histogram identifier. `ID=0` means edit all existing histograms.

`CHOICE` Character variable that selects subhistograms (irrelevant for the one-dimensional case). See routine `HUNPAK` for possible values.
`CHOICE=' '` is equivalent to `CHOICE='HIST'`

`NUM` Serial order of the slice or band. `NUM=0` is the same as `NUM=1`

Routine `HPHIST` ignores the option `HIDOPT(ID,'ROTA')`

CALL **HPROT** (ID,CHOICE,NUM)

Action: Analogous to HPHIST, but with a presentation down the page. Parameters, special values and remarks are the same as for HPHIST.

CALL **HPSCAT** (ID)

Action: Edits a 2-dimensional histogram as a scatter-plot.

Input parameter:

ID Histogram identifier (2-dimensional).
ID=0 means to edit all histograms.

Remark:

- The 2-dimensional histogram with identifier ID might have been booked as a table and will be output as a scatter-plot
- Projections are not printed, see HPHS.

CALL **HPTAB** (ID)

Action: Edits a 2-dimensional histogram as a table.

Input parameter:

ID Histogram identifier (2-dimensional).
ID=0 means to edit all histograms.

Remark:

- The 2-dimensional histogram with identifier ID might have been booked as a scatterplot but it will be output as a table.

The following two routines can be used to save space when the program does not print tables and rotated 1-dimensional histograms.

CALL **HPHS** (ID)

Action: Analogous to HPRINT, but ignore tables and HIDOPT(ID,'ROTA').

CALL **HPHST** (ID)

Action: Analogous to HPRINT, but ignore HIDOPT(ID,'ROTA').

4.3.7 Printing after System Error Recovery

The operating systems of some computers define CP time limits for job execution, and abort the job with a system error when this occurs. In most of the cases, users recover from the time limit error transfering control to a summary subroutine that will eventually edit the histograms, calling, e.g. `HISTDO`. This can be inconvenient if the time limit condition has been reached in `HISTDO` or other printing routines, because the printing will restart from the beginning. To avoid this, `HBOOK` can be instructed to start printing just where it stopped before.

`CALL` **HPONCE**

Action: In case of system error recovery during histogram editing, a possible recovery editing will start where the original printing stopped.

Remark:

If `HPONCE` has been called before printing, then a histogram that has been output completely will no longer be printed.

4.3.8 Changing Logical unit numbers for output and message files

The output file, containing the histograms, is by default the line printer file, where also error messages will be written.
The names of the result and error files can be redefined using:

`CALL` **HOUTPU** `(LOUT)` and `CALL` **HERMES** `(LERR)`

Action: Replaces the logical unit value for the results (`HOUTPU`) or the error messages (`HERMES`).

Input parameters:

`LOUT` logical unit number of the file with the printed output

`LERR` logical unit number of the file with error messages

Example of printing options

```
      SUBROUTINE HEXAM4
*.==========>
*.           TEST PRINTING OPTIONS
*..=========> ( R.Brun )
      DATA XMIN,XMAX/0.,1./
*.__________________________________________
*
*             Get hist 110 from data base
*
      CALL HRGET(110,'hexam.dat',' ')
*
*             Book 2 new histograms
*
      CALL HBOOK1(1000,'TEST OF PRINTING OPTIONS',40,1.,41.,0.)
      CALL HBOOK1(2000,'TEST OF BIG BIN',20,XMIN,XMAX,0.)
      CALL HIDOPT(1000,'ERRO')
*
*             Fills new IDs
*
      DO 10 I=1,40
         J=2*I-1
         W=HI(110,J)+HI(110,J+1)
         CALL HFILL(1000,FLOAT(I),0.,W)
  10  CONTINUE
*
      DO 20 I=1,20
         J=5*I
         W=SQRT(HI(110,J))
         CALL HIX(2000,I,X)
         CALL HF1(2000,X,W)
  20  CONTINUE
*
*             Set various printing options
*
      CALL HIDOPT(110,'BLAC')
      CALL HIDOPT(110,'NPLO')
      CALL HIDOPT(110,'NPST')
      CALL HPHIST(110,'HIST',1)
      CALL HMAXIM(110,100.)
      CALL HIDOPT(110,'1EVL')
      CALL HIDOPT(110,'NPCH')
      CALL HPHIST(110,'HIST',1)
*
      CALL HIDOPT(1000,'NPCH')
      CALL HIDOPT(1000,'NPCO')
      CALL HPROT(1000,'HIST',1)
      CALL HIDOPT(1000,'LOGY')
      CALL HPRINT(1000)
      CALL HIDOPT(1000,'INTE')
      CALL HIDOPT(1000,'PERR')
      CALL HIDOPT(1000,'ROTA')
      CALL HPRINT(1000)
*
      CALL HBIGBI(2000,5)
      CALL HIDOPT(2000,'NPCO')
      CALL HIDOPT(2000,'NPLO')
```

```
      CALL HPRINT(2000)
*
      END
```

Output Generated

```
THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCTION HTFUN1

HBOOK     ID =       110                                    DATE  17/12/91             NO =   8

     172                                    7
     168                                    X
     164                                    X
     160                                   2X
     156                                   XX 5
     152                                   XX5X
     148                                   XXXX7
     144                                 25XXXXX
     140                                 XXXXXXX5
     136                                 XXXXXXXX
     132                                 XXXXXXXX
     128                                 XXXXXXXX2
     124                                5XXXXXXXXX
     120                               5XXXXXXXXXX
     116                               XXXXXXXXXXX
     112                               XXXXXXXXXXX
     108                               XXXXXXXXXXX
     104                              5XXXXXXXXXXX2
     100                              XXXXXXXXXXXXX
      96                              XXXXXXXXXXXXX 7
      92                              XXXXXXXXXXXXX7X
      88                             XXXXXXXXXXXXXXXX
      84                             XXXXXXXXXXXXXXXX 5                              2 7
      80                             XXXXXXXXXXXXXXXX X                        2     X X  5
      76                             XXXXXXXXXXXXXXXX X                        X2X  2X X  X
      72                             XXXXXXXXXXXXXXXX XX                       XXX2 XX X  X 2
      68                             XXXXXXXXXXXXXXXX2XX                    2  XXXX2XXXX2XXXX
      64                             XXXXXXXXXXXXXXXXXXX                  75X  XXXXXXXXXXXXXX7
      60                           X XXXXXXXXXXXXXXXXXXX                  XXX 7XXXXXXXXXXXXXXX
      56                           XXXXXXXXXXXXXXXXXXXXX                  XXX2XXXXXXXXXXXXXXXX 5
      52                           XXXXXXXXXXXXXXXXXXXXXX               X5XXXXXXXXXXXXXXXXXXXX2X
      48                          5XXXXXXXXXXXXXXXXXXXXXX2              XXXXXXXXXXXXXXXXXXXXXXXX
      44                          XXXXXXXXXXXXXXXXXXXXXXXX             5XXXXXXXXXXXXXXXXXXXXXXXX5  X
      40                          XXXXXXXXXXXXXXXXXXXXXXXX2           7XXXXXXXXXXXXXXXXXXXXXXXXXX  X
      36                          XXXXXXXXXXXXXXXXXXXXXXXXX           XXXXXXXXXXXXXXXXXXXXXXXXXXX52XX
      32                          XXXXXXXXXXXXXXXXXXXXXXXXX    2     5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      28                         7XXXXXXXXXXXXXXXXXXXXXXXXX7 5 X 7  2XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX2 X
      24                       2XXXXXXXXXXXXXXXXXXXXXXXXXXXX2X X X2 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX X25
      20                      5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX X5XX5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX 7
      16                      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX7X
      12                     7XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX77
       8                 5 5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX5727
       4            5225XX5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

CHANNELS 100   0                                                                                                  1
          10   0         1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                          1111111111111
          10                112224658012445755432099687543222121221233455666557776678686676664543343222221111
           1.       21124626818147606828212710478511552225771649871850922032539736953183588893942434650812591167574
```

```
THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCTION HTFUN1

HBOOK     ID =       110                                        DATE  17/12/91              NO =   9

     100                              XXXXXXXXXXXXX
      96                              XXXXXXXXXXXXX 7
      92                              XXXXXXXXXXXXX7X
      88                             XXXXXXXXXXXXXXXX
      84                             XXXXXXXXXXXXXXXX 5                              2 7
      80                             XXXXXXXXXXXXXXXX X                        2     X X  5
      76                             XXXXXXXXXXXXXXXX X                        X2X  2X X  X
      72                             XXXXXXXXXXXXXXXX XX                       XXX2 XX X  X 2
      68                             XXXXXXXXXXXXXXXX2XX                    2  XXXX2XXXX2XXXX
      64                             XXXXXXXXXXXXXXXXXXX                  75X  XXXXXXXXXXXXXX7
      60                           X XXXXXXXXXXXXXXXXXXX                  XXX 7XXXXXXXXXXXXXXX
      56                           XXXXXXXXXXXXXXXXXXXXX                  XXX2XXXXXXXXXXXXXXXX 5
      52                           XXXXXXXXXXXXXXXXXXXXXX               X5XXXXXXXXXXXXXXXXXXXX2X
      48                          5XXXXXXXXXXXXXXXXXXXXXX2              XXXXXXXXXXXXXXXXXXXXXXXX
      44                          XXXXXXXXXXXXXXXXXXXXXXXX             5XXXXXXXXXXXXXXXXXXXXXXXX5  X
      40                          XXXXXXXXXXXXXXXXXXXXXXXX2           7XXXXXXXXXXXXXXXXXXXXXXXXXX  X
      36                          XXXXXXXXXXXXXXXXXXXXXXXXX           XXXXXXXXXXXXXXXXXXXXXXXXXXX52XX
      32                          XXXXXXXXXXXXXXXXXXXXXXXXX    2     5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      28                         7XXXXXXXXXXXXXXXXXXXXXXXXX7 5 X 7  2XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX2 X
      24                       2XXXXXXXXXXXXXXXXXXXXXXXXXXXX2X X X2 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX X25
      20                      5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX X5XX5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX 7
      16                      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX7X
      12                     7XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX77
       8                 5 5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX5727
       4            5225XX5XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

CONTENTS 100                          1111111111111
          10                 112224658012445755432099687543222121221233455666557776678686676664543343222221111
           1.       21124626818147606828212710478511552225771649871850922032539736953183588893942434650812591167574

TEST OF PRINTING OPTIONS

HBOOK     ID =      1000                                        DATE  17/12/91              NO =  10

    100                               1   1   1   1   1   1   2   2   2   2   2   2   3   3   3
     10       1   3   4   6   8   9   1   2   4   6   7   9   0   2   4   5   7   8   0   2   3
      1.      6   2   8   4   0   6   2   8   4   0   6   2   8   4   0   6   2   8   4   0   6

 LOW EDGE I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---
    2
    2
    3      O
    4      O
    5      IOI
    6       OI
    7        IOI
    8           IO-I
    9               IO-I
   10                      I-O-I
   11                                I-O--I
   12                                                  I--O--I
   13                                                              I--O---I
   14                                                                        I---O---I
   15                                                                                   I---O---I
   16                                                                             I---O----I
   17                                                                         I---O---I
   18                                                          I---O---I
   19                                                 I--O--I
   20                                       I--O--I
   21                                  I-O--I
   22                        I-O-I
   23                IO-I
   24              IO-I
   25                IO-I
   26                IO-I
   27               IO-I
   28                     I-O-I
   29                           I-O-I
   30                               I-O--I
   31                                  I--O--I
   32                               I-O--I
   33                                        I--O--I
   34                                       I--O--I
   35                                     I--O--I
   36                                        I--O--I
   37                                       I--O---I
   38                                       I--O--I
   39                                     I--O--I
   40                               I-O--I
 LOW EDGE I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---

    100                               1   1   1   1   1   1   2   2   2   2   2   2   3   3   3
     10       1   3   4   6   8   9   1   2   4   6   7   9   0   2   4   5   7   8   0   2   3
      1.      6   2   8   4   0   6   2   8   4   0   6   2   8   4   0   6   2   8   4   0   6

* ENTRIES =         40      * ALL CHANNELS = 0.4556E+04      * UNDERFLOW = 0.0000E+00       * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E+01      * MEAN VALUE   = 0.2331E+02      * R . M . S = 0.9558E+01
```

```
TEST OF PRINTING OPTIONS

HBOOK     ID =      1000                                         DATE  17/12/91              NO =  11

     354.814                 0I
     316.228                0I00
     281.838               II  I
     251.189               0    0
     223.872              I     II
     199.526              0      0
     177.828              I      II            I  II
     158.489                      0            00I000I
     141.254             I        II         0 II0III0
     125.893             0         0        0II      II
     112.202             I                 II 0       0
     100                                I      0
      89.125            I           0      I
      79.433            0           I     I
      70.795            I                 0
      63.096                              I
      56.234           I             I II
      50.119           0             0I00I
      44.668           I             I0II0
      39.811           I              I  I
      35.481          I               I
      31.623          0
      28.184          I
      25.119          I
      22.387
      19.953
      17.783         I
      15.849         I
      14.125         0
      12.589         I
      11.22         II
      10            I
       8.913       I0
       7.943       II
       7.079       II
       6.31        0I
       5.623       II
       5.012       I
       4.467       I
       3.981       I
       3.548     II
       3.162     II
       2.818     II
       2.512     II
       2.239     00

LOW-EDGE  10            1111111111222222222233333333334
           1.  1234567890123456789012345678901234567890

* ENTRIES =         40      * ALL CHANNELS = 0.4556E+04       * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E+01      * MEAN VALUE   = 0.2331E+02       * R . M . S = 0.9558E+01
```

```
TEST OF PRINTING OPTIONS

HBOOK     ID =      1000                                        DATE  17/12/91              NO =  12

                        100                                                                       1   1   1   1   2   3
                         10                               1   1   1   1   2   3   3   5   6   7   0   2   5   9   5   1
                          1.  2   2   3   3   5   6   7   0   2   5   9   5   1   9   0   3   9   0   5   8   9   1   6
                          0   0   5   1   9   0   3   9   0   5   8   9   1   6   8   1   1   4   0   8   4   5   1   2
                          0   0   1   6   8   1   1   4   0   9   5   5   2   2   1   2   0   3   0   9   9   3   9   3

 LOW EDGE  INTEGRAT   ERRORS  I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I--
    2
    2
    3         2         1.414 O--------I
    4         4         1.414 O--------I
    5        10         2.449           I--------O-----I
    6        18         2.828                 I-------O----I
    7        32         3.742                             I----O---I
    8        61         5.385                                           I---O--I
    9       106         6.708                                                    I--O-I
   10       179         8.544                                                             I-O-I
   11       295        10.77                                                                      I-O-I
   12       485        13.784                                                                              I-OI
   13       725        15.492                                                                                   IOI
   14      1008        16.823                                                                                      IOI
   15      1336        18.111                                                                                        IOI
   16      1640        17.436                                                                                       IOI
   17      1925        16.882                                                                                      IOI
   18      2151        15.033                                                                                 I-OI
   19      2337        13.638                                                                              IO-I
   20      2484        12.124                                                                          IO-I
   21      2608        11.136                                                                       IO-I
   22      2690         9.055                                                               I-O-I
   23      2738         6.928                                                     I--O-I
   24      2778         6.325                                                  I--O-I
   25      2825         6.856                                                     I-O--I
   26      2873         6.928                                                     I--O-I
   27      2916         6.557                                                   I--O-I
   28      2985         8.307                                                            I-O-I
   29      3079         9.695                                                                  IO-I
   30      3192        10.63                                                                      I-OI
   31      3319        11.269                                                                       I-OI
   32      3431        10.583                                                                     IO-I
   33      3581        12.247                                                                          I-OI
   34      3726        12.042                                                                         I-OI
   35      3864        11.747                                                                         IO-I
   36      4013        12.207                                                                          IO-I
   37      4161        12.166                                                                          IO-I
   38      4307        12.083                                                                          IOI
   39      4444        11.705                                                                        I-OI
   40      4556        10.583                                                                     IO-I
 LOW EDGE  INTEGRAT   ERRORS  I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I---I--

                        100                                                                       1   1   1   1   2   3
                         10                               1   1   1   1   2   3   3   5   6   7   0   2   5   9   5   1
                          1.  2   2   3   3   5   6   7   0   2   5   9   5   1   9   0   3   9   0   5   8   9   1   6
                          0   0   5   1   9   0   3   9   0   5   8   9   1   6   8   1   1   4   0   8   4   5   1   2
                          0   0   1   6   8   1   1   4   0   9   5   5   2   2   1   2   0   3   0   9   9   3   9   3

* ENTRIES =         40      * ALL CHANNELS = 0.4556E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E+01      * MEAN VALUE   = 0.2331E+02      * R . M . S = 0.9558E+01
```

```
TEST OF BIG BIN

HBOOK     ID =      2000                                        DATE  17/12/91              NO =  13

      13.25                             -----
      13                                I   I
      12.75                             I   I
      12.5                              I   I
      12.25                             I   I
      12                                I   I
      11.75                             I   I
      11.5                              I   I
      11.25                             I   I-----
      11                           -----I        I
      10.75                        I             I
      10.5                         I             I
      10.25                        I             I
      10                           I             I
       9.75                        I             I
       9.5                         I             I
       9.25                        I             I-----
       9                           I                  I                    -----
       8.75                        I                  I                    I   I-----
       8.5                         I                  I                    I        I
       8.25                        I                  I                    I        I-----
       8                           I                  I               -----I             I
       7.75                        I                  I               I                  I
       7.5                         I                  I               I                  I
       7.25                        I                  I               I                  I
       7                      -----I                  I               I                  I-----
       6.75                   I                       I               I                       I-----
       6.5                    I                       I               I                            I
       6.25                   I                       I               I                            I
       6                      I                       I               I                            I
       5.75                   I                       I               I                            I
       5.5                    I                       I          -----I                            I
       5.25                   I                       I-----     I                                 I
       5                      I                            I     I                                 I
       4.75                   I                            I     I                                 I-----
       4.5                    I                            I     I                                      I
       4.25                   I                            I-----I                                      I
       4                      I                                                                         I
       3.75                   I                                                                         I
       3.5               -----I                                                                         I-----
       3.25              I                                                                                   I
       3                 I                                                                                   I
       2.75              I                                                                                   I
       2.5               I                                                                                   I
       2.25              I                                                                                   I
       2            -----I                                                                                   I-----
       1.75         I                                                                                             I
       1.5          I                                                                                             I
       1.25         I                                                                                             I
       1            I                                                                                             I
        .75         I                                                                                             I
        .5          I                                                                                             I
        .25         I                                                                                             I

CHANNELS  10       0                                            1                                                 2
           1       1    2    3    4    5    6    7    8    9    0    1    2    3    4    5    6    7    8    9    0

* ENTRIES =         20      * ALL CHANNELS = 0.1282E+03      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.5000E-01      * MEAN VALUE   = 0.4963E+00      * R . M . S = 0.2391E+00
```

Chapter 5: Accessing Information

The information contained in a histogram can be made available in local Fortran variables with the commands described below. It is possible to access channel contents (all together or individually) and also mean value and standard deviation of 1-dimensional distributions.

5.1 Testing if a histogram exists in memory

```
LOGVAR = HEXIST (ID)
```

Action: Returns a logical value of `.TRUE.` if and histogram exists and `.FALSE.` otherwise.

Input parameter:

`ID` Histogram identifier

Remark:

`HEXIST` has to be declared LOGICAL in the calling routine.

5.2 List of histograms

```
CALL HID1 (IDVECT*,N*)
```

Action: Returns the number and identifiers of all existing 1-dimensional histograms.

Output Parameters:

`IDVECT` Array which will contain the histogram identifiers, in booking order. Its dimension should be at least equal to the number of 1-dimensional histograms.

`N` Number of 1-dimensional histograms.

```
CALL HID2 (IDVECT*,N*)
```

Action: Returns the number and identifiers of all existing 2-dimensional histograms. (see `HID1`).

```
CALL HIDALL (IDVECT*,N*)
```

Action: Returns the number and identifiers of **all** existing histograms. (see `HID1`).

5.3 Number of entries

```
CALL HNOENT (ID,NOENT*)
```

Action: Provides the number of entries of a **memory resident** histogram, plot or Ntuple. **N.B. The value returned includes also the contents of the overflow and underflow bins.**

Input parameter:

`ID` Histogram identifier

Output Parameter:

`NOENT` Number of entries in the given histogram.

5.4 Histrogram attributes Contents

CALL **HKIND** (ID,KIND*,CHOPT)

Action: Returns the attributes of a histogram

Input parameters:

ID Histogram identifier

CHOPT Character variable specifying desired option.

' ' (default) only KIND(1) is filled, according to the following convention:

- -1 unknown kind of histogram;
- 0 identifier ID does not exits;
- 1 one-dimensional plot;
- 2 two-dimensional plot;
- 3 table;
- 4 Ntuple;
- 8 profile histogram.

'A' More complete information on histogram; all "status bits" characterizing the histogram are expanded into the vector KIND(32), using the following conventions:

KIND(1)	HBOOK1	KIND(17)	HBIGBI
KIND(2)	HBOOK2	KIND(18)	HNORMA
KIND(3)	HTABLE	KIND(19)	HSCALE
KIND(4)	NTUPLE	KIND(20)	HMAXIM
KIND(5)	Automatic binning	KIND(21)	HMINIM
KIND(6)	Variable bin sizes	KIND(22)	HINTEG
KIND(7)	HBSTAT	KIND(23)	H2PAGE
KIND(8)	Profile histogram	KIND(24)	H1EVLI
KIND(9)	HBARX	KIND(25)	HPRSTA
KIND(10)	HBARY	KIND(26)	HLOGAR
KIND(11)	HERROR	KIND(27)	HBLACK
KIND(12)	HFUNC	KIND(28)	HSTAR
KIND(13)	HROTAT	KIND(29)	HPRCHA
KIND(14)	HPRFUN	KIND(30)	HPRCON
KIND(15)	HPRLOW	KIND(31)	HPRERR
KIND(16)	HPRHIS		

Output parameter:

KIND Integer array (of dimension 32) which will contain the information returned about histogram ID. See above for a detailed explanation of its contents.

5.5 Contents

```
CALL HUNPAK (ID,CONTEN*,CHOICE,NUM)
```

Action: Transfer the contents of a histogram or a selected projection of a 2-dimensional histogram into a local array.

Input parameters:

`ID`	Histogram identifier
`CHOICE`	Character variable selecting subhistograms (irrelevant for the 1-dimensional case)

`'HIST'`	the 2-dimensional histogram itself. Default `CHOICE=' '` is equivalent to `'HIST'`.
`'PROX'`	X projection
`'PROY'`	Y projection
`'SLIX'`	X slice
`'SLIY'`	Y slice
`'BANX'`	X band
`'BANY'`	Y band

`NUM`	Serial order of the slice or band that is requested. If `NUM=0`, it is assumed to be `1`.

Output Parameter:

`CONTEN`	Array to be dimensioned at least to the number of channels of the histogram (or projection), i.e. `DIMENSION CONTEN(NX)` in the 1-dimensional case and `DIMENSION CONTEN(NX,NY)` in the 2-dimensional case.

```
VARIAB = HI (ID,I) and VARIAB = HIJ (ID,I,J)
```

Action: These functions return the channel contents in a given histogram bin in the 1-dimensional and 2-dimensional case respectively.

Input parameters:

`ID`	Histogram identifier.
`I`	Bin number for `X`-coordinate. For `I=0` `HI` returns the number of underflows in `X`.
`J`	(`HIJ` only) Bin number for `Y`-coordinate. For `J=0` `HIJ` returns the number of underflows in `Y`.

When `NX, NY` are respectively the number of channels in `X` and `Y` and `I=NX+1, J=NY+1`, then `HI/HIJ` returns the number of overflows

```
VARIAB = HX (ID,X) and VARIAB = HXY (ID,X,Y)
```

Action: These functions return the channel contents in a given histogram of the bin which contains a given value in `X` (1-dimensional case) or a given pair of `(X,Y)` (2-dimensional case).

Input parameters:

`ID`	Histogram identifier
`X`	X-value
`Y`	Y-value (2-dimensional case, i.e. `HXY` only)

5.6 Errors

`CALL HUNPKE (ID,CONTEN*,CHOICE,NUM)`

Action: Transfer the error contents of a histogram or a selected projection of a 2-dimensional histogram into the local array.

Input parameters:

`ID` Histogram identifier

`CHOICE` Character variable selecting subhistograms (irrelevant for the 1-dimensional case)

'HIST'	the 2-dimensional histogram itself
'PROX'	X projection
'PROY'	Y projection
'SLIX'	X slice
'SLIY'	Y slice
'BANX'	X band
'BANY'	Y band

`CHOICE=' '` is equivalent to `'HIST'`.

`NUM` Serial order of the slice or band that is requested.
If `NUM=0`, it is assumed to be `1`.

Output Parameter:

`CONTEN` Array to be dimensioned at least to the number of channels of the histogram (or projection), i.e. `DIMENSION CONTEN(NX)` in the 1-dimensional case and `DIMENSION CONTEN(NX,NY)` in the 2-dimensional case.

`VARIAB = HIE (ID,I)`

Action: Returns the value of the error that has been stored in a given 1-dimensional histogram channel. This corresponds to the square root of the sum of the squares of the weights.

Input parameters:

`ID` Histogram identifier.

`I` Channel (bin) number.

When `HBARX` has not been called `HIE` returns the square root of the contents of the given channel.

`VARIAB = HXE (ID,X)`

Action: Analogous to `HIE` but referring to the channel that contains a given X-value.

Input parameters:

`ID` Histogram identifier.

`X` X-value.

The same remark as for `HIE` applies.

```
VARIAB = HIJE (ID,I,J)
```

Action: Returns the value of the error that has been stored in a given 2-dimensional histogram channel. This is usually the square root of the contents of the channel, unless the user has filled his own values for the errors using `HPAKE`.

Input parameters:

`ID` Histogram identifier.

`I` Channel number in X ordinate.

`J` Channel number in Y ordinate.

```
VARIAB = HXYE (ID,X,Y)
```

Action: The same as for `HIJE`, except that the cell that contains both `X` and `Y` is computed, and the error in that cell returned.

Input parameters:

`ID` Histogram identifier.

`X` X value of point.

`Y` Y value of point.

5.7 Associated function

```
VARIAB = HIF (ID,I)
```

Action: Function returning the value of the associated function that has been stored in a given histogram channel. The function value will be zero if no associated function exists.

Input parameters:

`ID` Histogram identifier.

`I` Channel (bin) number.

5.8 Abscissa to channel number

```
CALL HXI (ID,X,I*) and CALL HXYIJ (ID,X,Y,I*,J*)
```

Action: Return the number of the channel (cell) which contains a given value in `X` (1-dimensional case) or a given pair of `(X,Y)` (2-dimensional case).

Input parameters:

`ID` Histogram identifier

`X` X-value

`Y` Y-value (2-dimensional case, i.e. `HXYIJ` only)

Output Parameters:

`I` Channel number in X-dimension.
Under/Overflows give `I=0` or `I=NCHANX+1` respectively.

`J` Channel number in Y-dimension (2-dimensional case, i.e. `HXYIJ` only).
Under/Overflows give `J=0` or `J=NCHANY+1` respectively.

`CALL` **HIX** `(ID,I,X*)` and `CALL` **HIJXY** `(ID,I,J,X*,Y*)`

Action: Returns the X-coordinate of the lower edge of a given channel (1-dimensional case) or the X-Y coordinate pair if a given cell (2-dimensional case).

Input parameters:

`ID` Histogram identifier.

`I` Channel or cell number in X-dimension, with $1 \leq$ `I` $\leq$ `NCHANX`.

`J` Cell number in Y-dimension with $1 \leq$ `J` $\leq$ `NCHANY`. (2-dimensional case, i.e. `HIJXY` only)

Output Parameters:

`X` X-coordinate of lower edge of channel or cell.

`Y` Y-coordinate of lower edge of cell. (2-dimensional case, i.e. `HIJXY` only).

5.9 Maximum and Minimum

`VARIAB =` **HMAX** `(ID)` and `VARIAB =` **HMIN** `(ID)`

Action: Returns the maximum or minimum channel contents of a histogram (without underflow and overflow). In the case of a 2-dimensional histogram the returned value does not take into account projections.

Input parameter:

`ID` Histogram identifier.

5.10 Rebinning

`CALL` **HREBIN** `(ID,X*,Y*,EX*,EY*,N,IFIRST,ILAST)`

Action: The specified channels of a 1-dimensional histogram are cumulated (rebinned) into new bins. The final contents of the new bin is the *average* of the original bins.

Input parameters:

`ID` Histogram identifier

`N` Number of elements in the output arrays `X,Y,EX,EY`.

`IFIRST` First histogram channel on which the rebinning has to be performed.

ILAST Last histogram channel on which the rebinning has to be performed.

Output Parameters:

X Array containing the new abscissa values.

Y Array containing the cumulated contents.

EX Array containing the X errors.

EY Array containing the Y errors.

The abscissa errors on the rebinned histogram are calculated to be half the bin width.

If the standard deviation on the abscissa values is instead required, then specify N as a negative number. In this case, the returned abscissa error for each bin is the bin width divided by the square root of 12.

This routine may also be used for histograms with unequal bin widths.

Example:

```
CALL HREBIN (ID,X,Y,EX,EY,25,11,85)
```

This call will regroup channels 11 to 85 three by three (25 bins) and return new abscissa, contents and error values in the output arrays. In this case the errors in X will be equal to 1.5*BINWIDTH.

```
CALL HREBIN (ID,X,Y,EX,EY,NCHAN,1,NCHAN)
```

This example shows a convenient way (using one subroutine call) to return the abscissa, contents and errors for a 1-dimensional histogram. Note that in this case the errors in X are equal to 0.5*BINWIDTH.

5.11 Integrated contents

VARIAB = **HSUM** (ID)

Action: Returns the integrated contents of a histogram (without underflow and overflow). In the case of a 2-dimensional histogram the returned value does not take into account projections.

Input parameter:

ID Histogram identifier.

5.12 Histogram definition

CALL **HDUMP** (ID)

Action: Prints a dump of the HBOOK storage area corresponding to a given histogram.

Input parameter:

ID Histogram identifier.
ID=0 will dump the whole of the HBOOK central memory storage area.

```
CALL HGIVE (ID,CHTITL*,NX*,XMI*,XMA*,NY*,YMI*,YMA*,NWT*,LOC*)
```

Action: Returns the booking parameters and address of a given histogram.

Input parameter:

`ID` Histogram identifier, cannot be zero.

Output Parameters:

`CHTITL` Histogram title (must be declared `CHARACTER*80`)

`NX` Number of channels in X

`XMI` Lower edge of first X channel

`XMA` Upper edge of last X channel

`NY` Number of channels in Y (zero for a 1-dimensional histogram)

`YMI` Lower edge of first Y channel

`YMA` Upper edge of last Y channel

`NWT` Number of machine words for the title. If there is no title, `NWT` is returned as `0` .

`LOC` Address of the histogram in the common `/PAWC/`.

5.13 Statistics

```
VARIAB = HSTATI (ID,ICASE,CHOICE,NUM)
```

Action: This function of type `REAL` returns the mean value, standard deviation or number of equivalent events of a 1-dimensional distribution. Underflows and overflows are not included in the calculation.

Input parameters:

`ID` Histogram identifier

`ICASE` `1` Mean value
`2` Standard deviation
`3` Number of equivalent events

`CHOICE` See `HUNPAK`

`NUM` See `HUNPAK`

If `HIDOPT(ID,'STAT')` has been called, the results are based on the information stored at filling time. Otherwise the results are based on the channel contents only. If x_i and w_i represent the value and contents of event i, then one has the following relations:

$$\begin{aligned}
\text{Expectation value } E(x) &= \frac{\sum_{i=1}^{n} w_i\, x_i}{\sum_{i=1}^{n}\, w_i} \\
\text{Mean value} &= E(x) \\
\text{Central moment of order n, } M(n) &= E((x - E(x))^n) \\
\text{Standard deviation} &= \sqrt{M(2)} \\
\text{Number of equivalent events} &= \frac{(\sum_{i=1}^{n} w_i)^2}{\sum_{i=1}^{n}\, w_i^2}
\end{aligned}$$

Chapter 6: Operations on Histograms

6.1 Arithmetic Operations

Histograms can be added, subtracted, divided or multiplied, provided their number of channels are the same.

```
CALL HOPERA  (ID1,CHOPER,ID2,ID3,C1,C2)
```

Action: Fills an histogram `I3` with values such that, logically (operands are the bin contents)

```
ID3 = C1 * ID1 (OPERATION) C2 * ID2
```

Input parameters:

`ID1,ID2` Operand histogram identifiers.

`CHOPER` Character variable specifying the kind of operation to be performed (`+`,`-`,`*`,`/`);
`'B'` compute binomial errors;
`'E'` compute error bars on the resulting histograms correctly, assuming that the input histograms `ID1` and `ID2` are independent.
For instance `/BE` will generate binomial errors for the division of `ID1` by `ID2`.

`ID3` Identifier of the histogram containing the result after the operation.

`C1,C2` Multiplicative constants.

Remark:

- `ID1`, `ID2` and `ID3` must have the same number of channels.
- If histogram `ID3` is not empty, its contents are overwritten
- The output histogram `ID3` can be either one of the input histograms `ID1` or `ID2`.
- If histogram `ID3` does not exist, it is created by `HOPERA` with the same specification as for histogram `ID1`.
- The mean value, standard deviation, etc. are calculated from the contents of the resulting histogram `ID3`, unless the `'STAT'` option is active and the operation is an addition or subtraction, in which case they are computed exactly.
- A division by zero gives zero.
- Negative results for bin contents in a packed histogram are meaningless
- The number of entries in the resulting histogram `ID3` is set to the sum of the entries in histograms `ID1` and `ID2`.
- When an operation is performed on two 1-dimensional histograms with the sum of the squares of the weights stored (option `HBARX`), the error on the resulting histogram is calculated supposing that the contents of the two input histograms `ID1` and `ID2` are uncorrelated. This is valid also for projections, slices and bands of 2-dimensional histograms.
- If histogram `ID3` is packed the number of bits allocated per channel (cell) has to be sufficient to store the results.

6.2 Statistical differences between histograms

```
CALL HDIFF (ID1,ID2,PROB*,CHOPT)
```

Action: Statistical test of compatibility in shape between two histograms using the Kolmogorov test. The histograms are compared and the probability that they could come from the same parent distribution is calculated.

The comparison may be done between two 1-dimensional histograms or between two 2-dimensional histograms. For further details on the method, see 6.2.2 below.

Input parameters:

`ID1` Identifier of first histogram to be compared.

`ID2` Identifier of second histogram to be compared.

`CHOPT` A character string specifying the options desired.

- `'D'` Debug printout, produces a blank line and two lines of information at each call, including the identifier numbers `ID`, the number of events in each histogram, the value of `PROB`, and the maximum Kolmogorov distance between the two histograms. For 2-dimensional histograms, there are two Kolmogorov distances (see below). If option `'N'` is specified, there is a third line of output giving the probalility `PROB` for shape and normalization alone separately.
- `'F1'` Histogram `ID1` has no errors (it is a function).
- `'F2'` Histogram `ID2` has no errors (it is a function).
- `'N'` Include a comparison of the relative normalization of the two histograms, in addition to comparing the shapes. The output parameter `PROB` is then a combined confidence level taking into account absolute contents.
- `'O'` Overflow, requests that overflow bins be taken into account (also valid for 2-dim).
- `'U'` Underflow, requests that underflow bins be taken into account (also valid for 2-dim).

For 2-dimensional histograms only

- `'L'` Left, include X-underflows in the calculation.
- `'R'` Right, include X-overflows in the calculation.
- `'B'` Bottom, include Y-underflows in the calculation.
- `'T'` Top, include Y-overflows in the calculation.

Output Parameter:

`PROB` The probability of compatibility between the two histograms.

Remark:

- Options `'O'` and `'U'` can also refer to 2-dimensional histograms, so that, for example the string `'UT'` means that underflows in X and Y and overflows in Y should be included in the calculation.
- The histograms `ID1` and `ID2` must exist and already have been filled before the call to `HDIFF`. They must also have identical binning (lower and upper limits as well as number of bins).

– The probability `PROB` is returned as a number between zero and one. A values close to one indicates very similar histograms, and a value near zero means that it is very unlikely that the two arose from the same parent distribution.
– By default (no options selected with `CHOPT`) the comparison is done only on the shape of the two histograms, without consideration of the difference in number of events, and ignoring all underflow and overflow bins.

6.2.1 Weights and Saturation

Weighted 1-dimensional histograms

It is possible to compare weighted with weighted histograms, and weighted with unweighted histograms, but only if `HBOOK` has been instructed to maintain the necessary information by appropriate calls (before filling) to `HBARX`. However it is not possible to take into account underflow or overflow bins if the events are weighted.

Saturated 1-dimensional histograms

If there is saturation (more than the maximum allowed contents in one or more bins), the probability `PROB` is calculated as if the bin contents were exactly at their maximum value, ignoring the saturation. This usually will result in a higher value of `PROB` than would be the case if the memory allowed the full contents to be stored, but not always. It should therefore be realized that the results of `HDIFF` are not accurate when there is saturation, and it is the user's responsability to avoid this condition.

2-dimensional histograms

Routine `HDIFF` cannot work if the events are weighted, since, in the current version of `HBOOK`, the necessary information is not maintained. `HDIFF` will also refuse to compare 2-dimensional histograms if there is saturation, since it does not have enough information in this case.

6.2.2 Statistical Considerations

The Kolmogorov Test

The calculations in routine `HDIFF` are based on the Kolmogorov Test (See, e.g. [11], pages 269-270). It is usually superior to the better-known Chisquare Test for the following reasons:

– It does not require a minimum number of events per bin, and in fact it is intended for unbinned data (this is discussed below).
– It takes account not only of the differences between corresponding bins, but also the sign of the difference, and in particular it is sensitive to a sequence of consecutive deviations of the same sign.

In discussing the Kolmogorov test, we must distinguish between the two most important properties of any test: its **power** and the calculation of its **confidence level.**

The Power

The job of a statistical test is to distinguish between a null hypothesis (in this case: that the two histograms are compatible) and the alternative hypothesis (in this case: that the two are not compatible). The power of a test is defined as the probability of rejecting the null hypothesis when the alternative is true. In our case, the alternative is not well-defined (it is simply the ensemble of all hypotheses except the null) so it is not possible to tell whether one test is more powerful than another in general, but only with respect to certain particular deviations from the null hypothesis. Based on considerations such as those given above, as well as considerable computational experience, it is generally believed that tests like the Kolmogorov or Smirnov-Cramer-Von-Mises (which is similar but more complicated to calculate) are probably the most powerful for the kinds of phenomena generally of interest to high-energy physicists. This is especially true for two-dimensional data where the Chisquare Test is of little practical use since it requires either enormous amounts of data or very big bins.

The Confidence Level for 1-dimensional data

Using the terms introduced above, the confidence level is just the probability of rejecting the null hypothesis when it is in fact true. That is, if you accept the two histograms as compatible whenever the value of `PROB` is greater than 0.05, then truly compatible histograms should fail the test exactly 5% of the time. The value of `PROB` returned by `HDIFF` is calculated such that it will be uniformly distributed between *zero* and *one* for compatible histograms, provided the data are not binned (or the number of bins is very large compared with the number of events). Users who have access to unbinned data and wish exact confidence levels should therefore not put their data into histograms, but should save them in ordinary Fortran arrays and call the routine `TKOLMO` which is being introduced into the Program Library. On the other hand, since `HBOOK` is a convenient way of collecting data and saving space, the routine `HDIFF` has been provided, and we believe it is the best test for comparison even on binned data. However, the values of `PROB` for binned data will be shifted slightly higher than expected, depending on the effects of the binning. For example, when comparing two uniform distributions of 500 events in 100 bins, the values of `PROB`, instead of being exactly uniformly distributed between *zero* and *one*, have a mean value of about 0.56. Since we are physicists, we can apply a useful rule: As long as the bin width is small compared with any significant physical effect (for example the experimental resolution) then the binning cannot have an important effect. Therefore, we believe that for all practical purposes, the probability value `PROB` is calculated correctly provided the user is aware that:

- The value of `PROB` should not be expected to have **exactly** the correct distribution for binned data.
- The user is responsible for seeing to it that the bin widths are small compared with any physical phenomena of interest.
- The effect of binning (if any) is always to make the value of `PROB` slightly too big. That is, setting an acceptance criterion of (`PROB>0.05` will assure that **at most** 5% of truly compatible histograms are rejected, and usually somewhat less.

The Confidence Level for Two-dimensional Data

The Kolmogorov Test for 2-dimensional data is not as well understood as for one dimension. The basic problem is that it requires the unbinned data to be ordered, which is easy in one dimension, but is not well-defined (i.e. not scale-invariant) in higher dimensions. Paradoxically, the binning which was a nuisance in one dimension is now very useful, since it enables us to define an obvious ordering. In fact there are two obvious orderings (horizontal and vertical) which give rise to two (in general different) Kolmogorov distance measures. Routine HDIFF takes the average of the two distances to calculate the probability value PROB, which gives very satisfactory results. The precautions necessary for 1-dimensional data also apply to this case.

6.3 Bin by bin histogram comparisons

```
CALL HDIFFB (ID1,ID2,TOL,NBINS,CHOPT,NBAD*,DIFFS*)
```

Action: Compare two histograms, bin by bin. For each bin, return the probability that the contents are from the same distribution. For details of the method see below.

The comparison may be done between two 1-dimensional histograms, two 2-dimensional histograms, or between two profile histograms.

Input parameters:

- ID1 The first histogram to be compared. The "reference" histogram in options A and C.
- ID2 The second histogram to be compared. The "data" histogram in options A and C.
  ID1, ID2 are a pair of 1-D, 2-D, or profile histograms booked with the same number of bins.
- TOL The tolerance for a passing the test. Under options S and C, TOL is a number between 0 and 1 which represents the smallest probability considered as an acceptable match. TOL=0.05 will cause DIFFS to reject the bin as bad if there is less than a 5% probability the two bins came from the same distribution. Under option A, TOL is the degree of precision of match required for the test to be considered as passed. TOL=2.0 means that a data bin differing from the reference mean by less than 2.0 times the reference error is compatible.
- NBINS The number of bins in the comparison. For a 1-dimensional histogram, this is the number of bins plus 0, 1 or 2, depending on whether the overflow and underflow channels are included. For a 2-dimensional histogram, this will have the total number of bins plus room for overflow bins along any of the axes requested. For more detail, see the discussion of DIFFS below.
- CHOPT A string allowing specification of the following options:
  - N Use the absolute contents of each histogram, thus including the normalization of the histogram as well as its shape in the comparison. By default, for the S and C options, in 1- and 2-dimensional histograms, the means are adjusted for the relative numbers of entries (including any overflow or underflow bins requested) in ID1 and ID2. No adjustment is ever made for profile histograms.
  - O Overflow, requests that overflow bins be taken into account.
  - U Underflow, requests that underflow bins be taken into account.
  - R Right overflow bin. For a 2-dimensional histogram, it includes the X-Axis overflow bin in the comparisons. If the O option is used, this is automatic.
  - L Left underflow bin. Same as above, but the X-Axis underflow is used. The U option uses this automatically.
  - T Top overflow bin. Same as R, but for the Y-Axis.
  - B Bottom underflow bin. Option L for the Y-Axis.

S Statistical comparison. Calculates the probability that both bins were produced from a distribution with the same mean. This probability is referred to in TOL and DIFFS.

C Compatibility test. Considers bins of the reference histogram (ID1) as perfectly describing the true distribution. Calculates the probability that the data (from ID2) was produced from that distribution. For 1- or 2-dimensional histograms, the Poisson mean is deduced from ID1. For profile histograms, the test assumes a Gaussian with mean and standard deviation given by the ID1. The C option should be used when comparing data to a function, a well-known reference, or a calibration distribution.

A Absolute test. Like the C test, except that TOL and DIFFS are in terms of the number of standard deviations, rather probability. The test is on the number of standard deviations by which the data from ID2 deviates from the mean. Both the mean and the standard deviation are deduced from ID1. Error bars must be on for this option. This forbids overflow bins, underflow bins, and 2-dimensional histograms. The A option ignores bins with zero contents in reference histogram.

Z Ignores bins with zero contents in the comparison. For the S option, ignores bins with zero contents in either histogram. For the C and A option, ignores bins with zero contents in the reference histogram. The default action is to consider all bins as significant.

D Debug printout, dumps the critical variables in the comparisons, along with indicators of its weight, etc. The default (no options selected) does the S option (statistical comparison), ignores underflow and overflow bins, and automatically corrects for the difference in entries between ID1 and ID2.

Output parameters:

NBAD* The number of bins failing the compatibility test according to the criteria defined by TOL and CHOPT.

DIFFS* An array of length the number of bins being compared, which gives the results of the test bin by bin (confidence levels for options S and C, deviations for option A). Results are passed back in the form:

1-D DIFFS(NX) for no over or underflow or DIFFS(0:NX+1), for overflow and/or underflow.

2-D DIFFS(NX,NY) or DIFFS(0:NX+1, 0:NY+1).

When to use HDIFFB instead of HDIFF:

HDIFFB treats the histogram bins individually, while HDIFF treats the histogram as a whole. In HDIFF, one is comparing the overall shapes of a probability distribution. Typically, an event is entered only in one channel, and the choice of channel depends on a measured value of a continuous coordinate, so that it makes sense for downward fluctuations in one bin to be considered as compensated by upward fluctuations in another bin. In HDIFFB, each bin is considered independently, except, perhaps, for an overall normalization factor which is the sum over all bins.

Thus HDIFFB is appropriate when:

- It makes sense to identify a single channel as "bad", for example if the bin contents correspond to hits in a given detector element.
- The data is heterogeneous, for example if the contents are counts versus trigger bit.
- You have already found a discrepancy on a shape with HDIFF and wish to focus on where disagreement is worst.

A plot of hits versus detector element, where the detector elements cover some angular range, is an example of a histogram which might be considered with either comparison utility. The choice depends on the question you wish to answer:

– If you want to know if the angular distribution looks the same, use `HDIFF`.
– If you want a report on bad detector elements, use `HDIFFB`.

6.3.1 Choice of `TOL`:

If you choose 0.05 for `TOL`, you should expect 5 or so bad bins per trial from a histogram with 100 channels. For monitoring, you must compromise between the number of false messages you can tolerate (based on the total number of channels you monitor), and the amount of data you will need to collect to claim a channel is bad. In general, a somewhat smaller fraction of channels than `TOL` will be flagged as bad, since for discrete distributions (Poisson statistics), the probability is quantized. For example, the probability might be 0.053 for 4 entries, and 0.021 for 3. If `TOL`=0.05, only bins with 3 or fewer entries would be flagged as bad.

When to use the `S` option:

The `S` option should be used when both histograms are filled with statistical data, for example a momentum distribution from two successive data runs. Using the `S` option when comparing data to a function or known reference yields poor results because it attributes errors to both histograms. In this case, the `C` option should be selected.

When to use the `C` option:

The `C` option assumes that the reference histogram contains the theoretically expected values with no (or negligible) errors. Examples might be a flat distribution hand-inserted as the expectation for a phi distribution, or a long data run to be compared with shorter data runs.

When to use the `A` option:

The `A` option can be used as an equivalent to the `C` option by choosing `TOL` in terms of standard deviations instead of probability, and returns z values in `DIFFS` for each bin.

The `A` option is intended for setting by hand absolute minima and maxima. To restrict an efficiency between 80 and 100%, load the reference histogram with a mean of 0.9 (via `HPAK`) and the error bar of 0.1 (via `HPAKE`), and use `HDIFFB` with `TOL`=1.0 and the `A` option. The `N` option should also be selected for this application.

Comparison of Weighted versus Unweighted events:

This is in general undesirable, as it forces you into the less accurate Gaussian approximation. Thus it is preferable, for example, to have unweighted Monte Carlo events if you need to use `HDIFFB` to compare with data. The only useful case is if the weighted histogram is the reference histogram in the `C` comparison, which only makes sense if you have much better accuracy than your data.

Using Profile histograms:

The N option is irrelevant for profile histograms. The overflow/underflow options are illegal for profile histograms because insufficient information is stored to calculate the error bars. None of the test options (S, C, or A) check on the number of entries in a profile histogram bin. (To do that, make a separate 1-dimensional histogram.) This has an unexpected effect when the number of entries are small. Bins with no entries always pass the S and C options (no data is compatible with any distribution), so in such cases more bins pass than called for by TOL.

Values of DIFFS:

The value of DIFFS may depend somewhat on the value of TOL chosen, as the approximation chosen to calculate DIFFS depends on both the number of entries and on the size of TOL (how accurately DIFFS must be calcuated).
The S option sometimes returns a confidence level of 1.0 in the small statistics calculation, i.e. there is no probability that the two numbers came from different distributions. This is due to finite precision. Values slightly higher than 1.0 will be returned when the two content values are identical, since no statistical test could claim they came from different distributions.

Other notes:

The normalization scaling (used unless N option selected) is based on channel contents for all channels requested (including overflow/underflow), provided you select one of the overflow/underflow options.

Negative bin contents are flagged as bad bins in S, C options.

Statistical methods and numerical notes:

(For simplicity, this is written as if the N option were in effect.)

The methods used for the S and C options are correct for unweighted events and Poisson statistics for 1- or 2- dimensional histograms. Errors may result in either the S and C options for small tolerances if bin contents are greater than the largest allowed integer.

For the S option with unweighted events, the test (which is uniformly most powerful) treats N = *sum of the two bin contents* as having chosen via a binomial distibution which histogram to enter. The binomial parameter p is given by the relative normalization of the histograms (0.5 if the total number of entries in each histogram was the same). For DIFFS values greater than TOL, the first two digits are correct. For values less than TOL, the two digits to the right of the first non-zero TOL digit are significant, i.e. for TOL=0.0001, 0.000xxx are significant. One can force higher accuracy by setting TOL smaller (or even 0), but calculation time will increase, and warning messages will be issued. A Gaussian approximation is used when there are 25 or more events in each bin, and TOL$>$0.001.

The C option for unweighted events in the data histogram simply calculates the Poisson probability of finding n, the ID2 bin value, given a mean equal to the bin value of ID1. A Gaussian approximation is used when the the mean is 10^6 or larger, and TOL is 0.001 or larger. Given the expected mean, the choice of TOL implies bounds $(n_<, n_>)$ on n (i.e. n within these bounds passes). An error occurs when the approximations used in calculating DIFFS give an incorrect value for $n_<$ or $n_>$. No such errors occur for mean $< 10^5$ and TOL $> 10^{-15}$. The errors in $n_<$ or $n_>$ are less than 2 for mean $< 10^6$, TOL $> 10^{-6}$, or mean $< 10^7$, TOL $> 10^{-5}$. There is a maximum n beyond which DIFFS returns zero, so bins with $n > n_{max}$ always fail. For mean $< 10^7$, this is irrelevant for values of TOL $> 10^{-9}$.

For the profile histogram S option, HDIFFB calculates the t test probability that both bin means were produced from a population with the same mean. The C option calculates the probability of finding the value in ID1 given a Gaussian with μ and σ given by the ID2 contents. Small numbers of entries for either test give DIFFS values which are too large, and HDIFFB will reject too many events in profile histograms.

For weighted events, the S and C options use a Gaussian approximation. This results in DIFFS values which are too low. HDIFFB rejects too many bins for weighted events, particularly for small numbers of equivalent events.

Error messages of HDIFFB:

`Warning: Zero tolerance`
: The passed value TOL is less than or equal to 0. TOL=0. can be used to force highest accuracy in the S option.

`Warning: Only one comparison at a time, please.`
: More than one type of comparison was selected. Only one of options S, C, and A may be used. The default S option will be used.

`Warning: Different binning.`
: The XMIN values for a 1-dimensional histogram or the XMIN and/or YMIN values on a 2-dimensional histogram are different. This may give inaccurate results.

`Warning: Weighted or saturated events in 2-dimensions.`
: HBOOK does not compute error bars for two dimensional histograms, thus weighted event are not allowed, and HDIFFB can not compute the correct statistics. An answer is still given, but it is probably not right. The only reliable case is a weighted 2-dimenension histogram as the reference histogram for the C option.

`Sum of histogram contents is zero!`
: The sum of the content bins is zero.

`Histograms must be the same dimension.`
: A 1-dimensional and a 2-dimensional histogram have been specified. In order for the routine to work, both must be the same dimensionality.

`Both histograms must be the standard or profile type.`
: Two different types of histograms have been specified. Both must be profile or non-profile. You cannot mix types.

`Not enough bins in DIFFS to hold result.`
: The parameter NBINS is less that the number of bins in the histograms.

`Number of channels is different.`
: The number of channels in the two histograms to compare are different. They must be the same before the routine will process the data.

`U/O/L/R/T/B Option with weighted events.`
: HBOOK does not compute an error bar for over-/under-flow bins, thus it may not be used with weighted events.

`U/O/L/R/T/B Option with profile histograms.`
: HBOOK does not compute an error bar for over-/under-flow bins, thus it may not be used with profile histograms.

`Weighted options and no HBARX.`
: The user had not told HBOOK to figure the error bars for the histograms. Therefore, the operations will not be valid.

`A-option with no error bars on reference histogram.`
: The user has not told HBOOK to compute error bars for the reference histogram. This error is also returned when the user attempts to select the `A` option to compare 2-dimensional histograms.

Statistical comments:

The methods used for the `S` and `C` mode are correct for unweighted events and Poisson statistics for one or two-dimensional histograms. For weighted events, a Gaussian approximation is used, which results in `DIFFS` values which are too low when there are fewer than 25 or so “equivalent events” (defined under `HSTATI`) per bin. This is caused by either few entries or by wide fluctuation in weights. The result is that `HDIFFB` rejects to many bins in this case.

Comparisons for profile histograms assume Gaussian statistics for the `S` and `C` mode comparisons of the channel mean. Fewer that 25 or so events will result in `DIFFS` values which are too large. The result is that `HDIFFB` rejects too many event in these low statistic cases.

Chapter 7: Fitting, parameterization and smoothing

7.1 Fitting

The fitting routines in HBOOK are based on the Minuit package [12]. Minuit is conceived as a tool to find the minimum value of a multi-parameter function and analyze the shape of the function around the minimum. The principal application is foreseen for statistical analysis, working on chisquare or log-likelihood functions, to compute the best-fit parameter values and uncertainties, including correlations between the parameters. It is especially suited to handle difficult problems, including those which may require guidance in order to find the correct solution.

In the case of χ^2 minimization, the final fitted parameter values correspond to the minimum of the χ^2 function as defined below:

$$\chi^2 = \sum_{i=1}^{n} \left(\frac{\mathtt{C(I)} - F(\mathrm{X(I)}, A_1, A_2, ..., A_k)}{\mathtt{E(I)}} \right)^2$$

where the following definitions are used:

`n`	Number of channels (cells) in the 1-dimensional or 2-dimensional histogram (`HFITH`, `HFITHN`) or number of points of the distribution (`HFITV`)
`C(I)`	Contents of channel (cell) `I`
`E(I)`	Error on `C(I)`
`X(I)`	Coordinate(s) of centre of channel (cell) `I` or coordinate vector of point `I` of the distribution
$A_1..A_k$	Parameters of the parametric function.
F	Parametric function to be fitted to the data points.

Remarks:

- If no errors are specified by the user, they are taken to be the square root of the bin contents. In this case:
  - empty channels are ignored by the fitting procedure;
  - If at least one of `C(I)<0`, then `E(I)` is set to 1 for all channels (cells).
- If errors are correctly defined via `HBARX` or `HPAKE`, then all channels will be taken into account.

The minimization algorithm requires the calculation of derivatives of the function with respect to the parameters and this is normally done numerically by the fitting routine. If the analytical expression of the derivatives is known, the fit can be speeded up by making use of this information (see option `D` in the control flag of the various fitting routines).

For a log-likelihood fit, the likelihood is formed by determining the Poisson probability that given a number of entries in a particualar bin, the fit would predict its value. This is then done for each bin, and the sum of the logs is taken as the likelihood.

7.1.1 One and two-dimensional distributions

```
CALL HFITH (ID,FUN,CHOPT,NP,*PARAM*,STEP,PMIN,PMAX,SIGPAR*,CHI2*)
```

Action: Fits a given parametric function to the contents of a 1- or 2-dimensional histogram, and optionally superimposes it to the 1-dimensional histogram when editing.

Input parameters:

`ID` Histogram identifier.

`FUN` Parametric function (to be declared `EXTERNAL`, see 7.1.5)
Can be defined interactively in the interactive version (see `paw` manual)

`CHOPT` Character variable specifying the desired options.

- `'B'` Some or all parameters are bounded. The arrays `STEP`, `PMIN` and `PMAX` must be specified. By default all parameters vary freely.
- `'D'` The user specifies the derivatives of the function analytically by providing the user routine `HDERIV`. By default derivatives are computed numerically.
- `'E'` Perform a detailed error analysis using the MINUIT routines `HESSE` and `MINOS`
- `'F'` Force storing of the result of the fit bin by bin with the histogram for an any-dimensional histogram.
- `'K'` `'KM'` means: do to reset the parameters of `Application HMINUIT`.
- `'L'` Use the logaritmic Likelihood fitting method. By default the chisquared method is used.
- `'M'` Invoke interactive `MINUIT`.
- `'N'` The results of the fit are not stored bin by bin with the histogram. By default the function is calculated at the centre of each bin in the specified range.
- `'Q'` Quiet mode. No printing.
- `'R'` Fit a Restricted area of a 1-D or 2-D histogram. The limits for the fit are given using in the vector `IQUEST` is in the communication common `/QUEST/IQUEST(100)`, as follows:
  `IFXLOW = IQUEST(11)` specifies the lower limit in X,
  `IFXUP = IQUEST(12)` specifies the upper limit in X,
  `IFYLOW = IQUEST(13)` specifies the lower limit in Y (2-D),
  `IFYUP = IQUEST(14)` specifies the upper limit in Y (2-D).
- `'U'` User function value is taken from `/HCFITD/FITPAD(24),FITFUN`, see section 7.1.5. All calculations are performed in double precision.
- `'V'` Verbose mode. Results are printed after each iteration. By default only final results are printed.
- `'W'` Set the event weights equal to one. By default weights are taken according to statistical errors.

`NP` Number of parameters ($NP \leq 25$).

`PARAM` Array of dimension `NP` with initial values for the parameters.

`STEP` Array of dimension `NP` with initial step sizes for the parameters (`'B'` option only).

`PMIN` Array of dimension `NP` with the lower bounds for the parameters (`'B'` option only).

`PMAX` Array of dimension `NP` with the upper bounds for the parameters (`'B'` option only).

Output parameters:

PARAM Array of dimension NP with the final fitted values of the parameters.

SIGPAR Array of dimension NP with the standard deviations on the final fitted values of the parameters.

CHI2 Chisquared of the fit.

7.1.2 Fitting one-dimensional histograms with special functions

```
CALL HFITHN (ID,CHFUN,CHOPT,NP,*PAR*,STEP,PMIN,PMAX,SIGPAR*,CHI2*)
```

Action: Fits the given special function to the contents of a one-dimensional histogram, and optionally superimposes it to the histogram when editing.

Input parameters:

ID Histogram identifier.

CHFUN Character variable specifying the desired parametric function. Possible keywords are:

- G to fit gaussian PAR(1)*exp(-0.5*((x-PAR(2))/PAR(3))**2).
  PAR(1) corresponds to the normalization,
  PAR(2) corresponds to the mean value, and
  PAR(3) corresponds to the half width of the Gaussian.
- E to fit exponential exp(PAR(1)+PAR(2)*x)
- Pn to fit polynomyal PAR(1)+PAR(2)*x+PAR(3)*x**2......+PAR(n+1)*x**n

Any combination of these keywords with the 2 operators + or * is allowed, e.g. 'p4+g', a combination of a 4th degree polynomial and a gaussian, which needs eight parameters or p2*g+g, a second degree polynomyal and 2 gaussians, needing 9 parameters. The order of the parameters in PAR must correspond to the order of the basic functions. For example, in the first case above, PAR(1:5) apply to the polynomial of degree 4 and PAR(6:8) to the gaussian while in the second case PAR(1:3) apply to the polynomial of degree 2, PAR(4:6) to the first gaussian and PAR(7:9) to the second gaussian. Blanks are not allowed in the expression.

CHOPT
- 'B' Some or all parameters are bounded. The arrays STEP, PMIN and PMAX must be specified. By default all parameters vary freely.
- 'D' The user is assumed to compute derivatives analytically using the routine HDERIV. By default, derivatives are computed numerically.
- 'E' Perform a detailed error analysis using the minuit routines HESSE and MINOS
- 'F' Force storing of the result of the fit bin by bin with the histogram.
- 'L' Use the logaritmic Likelihood fitting method. By default the chisquared method is used.
- 'M' Invoke interactive minuit.
- 'N' The results of the fit are not stored bin by bin with the histogram. By default the function is calculated at the centre of each bin in the specified range.
- 'Q' Quiet mode. No printing.
- 'R' Fit a Restricted area of the 1-D histogram. IFTLOW = IQUEST(11) specifies the lower limit of the minimization domain,
  IFTUP = IQUEST(12) specifies the upper limit of the minimization domain.

- 'V' Verbose mode. Results are printed after each iteration. By default only final results are printed.
- 'W' Set event weights to one. By default weights are taken according to statistical errors.

NP Number of parameters.

PAR Array of dimension NP with initial values for the parameters.

STEP Array of dimension NP with initial step sizes for the parameters ('B' option only).

PMIN Array of dimension NP with the lower bounds for the parameters ('B' option only).

PMAX Array of dimension NP with the upper bounds for the parameters ('B' option only).

Output parameters:

PAR Array of dimension NP with the final fitted values of the parameters.

SIGPAR Array of dimension NP with the standard deviations on the final fitted values of the parameters.

CHI2 Chisquared of the fit.

7.1.3 Fitting one or multi-demensional arrays

```
CALL HFITV  (N,NDIM,NVAR,X,Y,EY,FUN,CHOPT,NP,*PAR*,STEP,PMIN,PMAX,SIGPAR*,
            CHI2*)
```

Action: Fits a given parametric function to a number of value pairs with associated errors.

Input parameters:

N Number of points to be fitted.

NDIM Declared first dimension of array X.

NVAR Dimension of the distribution.

X Array of dimension N containing the X-coordinates of the points to be fitted.

Y Array of dimension N containing the Y-coordinates of the points to be fitted.

EY Array of dimension N containing the errors on the Y-coordinates of the points to be fitted.

FUN Parametric function (to be declared EXTERNAL)

CHOPT Character variable specifying the desired options.

- 'B' Some or all parameters are bounded. The arrays STEP, PMIN and PMAX must be specified. By default all parameters vary freely.
- 'D' The user provides the derivatives of the function analytically by specifying the user routine HDERIV. By default derivatives are computed numerically.
- 'E' Perform a detailed error analysis using the minuit routines
- 'L' Use the logaritnic Likelihood fitting method. By default the chisquared method is used.
- 'M' Invoke interactive MINUIT.
- 'Q' Quiet mode. No printing.
- 'U' User function value is taken from /HCFITD/FITPAD(24),FITFUN, see section 7.1.5. All calculations are performed in double precision.

- `'V'` Verbose mode. Results are printed after each iteration. By default only final results are printed.
- `'W'` Set the event weights equal to one. By default weights are taken according to statistical errors. `HESSE` and `MINOS`

`NP` Number of parameters (`NP`$\leq$`25`).

`PAR` Array of dimension `NP` with initial values for the parameters.

`STEP` Array of dimension `NP` with initial step sizes for the parameters (`'B'` option only).

`PMIN` Array of dimension `NP` with the lower bounds for the parameters (`'B'` option only).

`PMAX` Array of dimension `NP` with the upper bounds for the parameters (`'B'` option only).

Output parameters:

`PAR` Array of dimension `NP` with the final fitted values of the parameters.

`SIGPAR` Array of dimension `NP` with the standard deviations on the final fitted values of the parameters.

`CHI2` Chisquared of the fit.

7.1.4 Results of the fit

When the fit is complete, the parameters and the errors on the parameters are returned to the calling program. By default (unless option `'N'` is specified), the fitted parameters, the errors on these parameters, their names (see below), the chi-squared and the number of degrees of freedom of the fit are stored in a data structure associated to the histogram `ID` when routines `HFITH` and `HFITHN` are invoked.

- For `HFITH` the value of the fitted function in each histogram channel is also stored in the histogram data structure. The parameters are given the default names: `P1`, `P2`,...,`Pn`.
- For `HFITHN` the type of the function being fitted is stored instead of the fitted values for each channel.

The information stored in the associated data structure is used during the printing/plotting phase. In particular it is written when the histogram is stored in a file with `HROUT`.

Naming the parameters of a fit

```
CALL HFINAM  (ID,CHPNAM,NPAR)
```

Action: Modify the names of the fitted parameters in the data structure associated with the given histogram.

Input parameter:

`ID` Histogram identifier.

`CHPNAM` `CHARACTER` array specifying the name(s) to be given to the parameter(s) of the fit (truncated to 8 characters).

`NPAR` Number of parameters specified.

Retrieving the fitted parameters

```
CALL HGFIT (ID,NFPAR*,NPFITS*,FITCHI*,FITPAR*,FITSIG*,FITNAM*)
```

Action: Retrieve the fitted parameters values from the data structure associated with a given histogram.

Input parameter:

ID Histogram identifier.

Output parameters:

NFPAR Number of parameters.

NPFITS Number of data points used in the fit.

FITCHI χ^2 of the fit.

FITPAR Array of dimension at least NFPAR, containing the value of the fitted parameters.

FITSIG Array of dimension at least NFPAR, containing the standard deviations of values of the fitted parameters.

FITNAM Character array of dimension at least NFPAR, containing the names of the fitted parameters (truncated to 8 characters). See also HFINAM above.

7.1.5 The user parametric function

When routines HFITH and HFITV are invoked, a user parametric function FUN, specified as an argument to those routines, is called during the minimization procedure.

If the 'U' option is specified with these routines, the user function is calculated in double precision (in the case of HFITHN with the predefined functions (G,E,Pn) double precision is always used). In this case you must reference the common block /HCFITD/, which contains the parameter values in double precision, and store the resulting function value in variable FITFUN, as shown in the example below.

Example of user function in double precision

```
      FUNCTION UFIT(X)
*    The dimension of DPAR  ||  MUST be 24!
*                           VV
      DOUBLE PRECISION DPAR(24),FITFUN
      COMMON/HCFITD/DPAR,FITFUN
      FITFUN = DPAR(1)+DPAR(2)*SQRT(X) +DPAR(3)/X
      UFIT=FITFUN
      END
```

Even is you do not want to use a double precision function value (i.e. you do not specify the 'U' option), you should still compute the fit function as accurately as possible, using double precision variables in strategic places. This function should also be protected against possible arithmetic exception conditions, like under or overflows and negative arguments for square roots or logarithms.

User specified derivatives

```
CALL HDERIV (DERIV)
```

Action: User provided subroutine, which calculates the derivatives of the parameters of the function being fitted. This routine must be called from the user function `FUN` when option `'D'` is selected with `HFITH` or `HFITN`.

Input parameter:

`DERIV` Array containing the derivatives of the function being fitted.

7.2 Basic concepts of MINUIT

The `minuit` package acts on a multiparameter Fortran function to which one must give the generic name `FCN`. In the `paw/hbook` implementation, the function `FCN` is called `HFCNH` when the command `Histo/Fit` (`paw`) or the routine `HFITH` are invoked. It is called `HFCNV` when the command `Vector/Fit` or the routine `HFITV` are invoked. The value of `FCN` will in general depend on one or more variable parameters.

To take a simple example, suppose the problem is to fit a polynomial through a set of data points with the command Vector/Fit. Routine `HFCNV` called by `HFITV` calculates the chisquare between a polynomial and the data; the variable parameters of `HFCNV` would be the coefficients of the polynomials. Routine `HFITV` will request MINUIT to minimize `HFCNV` with respect to the parameters, that is, find those values of the coefficients which give the lowest value of chisquare.

7.2.1 Basic concepts - The transformation for parameters with limits.

For variable parameters with limits, MINUIT uses the following transformation:

$$P_{\text{int}} = \arcsin\left(2\frac{P_{\text{ext}} - a}{b - a} - 1\right) \qquad\qquad P_{\text{ext}} = a + \frac{b-a}{2}\left(\sin P_{\text{int}} + 1\right)$$

so that the internal value P_{int} can take on any value, while the external value P_{ext} can take on values only between the lower limit a and the upper limit b. Since the transformation is necessarily non-linear, it would transform a nice linear problem into a nasty non-linear one, which is the reason why limits should be avoided if not necessary. In addition, the transformation does require some computer time, so it slows down the computation a little bit, and more importantly, it introduces additional numerical inaccuracy into the problem in addition to what is introduced in the numerical calculation of the `FCN` value. The effects of non-linearity and numerical roundoff both become more important as the external value gets closer to one of the limits (expressed as the distance to nearest limit divided by distance between limits). The user must therefore be aware of the fact that, for example, if he puts limits of $(0, 10^{10})$ on a parameter, then the values 0.0 and 1.0 will be indistinguishable to the accuracy of most machines.

The transformation also affects the parameter error matrix, of course, so MINUIT does a transformation of the error matrix (and the "parabolic" parameter errors) when there are parameter limits. Users should however realize that the transformation is only a linear approximation, and that it cannot give a meaningful result if one or more parameters is very close to a limit, where $\partial P_{\text{ext}}/\partial P_{\text{int}} \approx 0$. Therefore, it is recommended that:

- Limits on variable parameters should be used only when needed in order to prevent the parameter from taking on unphysical values.
- When a satisfactory minimum has been found using limits, the limits should then be removed if possible, in order to perform or re-perform the error analysis without limits.

7.2.2 How to get the right answer from MINUIT

MINUIT offers the user a choice of several minimization algorithms. The `MIGRAD` (Other algorithms are available with Interactive MINUIT, as described on Page 121) algorithm is in general the best minimizer for nearly all functions. It is a variable-metric method with inexact line search, a stable metric updating scheme, and checks for positive-definiteness. Its main weakness is that it depends heavily on knowledge of the first derivatives, and fails miserably if they are very inaccurate. If first derivatives are a problem, they can be calculated analytically inside the user function and communicated to `paw` via the routine `HDERIV`.

If parameter limits are needed, in spite of the side effects, then the user should be aware of the following techniques to alleviate problems caused by limits:

Getting the right minimum with limits.

If MIGRAD converges normally to a point where no parameter is near one of its limits, then the existence of limits has probably not prevented MINUIT from finding the right minimum. On the other hand, if one or more parameters is near its limit at the minimum, this may be because the true minimum is indeed at a limit, or it may be because the minimizer has become "blocked" at a limit. This may normally happen only if the parameter is so close to a limit (internal value at an odd multiple of $\pm\frac{\pi}{2}$ that MINUIT prints a warning to this effect when it prints the parameter values.

The minimizer can become blocked at a limit, because at a limit the derivative seen by the minimizer $\partial F/\partial P_{\mathrm{int}}$ is zero no matter what the real derivative $\partial F/\partial P_{\mathrm{ext}}$ is.

$$\frac{\partial F}{\partial P_{\mathrm{int}}} = \frac{\partial F}{\partial P_{\mathrm{ext}}}\frac{\partial P_{\mathrm{ext}}}{\partial P_{\mathrm{int}}} = \frac{\partial F}{\partial P_{\mathrm{ext}}} = 0$$

Getting the right parameter errors with limits.

In the best case, where the minimum is far from any limits, MINUIT will correctly transform the error matrix, and the parameter errors it reports should be accurate and very close to those you would have got without limits. In other cases (which should be more common, since otherwise you wouldn't need limits), the very meaning of parameter errors becomes problematic. Mathematically, since the limit is an absolute constraint on the parameter, a parameter at its limit has no error, at least in one direction. The error matrix, which can assign only symmetric errors, then becomes essentially meaningless.

7.2.3 Interpretation of Parameter Errors:

There are two kinds of problems that can arise: the **reliability** of MINUIT's error estimates, and their **statistical interpretation**, assuming they are accurate.

Statistical interpretation:

For discussuion of basic concepts, such as the meaning of the elements of the error matrix, or setting of exact confidence levels (see [11]).

Reliability of MINUIT error estimates.

MINUIT always carries around its own current estimates of the parameter errors, which it will print out on request, no matter how accurate they are at any given point in the execution. For example, at initialization, these estimates are just the starting step sizes as specified by the user. After a `MIGRAD` or `HESSE` step, the errors are usually quite accurate, unless there has been a problem. MINUIT, when it prints out error values, also gives some indication of how reliable it thinks they are. For example, those marked `CURRENT GUESS ERROR` are only working values not to be believed, and `APPROXIMATE ERROR` means that they have been calculated but there is reason to believe that they may not be accurate.

If no mitigating adjective is given, then at least MINUIT believes the errors are accurate, although there is always a small chance that MINUIT has been fooled. Some visible signs that MINUIT may have been fooled are:

- Warning messages produced during the minimization or error analysis.
- Failure to find new minimum.
- Value of `EDM` too big (estimated Distance to Minimum).
- Correlation coefficients exactly equal to zero, unless some parameters are known to be uncorrelated with the others.
- Correlation coefficients very close to one (greater than 0.99). This indicates both an exceptionally difficult problem, and one which has been badly parameterized so that individual errors are not very meaningful because they are so highly correlated.
- Parameter at limit. This condition, signalled by a MINUIT warning message, may make both the function minimum and parameter errors unreliable. See the discussion above "*Getting the right parameter errors with limits*".

The best way to be absolutely sure of the errors, is to use "independent" calculations and compare them, or compare the calculated errors with a picture of the function. Theoretically, the covariance matrix for a "physical" function must be positive-definite at the minimum, although it may not be so for all points far away from the minimum, even for a well-determined physical problem. Therefore, if MIGRAD reports that it has found a non-positive-definite covariance matrix, this may be a sign of one or more of the following:

A non-physical region: On its way to the minimum, MIGRAD may have traversed a region which has unphysical behaviour, which is of course not a serious problem as long as it recovers and leaves such a region.

An underdetermined problem: If the matrix is not positive-definite even at the minimum, this may mean that the solution is not well-defined, for example that there are more unknowns than there are data points, or that the parameterization of the fit contains a linear dependence. If this is the case, then MINUIT (or any other program) cannot solve your problem uniquely, and the error matrix will necessarily be largely meaningless, so the user must remove the underdeterminedness by reformulating the parameterization. MINUIT cannot do this itself.

Numerical inaccuracies: It is possible that the apparent lack of positive-definiteness is in fact only due to excessive roundoff errors in numerical calculations in the user function or not enough precision. This is unlikely in general, but becomes more likely if the number of free parameters is very large, or if the parameters are badly scaled (not all of the same order of magnitude), and correlations are also large. In any case, whether the non-positive-definiteness is real or only numerical is largely irrelevant, since in both cases the error matrix will be unreliable and the minimum suspicious.

An ill-posed problem: For questions of parameter dependence, see the discussion above on positive-definiteness.
Possible other mathematical problems are the following:

Excessive numerical roundoff: Be especially careful of exponential and factorial functions which get big very quickly and lose accuracy.

Starting too far from the solution: The function may have unphysical local minima, especially at infinity in some variables.

7.2.4 MINUIT interactive mode

With the routines `HFITH` or `HFITV` and the `M` option, HBOOK goes into interactive mode and gives control to the MINUIT program. In this case, the user may enter MINUIT control statements directly.

Overview of available MINUIT commands

CLEar

Resets all parameter names and values to undefined. Must normally be followed by a PARAMETER command or equivalent, in order to define parameter values.

CONtour par1 par2 [devs] [ngrid]

Instructs MINUIT to trace contour lines of the user function with respect to the two parameters whose external numbers are **par1** and **par2**. Other variable parameters of the function, if any, will have their values fixed at the current values during the contour tracing. The optional parameter **[devs]** (default value 2.) gives the number of standard deviations in each parameter which should lie entirely within the plotting area. Optional parameter **[ngrid]** (default value 25 unless page size is too small) determines the resolution of the plot, i.e. the number of rows and columns of the grid at which the function will be evaluated.

EXIT

End of Interactive MINUIT. Control is returned to `paw`.

FIX parno

Causes parameter **parno** to be removed from the list of variable parameters, and its value will remain constant (at the current value) during subsequent minimizations, etc., until another command changes its value or its status.

HELP [SET] [SHOw]

Causes MINUIT to list the available commands. The list of SET and SHOw commands must be requested separately.

HESse [maxcalls]

Instructs MINUIT to calculate, by finite differences, the Hessian or error matrix. That is, it calculates the full matrix of second derivatives of the function with respect to the currently variable parameters, and inverts it, printing out the resulting error matrix. The optional argument **[maxcalls]** specifies the (approximate) maximum number of function calls after which the calculation will be stopped.

IMProve [maxcalls]

If a previous minimization has converged, and the current values of the parameters therefore correspond to a local minimum of the function, this command requests a search for additional distinct local minima. The optional argument **[maxcalls]** specifies the (approximate) maximum number of function calls after which the calculation will be stopped.

MIGrad [maxcalls] [tolerance]

Causes minimization of the function by the method of Migrad, the most efficient and complete single method, recommended for general functions (see also MINImize). The minimization produces as a by-product the error matrix of the parameters, which is usually reliable unless warning messages are produced. The optional argument **[maxcalls]** specifies the (approximate) maximum number of function calls after which the calculation will be stopped even if it has not yet converged. The optional argument **[tolerance]** specifies required tolerance on the function value at the minimum. The default tolerance is `0.1`. Minimization will stop when the estimated vertical distance to the minimum (`EDM`) is less than `0.001*[tolerance]*UP` (see `SET ERR`).

MINImize [maxcalls] [tolerance]

Causes minimization of the function by the method of Migrad, as does the MIGrad command, but switches to the SIMplex method if Migrad fails to converge. Arguments are as for MIGrad.

MINOs [maxcalls] [parno] [parno] ...

Causes a Minos error analysis to be performed on the parameters whose numbers **[parno]** are specified. If none are specified, Minos errors are calculated for all variable parameters. Minos errors may be expensive to calculate, but are very reliable since they take account of non-linearities in the problem as well as parameter correlations, and are in general asymmetric. The optional argument **[maxcalls]** specifies the (approximate) maximum number of function calls *per parameter requested,* after which the calculation will be stopped for that parameter.

RELease parno

If `parno` is the number of a previously variable parameter which has been fixed by a command: `FIX parno`, then that parameter will return to variable status. Otherwise a warning message is printed and the command is ignored. Note that this command operates only on parameters which were at one time variable and have been FIXed. It cannot make constant parameters variable; that must be done by redefining the parameter with a `PARAMETER` command.

REStore [code]

If no [**code**] is specified, this command restores all previously FIXed parameters to variable status. If [**code**]**=1**, then only the last parameter FIXed is restored to variable status.

SCAn [parno] [numpts] [from] [to]

Scans the value of the user function by varying parameter number [**parno**], leaving all other parameters fixed at the current value. If [**parno**] is not specified, all variable parameters are scanned in sequence. The number of points [**numpts**] in the scan is 40 by default, and cannot exceed 100. The range of the scan is by default 2 standard deviations on each side of the current best value, but can be specified as from [**from**] to [**to**]. After each scan, if a new minimum is found, the best parameter values are retained as start values for future scans or minimizations. The curve resulting from each scan is plotted on the output unit in order to show the approximate behaviour of the function. This command is not intended for minimization, but is sometimes useful for debugging the user function or finding a reasonable starting point.

SEEk [maxcalls] [devs]

Causes a Monte Carlo minimization of the function, by choosing random values of the variable parameters, chosen uniformly over a hypercube centered at the current best value. The region size is by default 3 standard deviations on each side, but can be changed by specifying the value of [**devs**].

SET ERRordef up

Sets the value of **up** (default value= 1.), defining parameter errors. MINUIT defines parameter errors as the change in parameter value required to change the function value by **up**. Normally, for chisquared fits **up=1**, and for negative log likelihood, **up=0.5**.

SET LIMits [parno] [lolim] [uplim]

Allows the user to change the limits on one or all parameters. If no arguments are specified, all limits are removed from all parameters. If [**parno**] alone is specified, limits are removed from parameter [**parno**]. If all arguments are specified, then parameter [**parno**] will be bounded between [**lolim**] and [**uplim**]. Limits can be specified in either order, MINUIT will take the smaller as [**lolim**] and the larger as [**uplim**]. However, if [**lolim**] is equal to [**uplim**], an error condition results.

SET PARameter parno value

Sets the value of parameter **parno** to **value**. The parameter in question may be variable, fixed, or constant, but must be defined.

SET PRIntout level

Sets the print level, determining how much output MINUIT will produce. The allowed values and their meanings are displayed after a **SHOw PRInt** command. Possible values for **level** are:

`-1` No output except from SHOW commands

`0` Minimum output (no starting values or intermediate results)

1 Default value, normal output

2 Additional output giving intermediate results.

3 Maximum output, showing progress of minimizations.

SET STRategy level

Sets the strategy to be used in calculating first and second derivatives and in certain minimization methods. In general, low values of **level** mean fewer function calls and high values mean more reliable minimization. Currently allowed values are 0, 1 (default), and 2.

SHOw XXXX

All **SET XXXX** commands have a corresponding **SHOw XXXX** command. In addition, the SHOw commands listed starting here have no corresponding SET command for obvious reasons. The full list of SHOw commands is printed in response to the command **HELP SHOw**.

SHOw CORrelations

Calculates and prints the parameter correlations from the error matrix.

SHOw COVariance

Prints the (external) covariance (error) matrix.

SIMplex [maxcalls] [tolerance]

Performs a function minimization using the simplex method of Nelder and Mead. Minimization terminates either when the function has been called (approximately) [**maxcalls**] times, or when the estimated vertical distance to minimum (`EDM`) is less than [**tolerance**]. The default value of [**tolerance**] is `0.1*UP` (see `SET ERR`).

7.3 Deprecated fitting routines

Fitting histograms – Long version

```
CALL HFITL  (ID,FUN,NP,*P*,CHI2*,IC,SIG*,COV*,ST,PMI,PMA)
```

Use `HFITH` instead.

Fitting histograms – Short version

```
CALL HFITS  (ID,FUN,NP,*P*,CHI2*,IC,SIG*)
```

Use `HFITH` instead.

Non-equidistant points in a multi-dimensional space – Long version

```
CALL HFITN  (X,Y,EY,NPTS,N1,NVAR,FUN,NP,*P*,CHI2*,IC,SIG*,COV*
```

Use `HFITV` instead.

Non-equidistant points in a multi-dimensional space – Short version

```
CALL HFIT1  (X,Y,EY,N,FUN,NP,*P*,CHI2*,IC,SIG*)
```

Use `HFITV` instead.

Histogram Fitting with Special Functions

```
CALL HFITEX  (ID,AA*,BB*,CHI2*,IC,SIG*)
```

Use `HFITHN` instead as `CALL HFITHN(ID,'E',' ',2,PAR,STEP,PMIN,PMAX,SIGPAR,CHI2)`.

```
CALL HFITGA  (ID,C*,AV*,SD*,CHI2*,IC,SIG*)
```

Use `HFITHN` instead as `CALL HFITHN(ID,'G',' ',3,PAR,STEP,PMIN,PMAX,SIGPAR,CHI2)`.

```
CALL HFITPO  (ID,NP,A*,CHI2*,IC,SIG*)
```

Use `HFITHN` instead as `CALL HFITHN(ID,'Pn',' ',NP,PAR,STEP,PMIN,PMAX,SIGPAR,CHI2)`, where `n=NP-1` in the second argument `'Pn'`.

7.4 Parametrization

In analyzing experimental data, it is sometimes very important to be able to **parametrize** relationships among data by means of linear combinations of **elementary** functions. One of these **expansions** is the well known Taylor series which is an expansion of an analytic function using as elementary functions (regressors) the powers of the independent variables. In the case of the Taylor series, the coefficients of the linear combination are a well known expression involving the derivatives of the function to be represented at a given (initial) point. Even if the Taylor series is very powerful for its noticeable features and its analytical simplicity, from the point of view of the numerical analist it might be not the best expansion in terms of elementary functions. Ideally one would like to use the smallest possible number of regressors, in order to describe the relationship among data with a given precision, and this is not always guaranteed using the Taylor series. Another feature of the monomials is that they do not form a complete orthonormal set of functions, in the sense of the Hilbert spaces, while other functions, which possess this feature, may be more computationally convenient to use.

The entries `HPARAM` (for histograms and scatter plots) and `HPARMN` (for n-dimensional distributions) perform regressions on the data in order to find the best parametrization in terms of elementary functions (regressors).

Let us suppose that we have collected `NP` sets of `NDIM+1` data, being $(y_i, x_{1,i} \dots x_{NDIM,i})$ with $1 \leq i \leq$`NP` the i^{th} set. Here y_i is the value observed at the coordinates $x_{1,i} \dots x_{\mathtt{NDIM},i}$. `NDIM` must be greater or equal to 1 and it is the **dimensionality** of our parametrization problem, that is the number of independent variables that we want to use in order to parametrize our data. In the case of a histogram `NDIM` is clearly 1, x is the centre of a histogram channel, y is the contents of the corresponding channel and `NP` is the number of channels of the histogram. In the case of a scatter plot `NDIM` is 2, x_1 and x_2 are the ordinate and abscissa of the centre of a cell, y is the contents of the cell and `NP` is `NX*NY`, the total number of cells. In case of histograms or scatter plots the entry `HPARAM` should be used. For data which are not contained in an

HBOOK histogram or scatter plot and for higher dimensionality sets ($\mathtt{NDIM} \leq 10$) the entry HPARMN has to be used. We could express a possible expansion of our data in elementary functions in the following way:

$$
\begin{aligned}
y_1 &= c_1 * F_1(x_{1,1}, \cdots, x_{NDIM,1}) + \cdots \\
&\qquad\qquad + c_{NCO} * F_{NCO}(x_{1,1}, \cdots, x_{NDIM,1}) + u_1 \\
&\qquad\qquad \vdots \\
y_{NP} &= c_1 * F_1(x_{1,NP}, \cdots, x_{NDIM,NP}) + \cdots \\
&\qquad\qquad + c_{NCO} * F_{NCO}(x_{1,NP}, \cdots, x_{NDIM,NP}) + u_{NP}
\end{aligned}
$$

where we are summing NCO elementary functions each one multiplied by its own coefficient. In other words we are pretending that our data points are **fitted** by the given expansion but for a residual, namely u_i. The expansion itself is the linear combination of the **regressors** $F_j$computed at the j^{th} data point. The strategy of the two entries is to minimize the residual variance from fitting various possible regressors out of a set which is either system or user-defined. The previous expression can be rewritten in a more synthetical notation:

$$
y = Fc + u \qquad \text{with} \quad
\begin{array}{rl}
y & \text{array of NP data points} \\
F & \text{matrix of regressors (NP lines times NCO columns)} \\
c & \text{array of NCO coefficients} \\
u & \text{array for the NP residuals}
\end{array}
$$

As already said, we want to use the smallest possible number of regressors for a given set of data points, which yields the desired fit (in the terms explained below). That is to say that the rank of the matrix F should be NCO. If it were smaller, then some (at least one) of the columns could be represented as a linear combination of others, and so, rearranging the coefficients, we could get rid of these regressors.

The residual variance is minimized under the following constraints:

1 The NP values of the residuals should have a mean of 0.

2 The residuals should be independently distributed. This means that their covariance matrix has the form of a positive diagonal matrix (we call it D).

3 The regressors should be linearly independent.

Hypothesis 2 implies that $(F^tF)^{-1}$ exists, where $D(F^tF)^{-1}$ is the **covariance matrix** of the coefficients.

The coefficients and regressors are determined iteratively until the convergence criteria for the fit are reached. The user has the choice to specify that the criteria are met either when the residual variance stops decreasing or when the multiple correlation coefficient reaches the value specified via the input parameter R2MIN (see later). Once the list of all possible regressors has been established, at each step the one which gives the highest drop in the residual sum of squares is added to the expansion. In addition, all previously chosen regressors are tested for possible rejection, using standard test statistics (F-tests), as it can happen that a regressor becomes superfluous at a later stage of the fitting process.

The routines offer three choices for the regressors: standard elementary functions, user-given elementary functions or user-given regressors. In the first two cases each regressor is the product of NDIM elementary functions, one for each variable (the constant function may be included in the set). This means that in the first two cases we will have a **matrix** of NDIM*NCO elementary functions, and the array of regressors will be the result of the scalar product of the NDIM columns of this matrix. In the last case each regressor is user-defined, and we have just NCO regressors to be specified as user functions (see below). The NCO regressors have to be linearly combined with the NCO coefficients contained in the output array COEFF to obtain the parametrization. Each elementary function, either standard or user-defined is identified by a three digit code, let's say nnm. The last digit, m, is a one digit code specifying the kind of regressor used, with the following meaning:

0 Standard elementary function

1 User-provided elementary function

2 User-provided regressor

The first two digits define the function number. In the first two cases, we have NDIM*NCO of these codes arranged in an array, so that the first NDIM codes are the code of the elementary functions to be multiplied to obtain the first regressor. For system defined elementary functions nn is the degree of the polynomial. For user-provided regressors, the meaning of this code is user-defined, in the sense that the user is free to give any meaning he wishes to this code in the routine he has to supply. In the case of user-provided regressors, we will have just NCO regressor codes in the array ITERM at the end of the fitting process. Only one code is needed to define a user-given regressor, whereas NDIM codes are needed to specify a regressor composed of elementary functions.

The parametrization routines will select the most efficient subset of regressors out of the set selected by the user, in the sense of the criteria specified above.

Once the initial set of regressors has been specified, the user still has the opportunity to tell the system how to make a further selection among those regressors, before the fitting process actually starts:

- The maximum degrees of the standard polynomials for each independent variable are given by MAXPOW (array of dimension NDIM). This input parameter is mandatory and there is no default provided for it.
- The total degree of a regressor made up from the product of standard polynomials, may be limited by setting PSEL (via HSETPR) to a positive value <NDIM. PSEL controls the exclusion of the combinations of standard polynomials which give the higher order regressors (see the description of this parameter).
- Each initial regressor, whose code is passed to the logical function HSELBF, written by the user, may be accepted or rejected according to user criteria
- The argument ITERM (under control of IC below) may be used as input to the routines to contain the list of the codes of the acceptable regressors.

As soon as the best parametrization is obtained, the user may call the function HRVAL(X), which is of type DOUBLE PRECISION and which returns the value of the parametrization, computed at point X, where X is an array of dimension NDIM.

The program can handle up to 10 dimensions (i.e. NDIM$\leq$ 10) Up to 50 regressors may appear in the final expression. This is controlled by the PNCX parameter set by the routine HSETPR (see below).

Memory requirements: a 1-dimensional histogram with 100 channels and with the maximum number of regressors PNCX set to 10, requires in DOUBLE PRECISION version, less than 5000 words; for large values of PNCX and a large number of points, memory behaves roughly as 2*NP*PNCX (DOUBLE PRECISION).

Histograms and plots

```
CALL HPARAM (ID,IC,R2MIN,MAXPOW,COEFF*,ITERM*,NCO*)
```

Input parameters:

`ID` Histogram or plot identifier.

`IC` Control word (see below)

`R2MIN` Maximum required value of multiple correlation coefficient

`MAXPOW` Maximum degrees of standard polynomials (`INTEGER` array of size `NDIM`)

`ITERM` Acceptable function codes (see explanation above) (`INTEGER` array of size ≤`PNBF`, see explanation above)

Output parameters:

`NCO` number of regressors in final expression.

`COEFF` Coefficients of terms (`DOUBLE PRECISION` array of size `NCO`)

`ITERM` Accepted regressors codes (`INTEGER` array of size `NDIM*NCO` or `NCO`, see explanation above)

`IC` is a coded integer with the following fields:

$$\mathtt{IC} = \mathtt{N} * 10^7 + \mathtt{R} * 10^6 + \mathtt{C} * 10^5 + \mathtt{B} * 10^4 + \mathtt{T} * 10^3 + \mathtt{W} * 10^2 + \mathtt{P} * 10 + \mathtt{S}$$

`S` This switch controls the superimposition of the result when printing the histogram, it is effective only for 1-dimensional histograms

- `1` Resulting parametric fit superimposed on histogram
- `0` No superposition

`P` This switch controls the amount of information printed during the fitting process

- `0` Minimal output: the residual sum of squares is printed
- `1` Normal output: in addition, the problem characteristics and options are printed; also the standard deviations and confidence intervals of the coefficients
- `2` extensive output: the results of each iteration are printed with the normal output

`W` This switch controls the weights to applied to the data during the fit

- `0` weights on histogram contents are already defined via `HBARX` or `HPAKE`. If not they are taken to be equal to the square-root of the contents
- `1` weights are equal to 1

`T` This switch controls the system-defined elementary functions set to use

- `0` Monomials will be selected as the standard elementary functions
- `1` Chebyshev polynomials with a definition region: $[-1, 1]$
- `2` Legendre polynomials with a definition region: $[-1, 1]$
- `3` shifted Chebyshev polynomials with a definition region: $[0, 1]$
- `4` Laguerre polynomials with a definition region: $[0, +\infty]$
- `5` Hermite polynomials with a definition region: $[-\infty, +\infty]$

B This switch controls the kind of regressor used in the fit

- 0 Regressors are products of standard polynomials (see preceeding switch)
- 1 Regressors are products of user-defined elementary functions. The user should write a DOUBLE PRECISION function HELEFT(IEF,X) where IEF is the elementary function code in the sense explained above: 10 times the function code plus 1. The function code number can vary from 1 to PNEF, number of user supplied elementary functions. PNEF has to be specified by the user **before** calling HPARAM, via a call to the routine HSETPR described below. The seconf parameter X is the point where the function should be calculated.
- 2 Regressors are user-defined, in this case the variable PNBF, number of basic functions, must be set by the user via a call to HSETPR (see below). User regressors values are to be returned by the user-supplied DOUBLE PRECISION function HBASFT(IBF,X) where IBF is the user-defined regressor code in the sense explained above: 10 times the regressor code plus 2. The regressor code number can vary from 1 to PNBF, number of basic functions used for the parametrization. PNBF has to be specified by the user **before** calling HPARAM, via a call to the routine HSETPR described below, in the case that the switches B or C of the control parameter IC have the value 2. The parameter X is an array of length NDIM defining the coordinate where the regressor should be calculated.

C This switch controls the selection of the regressors

- 0 Regressors are selected by the system. The parameter PSEL and the array MAXPOW help the user in controlling the total degree of each regressor (see below).
- 1 for each elementary function or for each regressor, the logical function HSELBF(ELEF) gets called once before the beginning of the actual fitting procedure to set up the table of available elementary functions or regressors. IELEF is the code of the regressor or of the function being tested for acceptance. A value of .TRUE. returned will cause the regressor/elementary function to be accepted. The default version of this function which is supplied in HBOOK always returns the value .TRUE., while the user may want to write his own version of this function to exclude some of the regressors or of the elementary functions (according to the value of the B switch he has selected).
- 2 The input array ITERM contains a list of selected regressors or elementary functions according to the value of the switch B. The array has to be at least NDIM*PNBF words and the variable PNBF, maximum number of elementary functions or regressors, should have been set via a call to HSETPR. In the case of elementary functions, the element ITERM(IDIM+(IBF-1)*NDIM) is the function of the variable x_{IDIM} to be multiplied by the coefficent number IBF, given a maximum expected number of PNBF coefficents. This can be of course reduced by the fitting program under considerations of linear dependency, as stated above, returning only NCO coefficents, thus after the fit ITERM will identify which regressors were actually used. In the case of user-defined regressors, only the first PNBF position of the ITERM array need to be filled, and the array will contain directly the code of the selected user-defined regressors.

R This switch controls the system selection mechanism for the regressors:

- 0 Stepwise regression, the regression is calculated as explained before, and selected regressors may be eliminated in a further step of the procedure
- 1 Forward regression. The backward stage is suppressed: a regressor included at one time will always remain in the regression later on
- 2 Fixed-term regression: all selected regressors will appear in the final expression

`N` This switch controls the normalization of the `X` range during the computation.

- `0` No normalization of X-range
- `1` X scaled in the range $[-1, 1]$
- `2` X scaled in the range $[0, 1]$
- `3` X scaled in the range $[0, +\infty]$

The value of `R2MIN` is used to determine the satisfactory end of the fitting process. If $0 <$`R2MIN`< 1, this value will be compared to the current sum of the squares of the residuals to determine whether the fit should be stopped or continued. If `R2MIN`≥ 1, the fitting process will be halted when the residual variance is minimal.

Various parameters which are relevant for the parametrization can be set via the routine `HSETPR`.

```
CALL HSETPR  (CHNAME,VALUE)
```

Input parameters:

`CHNAME` Name of the parameter to be set (of type `CHARACTER`)

`VALUE` Value assigned to parameter `CHNAME` (of type `REAL`)

Possible values for `CHNAME` are:

`'PNEF'` This parameter specifies to the system the number of elementary functions that are supplied by the user, in case the switch `B` of the `IC` parameter is set to 1. The system will build `PNBF` basic regressors made up by products of `NDIM` elementary functions, possibly user selected, as specified by the switch `C` of the parameter `IC`.

`'PNBF'` This parameter must be specified in case user regressors are used (`B` switch of `IC` set to 2), or in case the `ITERM` contains on input the selected regressors or basic elementary functions (`C` switch of `IC` parameter set to 2). The parameter is ignored in the other cases. This is the total number of user-defined regressors or elementary functions which the system will use for the parametrization process. Please note that in case of user given regressors, if the `C` switch of the `IC` parameter is either 0 or 1, the logical function `HSELBF(ELEF)` will always be called in order to verify the inclusion of the regressor `IELEF` in the list for the current fitting operation.

`'PSEL'` This parameter is used only in case of system-supplied elementary functions. It is the maximum limit for the sum of the terms `POW(I)/MAXPOW(I)` in each regressor, where `POW(I)` is the power of the system-supplied elementary function for the Ithvariable ($1 \leq$I<`NDIM`) and `MAXPOW(I)` is the user supplied maximum value for the degree of the system-supplied elementary functions for the Ith variable. This value must be `0<VALUE<NDIM`. Note that setting `PSEL` to 0 selects the constant term for all the regressors. Setting `PSEL` to a value $\geq$`NDIM` has the effect of removing any limitation on the total degree of the regressors, leaving `MAXPOW(I)` as the only effective limitation on the degree of the the elementary functions. This means that the total degree of the regressors can be equal to the sum of the `NDIM` elements of `MAXPOW(I)`. The system supplied default is 1.

`'PFLV'` This parameter determines the F-test significance level for rejection of already included regressors; by default it is set to 1. A higher value makes it more difficult for regressors to remain in the regression. The value of `PFLV` has to be > 0.

'PLUN' This parameter indicates the logical unit for writing the Fortran code of the function FPARAM(X). which gives the value of the parametrization at point X. This Fortran code can be compiled and used in subsequent jobs. By default no code is written.

'PNBX' Maximum number of regressors that may be entered as input to the fitting process (after selection). By default PNBX is set to 500; setting PNBX to an appropriate value will avoid wasting space in dynamic area /PAWC/. This parameter may be set to the same value of PNBF or PNEF whichever is appropriate to save space.

'PNCX' Maximum number of regressors that may appear in the final expression of the parametrization (this number has to be ≤ 50). Default setting is 50. The same remark applies as for PNBX.

Distributions

```
CALL HPARMN (X,Y,EY,NP,NVAR,IC,R2MIN,MAXPOW,COEFF*,ITERM*,NCO*)
```

Input parameters:

X	Coordinates of data points (array of size NP*NVAR)
Y	Data to fit (array of length NP)
EY	Errors on data (array of length NP)
NP	Number of points to fit
NVAR	Dimension of X-space
MAXPOW	see HPARAM
IC	see HPARAM
R2MIN	see HPARAM

Output parameters:

See HPARAM. The only difference concerns option W of IC, where:

- W = 0 errors are taken from EY
- W = 1 errors are set to 1

7.5 Smoothing

Histograming is the least expensive and most popular density estimator, but has several statistical drawbacks. To name only two, it fails to identify structures that are much narrower than the bin size, and exhibits sharp discontinuities (statistical fluctuations) among adjacent low population bins.

The first problem is usually solved by adapting the bin width to the experimental resolution, or by rebinning after looking at the histogram. To filter out the statistical fluctuations, smoothing algorithms can be applied.

Three such techniques are implemented in HBOOK, the so called **353QH** (HSMOOF), the method of **B-splines** (HSPLI1, HSPLI2, HSPFUN), and multiquadric smoothing (HQUAD). Before trying them out references [13, 14, 15, 16], and [16] should be consulted, and results taken with care.

`CALL` **HSMOOF** `(ID,ICASE,CHI2*)`

Action: Routine to smooth a 1-dimensional histogram according to algorithm `353QH`, `TWICE` (see [13]).

Input parameters:

`ID` Histogram identifier

`ICASE` 0 and 1 replace original histogram by smoothed version;
2 superimposes as a function when editing.

Output Parameter:

`CHI2` chisquare χ^2 between original and smoothed histogram.

Remark:

- The mean value and standard deviation are recalculated if `ICASE=1`
- The routine can be called several times for the same histogram identifier `ID`, for `ICASE=1` or `2`.

`CALL` **HSPLI1** `(ID,IC,N,K,CHI2*)`

Action: B-splines smoothing of a 1-dimensional histogram.

Input parameters:

`ID` Identifier of an existing 1-dimensional histogram

`IC` Superimposition flag (`IC=0` is identical to `IC=1`)
1 Replaces original contents by the value of the spline;
2 Superimposes the spline function when editing.

`N` Number of knots (when `N`$\leq$`0` then `N=13`).

`K` Degree of the splines (when `K`$\geq$`3` then `K=3`).

Output Parameter:

`CHI2` chisquare χ^2 between original and smoothed histogram.

Remarks:

- `HSPLI1` can be called several times for the same histogram identifier `ID`, for any value of the parameters
- If the distribution to be smoothed exibits `NP` statistically relevant peaks then a rule of thumb to define the number of knots is, `N = 4*NP+6` for a spline of degree 3.

```
CALL HSPLI2 (ID,NX,NY,KX,KY)
```

Action: B-splines smoothing of a 2-dimensional histogram.

Input parameters:

`ID` Identifier of an existing 2-dimensional

`NX` Number of knots in the X interval (when `NX`$\leq$`0` then `NX=13`).

`NY` Number of knots in the Y interval (when `NY`$\leq$`0` then `NY=13`).

`KX` Degree of the spline in X (when `KX`$\geq$`3` then `KX=3`).

`KY` Degree of the spline in Y (when `KY`$\geq$`3` then `KY=3`).

Remark:

- The original contents of the histogram are replaced by the value of the spline approximation.
- See the remark about the number of knots for routine `HSPLI1`.

```
S = HSPFUN (ID,X,N,K)
```

Action: Performs a B-spline smoothing of a 1-dimensional histogram and returns the value at a given abscissa point.

Input parameters:

`ID` Identifier of an existing 1-dimensional histogram

`X` Abscissa

`N` Number of knots (when `N`$\leq$`0` then `N=13`).

`K` Degree of the splines (when `K`$\geq$`3` then `K=3`).

```
CALL HQUAD (ID,CHOPT,MODE,SENSIT,SMOOTH,NSIG*,CHISQ*,NDF*,FMIN*,FMAX*,
            IERR*)
```

Action: This routine fits multiquadric radial basis functions to the bin contents of a histogram or the event density of an Ntuple. (For Ntuples this is currently limited to “simple” ones, i.e., with 1, 2 or 3 variables; all events are used – no selection mechanism is implemented. Thus the recommended practice at the moment is to create a “simple” Ntuple and fill it from your “master” Ntuple with the `NTUPLE/LOOP` command and an appropriate `SELECT.FOR` function.) Routine `HQUAD` is called automatically in `paw` by the existing command `SMOOTH`. For a complete description of the method see reference [16].

Input parameters:

`ID` Histogram or Ntuple ID.

`CHOPT` Character variable containing option characters:

`0` Replace original histogram by smoothed.

2 Do not replace original histogram but store values of smoothed function and its parameters. (The fitted function is regenerated from the values or the parameters with the `FUNC` option in `HISTOGRAM/PLOT` for histograms or with `NTUPLE/DRAW` for Ntuples.)

V Verbose.

`MODE` Mode of operation

0 Same as `MODE = 3` (see below).

3 find significant points and perform unconstrained fit. If the histogram or Ntuple is unweighted perform a Poisson likelihood fit, otherwise a least squares fit (see `MODE = 4`).

4 force an unconstrained least squares fit in all cases. (This is a linear least squares problem and therefore the most efficient possible since it allows a single step calculation of the best fit and covariances. But note it assumes gaussian errors, even for low statistics, including the error on zero being 1.)

`SENSIT` Sensitivity parameter. It controls the sensitivity to statistical fluctuations (see Remarks). `SENSIT = 0.` is equivalent to `SENSIT = 1.`

`SMOOTH` Smoothness parameter. It controls the (radius of) curvature of the multiquadric basis functions. `SMOOTH = 0.` is equivalent to `SMOOTH = 1.`

Output parameters:

`NSIG` no. of significant points or centres found, i.e., no. of basis functions used.

`CHISQ` chi-squared (see Remarks).

`NDF` no. of degrees of freedom.

`FMIN` minimum function value.

`FMAX` maximum function value.

`IERR` error flag, 0 if all's OK. (Hopefully helpful error messages are printed where possible.)

Remarks:

- Empty bins are taken into account. (Poisson statistics are used for the unweighted case.)
- The multiquadric basis functions are $\sqrt{r^2 + \Delta^2}$, where r is the radial distance from its "centre", and Δ is a scale parameter and also the curvature at the "centre". "Centres", also referred to as "significant points", are located at points where the 2nd differential or Laplacian of event density is statistically significant.
- The data must be statistically independent, i.e., events (weighted or unweighted) drawn randomly from a parent probability distribution or differential cross-section, e.g., you cannot further smooth a previously smoothed distribution.
- For histograms, the chi-squared (`CHISQ`) is that of the fit to the original histogram assuming gaussian errors on the original histogram even for low statistics, including the error on zero being 1. It is calculated like this even for a Poisson likelihood fit; in that case the maximum likelihood may not correspond to the minimum chi-squared, but `CHISQ` can still be used, with `NDF` (the no. of degrees of freedom), as a goodness-of-fit estimator. For Ntuples, an internally generated and temporary histogram is used to calculate `CHISQ` in the same way.

7.6 Random Number Generation

```
R = HRNDM1 (ID)
```

Action: Returns a random number distributed according to the contents of 1-dimensional histogram.

Input parameter:

`ID` Identifier of an existing 1-dimensional histogram according to whose distribution random numbers have to be generated.

Remark:

- The first time `HRNDM1` is called on a given histogram with identifier `ID`, the channel contents of the original histogram are replaced by the integrated channel contents, normalized to 1.
- The histogram `ID` must be booked with 1 bin/word (`VMX=0`)
- If the histogram `ID` does not exist, zero is returned
- If the histogram `ID` is empty, or if the sum of its channel contents is not positive, a message is printed and a flat distribution is assumed.

```
CALL HRNDM2 (ID,RX*,RY*)
```

Action: Returns a random point `(RX, RY)` distributed according to the contents of a 2-dimensional histogram.

Input parameter:

`ID` Identifier of a 2-dimensional histogram

Output parameters

`RX,RY` Random numbers.

Remark:

- Same as `HRNDM1`
- These 2 entries can be used in conjunction with `HBFUN1` and `HBFUN2` respectively.

7.7 Fitting with finite Monte Carlo statistics

Most of the following text is taken from [17] - see this publication for more discussion and details of the algorithm, and examples.

Analysis of results from HEP experiments often involves estimation of the composition of a sample of data, based on Monte Carlo simulations of the various sources. Data values (generally of more than one dimension) are binned, and because the numbers of data points in many bins are small, a χ^2 minimisation is inappropriate, so a maximum likelihood technique using Poisson statistics is often used. This package incorporates the fact that the Monte Carlo statistics used are finite and thus subject to statistical fluctuations.

The Problem.

A common problem arises in the analysis of experimental data. There is a sample of real data, each member of which consists of a set of values $\{x_r\}$ – for example, a set of Z decay events with inclusive leptons, for each of which there is a value of $\{p^\ell, p_t^\ell, T, E_{vis}\}$, or a set of measured particle tracks, each with $\{p, \frac{dE}{dx}, \cos\theta\}$. You know that these arise from a number of sources: the lepton events from direct b decays, cascade b decays, c decays, and background, the tracks from π, K, and p hadrons. You wish to determine the proportions P_j of the different sources in the data.

There is no analytic form available for the distributions of these sources as functions of the $\{x_r\}$, only samples of data generated by Monte Carlo simulation. You therefore have to bin the data, dividing the multidimensional space spanned by the $\{x_r\}$ values into n bins. This gives a set of numbers $\{d_1, d_2...d_n\}$, where d_i is the number of events in the real data that fall into bin i. Let $f_i(P_1, P_2...P_m)$ be the predicted number of events in the bin, given by the strengths P_j and the numbers of Monte Carlo events a_{ji} from source j in bin i.

$$f_i = N_D \sum_{j=1}^{m} P_j a_{ji}/N_j \tag{7.1}$$

where N_D is the total number in the data sample,and N_j the total number in the MC sample for source j.

$$N_D = \sum_{i=1}^{n} d_i \qquad N_j = \sum_{i=1}^{n} a_{ji} \tag{7.2}$$

The P_j are then the actual proportions and should sum to unity. It is convenient to incorporate these normalisation factors into the strength factors, writing $p_j = N_D P_j/N_j$, giving the equivalent form

$$f_i = \sum_{j=1}^{m} p_j a_{ji} \tag{7.3}$$

One approach is then to estimate the p_j by adjusting them to minimise

$$\chi^2 = \sum_i \frac{(d_i - f_i)^2}{d_i} \tag{7.4}$$

This χ^2 assumes that the distribution for d_i is Gaussian; it is of course Poisson, but the Gaussian is a good approximation to the Poisson at large numbers.

Unfortunately it often happens that many of the d_i are small, in this case one can go back to the original Poisson distribution, and write down the probability for observing a particular d_i as

$$e^{-f_i} \frac{f_i^{d_i}}{d_i!} \tag{7.5}$$

and the estimates of the proportions p_j are found by maximising the total likelihood or, for convenience, its logarithm (remembering $a^b = e^{b \ln a}$, and omitting the constant factorials)

$$\ln \mathcal{L} = \sum_{i=1}^{n} d_i \ln f_i - f_i \tag{7.6}$$

This accounts correctly for the small numbers of data events in the bins, and is a technique in general use. It is often referred to as a "binned maximum likelihood" fit.

But this does not account for the fact that the Monte Carlo samples used may also be of finite size, leading to statistical fluctuations in the a_{ji}. In Equation 7.1 it can be seen that these are damped by a factor N_D/N_j, but we cannot hope that this is small.

So: disagreements between a particular d_i and f_i arise from incorrect p_j, from fluctuations in d_i, and from fluctations in the a_{ji}. Binned maximum likelihood reckons with the first two sources, but not the third. In the χ^2 formalism of Equation 7.4 this can be dealt with by adjusting the error used in the denominator

$$\chi^2 = \sum_i \frac{(d_i - f_i)^2}{d_i + N_D^2 \sum_j a_{ji}/N_j^2} \tag{7.7}$$

but this still suffers from the incorrect Gaussian approximation. The problem is to find the equivalent treatment for the binned maximum likelihood method.

Methodology.

The correct way to view the problem is as follows. For each source, in each bin, there is some (unknown) expected number of events A_{ji}. The prediction for the number of data events in a bin is not Equation 7.3 but

$$f_i = \sum_{j=1}^{m} p_j A_{ji} \tag{7.8}$$

From each A_{ji} the corresponding a_{ji} is generated by a distribution which is in fact binomial, but can be taken as Poisson if $A_{ji} << N_j$ (which is indeed the case, as our problem is just that a large number of total events gives a small number in each bin.)

The total likelihood which is to be maximised is now the combined probability of the observed $\{d_i\}$ and the observed $\{a_{ji}\}$ and we want to maximise

$$\ln \mathcal{L} = \sum_{i=1}^{n} d_i \ln f_i - f_i + \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ji} \ln A_{ji} - A_{ji} \tag{7.9}$$

The estimates for the p_j (which we want to know) and the A_{ji} (in which we're not really interested) are found by maximising this likelihood. This is the correct methodology to incorporate the MC statistics: unfortunately it consists of a maximisation problem in $m \times (n+1)$ unknowns. However, the problem can be made much more amenable.

The Solution.

To find the maximum we differentiate Equation 7.9 (including Equation 7.8 for f_i) and set the derivatives to zero. This gives two sets of equations, those for the differentials with respect to p_j

$$\sum_{i=1}^{n} \frac{d_i A_{ji}}{f_i} - A_{ji} = 0 \qquad \forall j \tag{7.10}$$

and those for the differentials with respect to A_{ji}

$$\frac{d_i p_j}{f_i} - p_j + \frac{a_{ji}}{A_{ji}} - 1 = 0 \qquad \forall i, j \tag{7.11}$$

These $m \times (n+1)$ simultaneous equations are nonlinear and coupled (remembering that the f_i that appear in them are functions of the p_j and the A_{ji}). However they can be remarkably simplified. Equations 7.11 can be rewritten

$$1 - \frac{d_i}{f_i} = \frac{1}{p_j}(\frac{a_{ji}}{A_{ji}} - 1) \qquad \forall i, j \tag{7.12}$$

The left hand side depends on i only, so write it as t_i.

$$t_i = 1 - \frac{d_i}{f_i} \tag{7.13}$$

The right hand side then becomes

$$A_{ji} = \frac{a_{ji}}{1 + p_j t_i} \tag{7.14}$$

which is a great simplification: for a given set of p_j, the $n \times m$ unknown quantities A_{ji} are given by the n unknown quantities t_i.

The t_i are given by Equation 7.13. If d_i is zero then t_i is 1: if not then

$$\frac{d_i}{1 - t_i} = f_i = \sum_j p_j A_{ji} = \sum_j \frac{p_j a_{ji}}{1 + p_j t_i} \tag{7.15}$$

If these n equations are satisfied, with Equation 7.14 used to define the A_{ji}, then all the $m \times n$ Equations 7.11 are satisfied.

The method adopted by `HMCLNL` is (for a given set of p_j), to solve equations 7.15 for the t_i, thus giving the A_{ji} via equation 7.14. The log likelihood may then be calculated using equation 7.9. The maximum of the likelihood may then be found using numerical means - `HMCMLL` uses MINUIT to perform this maximisation (this is equivalent to solving equations 7.10).

Although there are n equations 7.15, to be solved numerically, this does not present a problem. They are not coupled, and each equation clearly has one and only one solution in the 'allowed' region for t_i, i.e. the region where the A_{ji} are all positive, which lies between $t = -1/p_{max}$ and $t = 1$ (p_{max} being the largest of the p_j). $t = 0$ is a suitable place to start, and Newton's method readily gives a solution. Special considerations apply when there are no events from one or more of the MC sources - more details of the solution can be found in [17].

Other points concerning the solution

Some nice points emerge from the algebra. The Equations 7.10 can be written more simply as

$$\sum_{i=1}^{n} t_i A_{ji} = 0 \qquad \forall j \tag{7.16}$$

Also one can replace $\frac{d_i}{f_i}$ by $1 + (A_{ji} - a_{ji})/p_j A_{ji}$, from Equation 7.12, and the equations then reduce to

$$\sum_i A_{ji} = \sum_i a_{ji} \qquad \forall j \tag{7.17}$$

These are telling us that the estimates of the A_{ji} for some source will change the shape of the distribution from that of the MC data a_{ji}, but will not change the overall total number.

Equation 7.11 can be multiplied by A_{ji} and summed over j to give

$$\sum_j d_i - p_j A_{ji} + a_{ji} - A_{ji} = 0$$

summing over i, and using Equation 7.17, gives

$$\sum_i d_i = \sum_i \sum_j p_j a_{ji}$$

$$N_D = \sum_j p_j N_j \tag{7.18}$$

which nicely returns the normalisation, and makes clear the significance of the p_j. It is interesting that such an automatic normalisation does not occur in the χ^2 minimisation technique of Equation 7.4. If the different p_j are allowed to float independently they return a set of values for which the fitted number of events is generally less than the actual total number, as downward fluctuations have a smaller assigned error and are given higher weight.

Weighted Events

In some problems it is necessary to apply weights to the Monte Carlo data before comparing it with the real data.

An example occurs when events are detected with some efficiency, which differs from bin to bin, and the form of which is known exactly. Rather than reject MC events on a random basis, it is more effective to include them all, weighted by the appropriate efficiency.

Another such instance arises if MC data has been generated according to one function, but another one is desired. For example, data on $\{p, \frac{dE}{dx}, \cos\theta\}$ may have been generated using some form of the Bethe-Bloch Equation

$$\frac{dE}{dx} = F_0(p, \theta, m_j)$$

and with hindsight it is realised that some other form $F_1(p, \theta, m_j)$ is more correct. This can be accomodated by weighting each bin by

$$w_{ji} = F_1/F_0$$

In such a case the predicted number of events in each bin is modified and Equation 7.8 becomes

$$f_i = \sum_{j=1}^{m} p_j w_{ji} A_{ji} \tag{7.19}$$

The likelihood function of Equation 7.9 is unchanged. The differentials of Equation 7.10 become

$$\sum_{i=1}^{n} (\frac{d_i}{f_i} - 1) w_{ji} A_{ji} = 0 \qquad \forall j \tag{7.20}$$

and the differentials with respect to the A_{ji} give the equivalents of Equations 7.14 and 7.15.

$$A_{ji} = \frac{a_{ji}}{1 + p_j w_{ji} t_i} \tag{7.21}$$

$$\frac{d_i}{1-t_i} = f_i = \sum_j \frac{p_j w_{ji} a_{ji}}{1 + p_j w_{ji} t_i} \tag{7.22}$$

The solution of these 4 sets of equations proceeds as before. Notice that, as one would expect, if w_{ji} is the same for all i, then this merely amounts to a scaling of the Monte Carlo strength p_j.

So far this assumes that the weight is the same for all events from a given source in a given bin: the quantity w_{ji}. This may not be the case if either (a) the bin size is so large that the weight factor varies significantly within the bin or (b) the weight factor depends not only on the variable(s) x used in making the comparison but also on some other variable(s) – call it z – which is not binned and used in the comparison; perhaps it does not exist in the real data. In either case the weights of different events from the same source in the same bin can be different.

In such a case the Equations 7.19 – 7.22 still apply, with w_{ji} equal to the ideal average weight for source j in bin i. This may be a known quantity: more likely it has to be estimated using the actual weights attached to the MC data values themselves.

At this point one has to worry whether the discrepancy between the average actual weight and the true average weight should be included in the fitting procedure, estimation and errors. Now in practice this method of weighting only works satisfactorily if the weights do not differ very much. The variance of a sum of weights from Poisson sources is $\sum_i w_i^2$ [18] and thus the proportional error on the bin contents $\sqrt{\sum_i w_i^2} / \sum_i w_i$ is greater than the $1/\sqrt{N}$ obtained from unweighted Poisson statistics, and this effect get worse as the spread of weights, $\overline{w^2} - \overline{w}^2$, gets larger. Fluctuations in a small number of events with large weights will swamp the information obtained from low weight events. Thus in any application the spread in weights for a source in a bin should be small, and this means that the resulting uncertainty in its value will also be small.

Some insight can be gained by noting that in the set of Equations 7.19 – 7.22 the weights w_{ji} always appear together with the p_j. (Equation 7.20 can be multiplied by p_j to make this explicit). Thus if the weights are all too high by some factor the strengths will be low by exactly the same factor. So the error in the p_j estimates resulting from uncertainties in the weights is of the same order as that uncertainty, and in any application this should be small.

In `HMCINI`, the weight distributions provided are normalised so that

$$\sum_i w_{ji} a_{ji} = \sum_i a_{ji} = N_j$$

and the normalisation factors (These should always be 1 unless there is an **efficiency** component to the distribution) are preserved. Inclusion of weights is then regarded as a two stage problem.

1. The fitting of the reweighted Monte Carlo distributions to the data distribution, in which the Monte Carlo normalisation is preserved, to find a set of fractions $P_j\prime$. These correspond to the fractions of each source actually present in the data sample you provide.
2. The transformation of the $P_j\prime$ into the P_j, the fractions of each source which were present in the data sample **before the efficiencies were applied to the data**.

This is implemented as follows. The user (or `HMCMLL`) calls `HMCLNL` with the P_j. These are transformed into the $P_j\prime$ within `HMCLNL` using the normalisation factors α_j calculated by `HMCINI`.

$$P_j\prime = \frac{\sum_j P_j}{\sum_j \alpha_j P_j} \times \alpha_j P_j$$

where

$$\alpha_j = \frac{\sum_i w_{ji} a_{ji}}{N_j}$$

and HMCLNL calculates the correct log-likelihood using the $P_j\prime$ and the normalised weight distributions.

HBOOK routines

The following three routines are intended to help with problems of the above type. Subroutine HMCMLL uses minuit to perform the log-likelihood maximisation and return a set of fractions. Functions HMCINI and HMCLNL are provided for those who wish to perform the fit themselves.

N.B. Real parameters and functions are all REAL*8 (Double precision on most machines).

```
CALL HMCMLL  (IDD,IDM,IDW,NSRC,CHOPT,IFIX,FRAC,FLIM,START,
              STEP,UP,PAR*,DPAR*)
```

Action: Fits the given Monte Carlo distributions to the data distribution, using a binned maximum likelihood fit which includes the effect of both data and Monte Carlo statistics, and allows weights to be provided for each Monte Carlo distribution. The data, Monte Carlo and weight distributions must be presented in identically binned 1 dimensional histograms. Weight distributions which just change the shape of the Monte Carlo spectra (i.e. *not* efficiency distributions) must be normalised so that

$$\sum_i w_{ji} a_{ji} = \sum_i a_{ji} = N_j.$$

The best estimate of the fraction of each Monte Carlo distribution present in the data distribution is returned, with an error estimate where required.

Input parameters:

IDD Data histogram identifier.

IDM Array of dimension NSRC containing Monte Carlo histogram identifiers.

IDW Array of dimension NSRC containing weight histogram identifiers. ('W' option only).

NSRC Number of Monte Carlo sources. Must be greater than 1.

CHOPT
- 'F' Fix one or more of the fractions. Default is for all fractions to vary freely.
- 'L' Set limits on the fractions as given in FLIM. Default is no limits.
- 'W' Use the weight histograms provided. For non existent weight histograms, and if the 'W' option is not requested, a dummy weight histogram in which all entries are 1 is booked.
- 'S' Scan the likelihood function with respect to each fit parameter, before and after the fit. If the 'N' option is specified, the function will only be scanned once for each parameter.
- 'N' Do not perform the fit.
- 'P' Use the parameter start points and initial step sizes provided in START and STEP. If the 'P' option is not specified then the start point for each free parameter is

$$\frac{1 - \Sigma_f}{\mathtt{NSRC} - N_f}$$

, where Σ_f is the sum of the fixed fractions, and N_f is the number of fixed fractions; and the initial step size is 0.01.

'E' Perform a detailed error analysis using the MINUIT routines HESSE and MINOS.

IFIX Array of dimension NSRC containing '1' if a parameter is to be fixed in the fit, '0' otherwise. ('F' option only).

FRAC Array of dimension NSRC with the values at which parameters are to be fixed. ('F' option only).

FLIM Array of dimension (NSRC,2) with the lower, then upper limits on the parameters. ('L' option only.)

START Array of dimension NSRC with the start values for each parameter. ('P' option only - if 'P' option is chosen then default start values are used if values in START are negative).

STEP Array of dimension NSRC with initial step values for each parameter. ('P' option only - if 'P' option is chosen then default step values are used if values in STEP are negative).

UP UP value for the error estimate ('E' option only). Default 0.5 (if user supplies negative or zero value for UP when 'E' option is chosen). See the Minuit manual for definition of UP.

Output parameters:

PAR Array of dimension NSRC with the final fitted values of the parameters.

DPAR Array of dimension NSRC with the errors on the final fitted values of the parameters.

```
CALL HMCINI (IDDATA,IDMC,IDWT,NSRC,CHOPT,IERR)
```

Action: Initialisation routine for function HMCLNL, needs to be called each time a new set of histograms is introduced (generally once at the beginning of each fit). Performs some error checking and sets up a dummy weight histogram if necessary.

Input parameters:

IDDATA Data histogram identifier.

IFIXMC Array of dimension NSRC containing '1' if a

IDMC Array of dimension NSRC containing Monte Carlo histogram identifiers.

IDWT Array of dimension NSRC containing weight histogram identifiers. ('W' option only).

NSRC Number of Monte Carlo sources.

CHOPT 'W' Use the weight histograms provided. For non existent weight histograms, and if the W option is not requested, a dummy weight histogram in which all entries are 1 is booked.

IERR Error flag - set to 1 if the parameters sent to HMCINI were not usable (e.g. incompatibility between data and MC histograms, number of MC sources less than 2), 0 otherwise.

```
VARIAB = HMCLNL (FRAC)
```

Action: HMCLNL is a double precision function giving the log likelihood (including effect of both data and Monte Carlo statistics) that the data distribution arose from a distribution given by combining the Monte Carlo distributions, weighted by the weights provided, using the fractions given in FRAC. HMCINI must be called before this function may be used.

Input parameters:

FRAC Array of dimension NSRC containing the fraction of each Monte Carlo distribution you wish to assume is in the data distribution, in order to calculate the log likelihood.

Example of use of HMCMLL

```
      PROGRAM MCSTAT

      PARAMETER (NPAWC=10000)
      COMMON/PAWC/H(NPAWC)

      INTEGER NMCSRC
      PARAMETER (NMCSRC=2)

* declarations for HMCMLL
      INTEGER IDDATA,IDMC(NMCSRC),IDWT(NMCSRC),IFIXMC(NMCSRC)
      DOUBLE PRECISION FLIM(NMCSRC,2),FSTART(NMCSRC),
     + FSTEP(NMCSRC),FUP,FRAC(NMCSRC),ANS(NMCSRC),DANS(NMCSRC)

      DATA IDDATA,IDMC,IDWT/10,1301,1302,1351,1352/

      CALL HLIMIT(NPAWC)

* Set 'UP' to correspond to 70% confidence level for 2 parameter fit.
      FUP=1.2

* Read in your data, Monte Carlo and Weight histograms
      CALL HRGET(10,'HMCHIS.PAW',' ')
      DO 20 JSRC=1,NMCSRC
         CALL HRGET(IDMC(JSRC),'HMCHIS.PAW',' ')
         CALL HRGET(IDWT(JSRC),'HMCHIS.PAW',' ')
20    CONTINUE

* perform log likelihood maximisation and error analysis,
* using user weights + setting limits on the fractions.
      WRITE(6,1000)
1000  FORMAT(' ** Fit with error analysis - use user weights
     +and limits',/)
      FLIM(1,1)=0.0
      FLIM(2,1)=1.0D0
      FLIM(1,2)=0.0
      FLIM(2,2)=1.0D0
      CALL HMCMLL(IDDATA,IDMC,IDWT,NMCSRC,'EWL',IFIXMC,
     + FRAC,FLIM,FSTART,FSTEP,FUP,ANS,DANS)

      END
```

The program fits the first two histograms shown (1302 is dotted) to the second. The weights for the first distribution are all 1, for the second they are all 0.8.

Output Generated

```
 ** Fit with error analysis - use user weightsand limits

  MINUIT RELEASE 93.08  INITIALIZED.   DIMENSIONS 100/ 50  EPSMAC=  0.56E-16
 MCMLL: You have  2 free fractions and  0 fixed

 PARAMETER DEFINITIONS:
    NO.   NAME         VALUE      STEP SIZE      LIMITS
     1 'P1        '   0.50000      0.10000E-01    0.00000E+00   1.0000
     2 'P2        '   0.50000      0.10000E-01    0.00000E+00   1.0000
```

```
**********
**    1 **CALL FCN   1.000
**********
**********
**    2 **SET ERR  0.5000
**********
**********
**    3 **MIGRAD
**********

FIRST CALL TO USER FUNCTION AT NEW START POINT, WITH IFLAG=4.
START MIGRAD MINIMIZATION.  STRATEGY 1.  CONVERGENCE WHEN EDM .LT. 0.50E-04

FCN=  -8317.393     FROM MIGRAD    STATUS=INITIATE       8 CALLS       10 TOTAL
                    EDM= unknown      STRATEGY= 1      NO ERROR MATRIX

 EXT PARAMETER               CURRENT GUESS       STEP         FIRST
 NO.   NAME        VALUE          ERROR          SIZE      DERIVATIVE
  1      P1       0.50000       0.10000E-01   0.20001E-01   -8.1370
  2      P2       0.50000       0.10000E-01   0.20001E-01    8.7598
                              ERR DEF=  0.50

MIGRAD MINIMIZATION HAS CONVERGED.

MIGRAD WILL VERIFY CONVERGENCE AND ERROR MATRIX.
COVARIANCE MATRIX CALCULATED SUCCESSFULLY

FCN=  -8319.763     FROM MIGRAD    STATUS=CONVERGED     45 CALLS       47 TOTAL
                    EDM=  0.66E-08    STRATEGY= 1      ERROR MATRIX ACCURATE

 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME        VALUE          ERROR          SIZE      DERIVATIVE
  1      P1       0.64665       0.75183E-01   0.25797E-02  -0.77581E-03
  2      P2       0.35335       0.70935E-01   0.24335E-02  -0.10448E-02
                              ERR DEF=  0.50

EXTERNAL ERROR MATRIX.    NDIM=  50    NPAR=  2    ERR DEF=  0.50
 0.570E-02-0.460E-02
-0.460E-02 0.507E-02

PARAMETER  CORRELATION COEFFICIENTS
      NO.  GLOBAL     1     2
       1  0.85488  1.000-0.855
       2  0.85488 -0.855 1.000
**********
**    4 **SET ERR   1.200
**********
MCMLL: SET UP VALUE TO  1.20
MCMLL: FOR  2 FREE PARAMETERS
**********
**    5 **MINOS
**********

MINUIT TASK: *** HBOOK New ll maximisation

FCN=  -8319.763     FROM MINOS     STATUS=SUCCESSFUL    72 CALLS      119 TOTAL
                    EDM=  0.66E-08    STRATEGY= 1      ERROR MATRIX ACCURATE

 EXT PARAMETER                  PARABOLIC         MINOS ERRORS
 NO.   NAME        VALUE          ERROR      NEGATIVE      POSITIVE
  1      P1       0.64665       0.11579      -0.11144       0.12598
  2      P2       0.35335       0.10932      -0.11560       0.10891
                              ERR DEF=   1.2
```

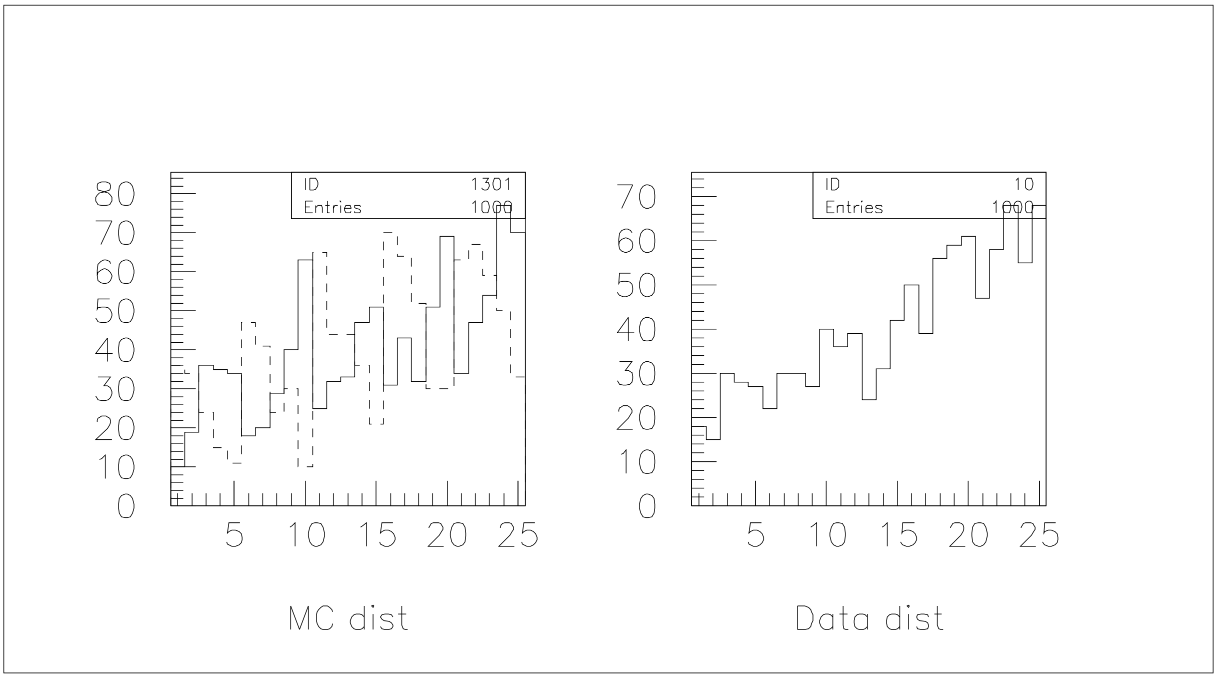


Figure 7.1: Monte Carlo distributions (left) and data distribution (right)

7.7.1 Example of fits

```
      SUBROUTINE HEXAM5
*.==========>
*.          OPERATIONS ON HISTOGRAMS AND FITTING
*..=========> (R.Brun, modified by M.Goossens)
      COMMON/HFPAR/PAR(6)
      COMMON/HFGAUS/AG,BG,CG
      DOUBLE PRECISION AG,BG,CG
      DIMENSION X(100),Y(100)
      DIMENSION XF(4000,2),YF(4000),EY(4000),SIGPAR(6)
      DOUBLE PRECISION COV(6,6)
      EXTERNAL HFUNF,HFUNFV,HFUNGA
      CHARACTER*12 TITL1
      DATA TITL1/'TITLE OF ID1'/
*.-------------------------------------------
*
*            GET hist 110 from data base
*
      CALL HRGET(110,'hexam.dat',' ')
      CALL HRGET(210,'hexam.dat',' ')
*
*
      CALL HBOOK1(1,TITL1,100,0.,1.,0.)
      CALL HCOPY(1,2,'TITLE OF ID = 2')
*
*            Gets information from ID=110 and fills new IDs 1,2
*
```

```
      CALL HUNPAK(110,X,'HIST',1)
      CALL UCOPY(X,Y,100)
      CALL VZERO(X(51),50)
      CALL HPAK(1,X)
      CALL HPHIST(1,'HIST',1)
      CALL VZERO(Y,50)
      CALL HPAK(2,Y)
      CALL HPHIST(2,'HIST',1)
*
*             adds 1 and 2. Identifier 3 is created and will contain
*             result of addition
*
      CALL HOPERA(1,'+',2,3,1.,1.)
      CALL HCOPY(3,4,' ')
*
*             Fits 3 with function HFUNF, similar to example 2 .
*             Initializes parameters. Prints results of the last
*             iteration.
*             Superimpose result of fit to the histogram
*             The result of this fit can be compared with the initial
*             parameters of example 2
*
      PAR(1) = 40.
      PAR(2) = 20.
      PAR(3) = 0.4
      PAR(4) = 0.6
      PAR(5) = 0.1
      PAR(6) = 0.1
*
      CALL HFITH(3,HFUNF,'V',6,PAR(1),ST,PMI,PMA,SIGPAR,CHI2)
*
      CALL HPHIST(3,'HIST',1)
*
*
*            Fits a two-dimensional distribution (xf,yf) with HFITN
*            initialize parameters. Prints results of the last
*            iteration.
*            Errors EY automatically computed as SQRT(yf)
*
      NY=0
      DO 10 J=1,40
         DO 5 I=1,100
            CONT=HIJ (210,I,J)
            IF (CONT.EQ.0.) GOTO 5
            NY=NY+1
            YF(NY)=CONT
            EY(NY)=SQRT(CONT)
            CALL HIJXY (210,I,J,X1,X2)
            XF(NY,1)=X1+0.005
            XF(NY,2)=X2+0.0125
    5    CONTINUE
   10 CONTINUE
      PAR(1) = 3.
      PAR(2) = 1.
      PAR(3) = 0.3
      PAR(4) = 0.7
      PAR(5) = 0.07
```

```
      PAR(6) = 0.12
*
      CALL HFITV (NY,NY,1,XF,YF,EY,HFUNFV,'V',6,PAR(1),ST,PMI,PMA,
     +            SIGPAR,CHI2)
*       Get covariance matrix of last fit from Minuit.
*       Minuit parameters on 4-byte machines are Double precision
      CALL MNEMAT(COV,6)
      WRITE(31,*) ' COVARIANCE MATRIX'
      WRITE(31,*) ' *****************'
      DO 20 I=1,6
        WRITE(31,'(6(D12.4,1X))') (COV(I,J),J=1,I)
   20 CONTINUE
*
*       Gaussian fit. Prints first and last iterations.
*
      AG = 2.
      BG = 0.4
      CG = 0.1
      CALL HDELET (0)
      CALL HBFUN1 (1,' ',100,0.,1.,HFUNGA)
      CALL HBOOK1 (5,' ',100,0.,1.,1000.)
      DO 30 I=1,5000
         XR=HRNDM1 (1)
         CALL HFILL (5,XR,0.,1.)
   30 CONTINUE
*
      PAR(1) = 200.
      PAR(2) = 0.4
      PAR(3) = 0.1
      CALL HFITHN(5,'G',' ',3,PAR(1),ST,PMI,PMA,SIGPAR,CHI2)
      CALL HPRINT (5)
      CALL HDELET (0)
*
      END
*
      FUNCTION HFUNF(X)
      COMMON/HFPAR/PAR(6)
      DOUBLE PRECISION A1,A2,C1,C2,XM1,XM2,XS1,XS2,X1,X2
*       Force double precision calculation
      C1  = PAR(1)
      C2  = PAR(2)
      XM1 = PAR(3)
      XM2 = PAR(4)
      XS1 = PAR(5)
      XS2 = PAR(6)
*
      A1=-0.5*((X-XM1)/XS1)**2
      A2=-0.5*((X-XM2)/XS2)**2
      IF(A1.LT.-20.)THEN
         X1=0.
      ELSEIF(A1.GT.20.)THEN
         X1=1.E5
      ELSE
         X1=C1*EXP(A1)
      ENDIF
      IF(A2.LT.-20.)THEN
         X2=0.
```

```
      ELSEIF(A2.GT.20.)THEN
         X2=1.E5
      ELSE
         X2=C2*EXP(A2)
      ENDIF
      HFUNF=X1+X2
      END
      FUNCTION HFUNFV (X)
      DIMENSION X(*)
*           Compute function value for 2-dim point X
      HFUNFV = HFUNF(X(1)) + HFUNF(X(2))
      END
      FUNCTION HFUNGA (X)
      COMMON/HFGAUS/AG,BG,CG
      DOUBLE PRECISION AG,BG,CG
      HFUNGA=AG*EXP(-0.5*((X-BG)/CG)**2)
      END
```

Output Generated

```
TITLE OF ID1

HBOOK     ID =         1                                        DATE  18/05/92              NO =    14

     172                                    -
     168                                    I
     164                                    I
     160                                   -I
     156                                   II -
     152                                   II-I
     148                                   I  I-
     144                                 --I   I
     140                                 I     I-
     136                                 I      I
     132                                 I      I
     128                                 I      I-
     124                                -I       I
     120                               -I        I
     116                               I         I
     112                               I         I
     108                               I         I
     104                              -I         I-
     100                              I           I
      96                              I           I -
      92                              I           I-I
      88                             -I             I
      84                             I              I -
      80                             I              I I
      76                             I              I I
      72                             I              I I-
      68                             I              I-II
      64                             I                 I
      60                           - I                 I
      56                           I-I                 I
      52                           I                   I-
      48                          -I                    I-
      44                          I                      I
      40                          I                      I-
      36                          I                       I
      32                          I                       I    -
      28                         -I                       I- - I
      24                       --I                         I-I I
      20                      -I                             I I-
      16                       I                             I-II
      12                     -I                                 I
       8                 - --I                                   I
       4            -----I-I                                     I

CHANNELS 100   0                                                                                                   1
          10   0         1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                          1111111111111
          10                112224658012445755432099687543222121
           1.       211246268181476068282127104785115522257716498

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        100      * ALL CHANNELS = 0.2825E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.3087E+00      * R . M . S = 0.7466E-01
```

```
TITLE OF ID = 2

HBOOK     ID =         2                                          DATE  18/05/92             NO =    15

      84                                                                               -
      82                                                                             - I
      80                                                                             I I
      78                                                                       -     I I  -
      76                                                                       I -   I I  I
      74                                                                       I-I  -I I  I
      72                                                                       I I  II I  I
      70                                                                       I I- II I  I -
      68                                                                       I  I II-I -I-I
      66                                                                    -  I  I-I  I-I  I
      64                                                                  - I  I            I-
      62                                                                  I-I  I             I
      60                                                                  I I -I             I
      58                                                                  I I I              I
      56                                                                  I I I              I
      54                                                                  I I-I              I -
      52                                                                - I                   I I
      50                                                                I-I                   I-I
      48                                                                I                      I
      46                                                                I                      I
      44                                                                I                      I   -
      42                                                               -I                      I-  I
      40                                                              -I                        I  I
      38                                                              I                         I  I
      36                                                              I                         I  I-
      34                                                              I                         I--II
      32                                                              I                             I
      30                                                             -I                             I
      28                                                         -   I                              I  -
      26                                                         I  -I                              I- I
      24                                                         I  I                                I I
      22                                                         I- I                                I I--
      20                                                         II I                                I-I I -
      18                                                         II-I                                    I I
      16                                                         I                                       I-I
      14                                                         I                                         I
      12                                                         I                                         I--
      10                                                         I                                           I
       8                                                         I                                           I - -
       6                                                         I                                           I-I-I
       4                                                         I                                               I-
       2                                                         I                                                I

CHANNELS 100   0                                                                                                  1
          10   0         1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10                                                     221233455666557776678686676664543343222221111
           1.                                                    71850922032539736953183588893942434650812591167574

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        100      * ALL CHANNELS = 0.2175E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.7102E+00      * R . M . S = 0.1063E+00
```

```
 MINUIT RELEASE 90.10  INITIALIZED.   DIMENSIONS 100/ 50  EPSMAC=  0.89E-15
**********
**    1 **SET EPS  0.1000E-06
**********
FLOATING-POINT NUMBERS ASSUMED ACCURATE TO   0.100E-06

    **********************************************
    *                                            *
    * Function minimization by SUBROUTINE HFITH  *
    * Variable-metric method                     *
    * ID =          3  CHOPT = V                 *
    *                                            *
    **********************************************
Convergence when estimated distance to minimum (EDM) .LT.  0.10E-03

PARAMETER DEFINITIONS:
   NO.   NAME         VALUE      STEP SIZE      LIMITS
    1 'P1        '    40.000       12.000         no limits
    2 'P2        '    20.000       6.0000         no limits
    3 'P3        '   0.40000      0.12000         no limits
    4 'P4        '   0.60000      0.18000         no limits
    5 'P5        '   0.10000      0.30000E-01     no limits
    6 'P6        '   0.10000      0.30000E-01     no limits
**********
**    2 **SET PRINT  0.0000
**********
**********
**    3 **MIGRAD   1160.       1.000
**********

MIGRAD MINIMIZATION HAS CONVERGED.

MIGRAD WILL VERIFY CONVERGENCE AND ERROR MATRIX.

FCN=   81.55959     FROM MIGRAD    STATUS=CONVERGED    391 CALLS      392 TOTAL
                    EDM=  0.21E-05    STRATEGY= 1      ERROR MATRIX ACCURATE

 EXT PARAMETER                                  STEP         FIRST
 NO.   NAME        VALUE          ERROR          SIZE      DERIVATIVE
  1      P1        154.37        3.8591       0.97447      -0.16735E-03
  2      P2        74.934        2.1210       0.51925       0.16237E-03
  3      P3       0.30351       0.15347E-02   0.76783E-03  -0.91430
  4      P4       0.70017       0.29587E-02   0.17713E-02   0.19339
  5      P5       0.69299E-01   0.12334E-02   0.28758E-03   0.39057
  6      P6       0.11985       0.27357E-02   0.62656E-03   0.52392

CHISQUARE = 0.9164E+00  NPFIT =   95
```

```
TITLE OF ID1

HBOOK     ID =          3                                       DATE  18/05/92              NO =    16

     172                                    -
     168                                    I
     164                                    I
     160                                   -I
     156                                   I***
     152                                   *I-I
     148                                   I  I*
     144                                 -*I   I
     140                                 I     I*
     136                                 *      I
     132                                 I      I*
     128                                 I      I-
     124                                *I       I
     120                               -I        I*
     116                               I         I
     112                               *         I
     108                               I         I *
     104                              -I         I-
     100                              I           I
      96                              *           I *
      92                              I           I-I
      88                             -I             I
      84                             *              I -                              - -
      80                             I              I*I                        -     I I  -
      76                             I              I I                        I--******  I
      72                            *I              I I-                       I**- II I**I -
      68                             I              I-*I                    - **  I-II-I--**I
      64                             I                 I                  --I* I            *-
      60                           * I                 *                  I * -I             *
      56                           I-I                 I                  I*I-I              I*-
      52                           I                   I-               --*                  I-*
      48                          *I                    *-              I*                     I*
      44                          I                      I             -*                      I-* -
      40                          I                      *-           **                        I **
      36                         *I                       I          *I                         I--I*
      32                          I                       *    -    *-I                             I*
      28                        *-I                       I* - I -**-I                              I-*-
      24                       *-I                         I***I**- I                                I *--
      20                      -I                             I *-II-I                                I-I** -
      16                      *                              I-I                                         I**
      12                    **I                                                                            I**
       8                 - *-I                                                                               I****
       4       ************I                                                                                     I*

CHANNELS 100   0                                                                                                  1
         10   0        1         2         3         4         5         6         7         8         9         0
          1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                          1111111111111
         10                  112224658012445755432099687543222121221233455666557776678686676664543343222221111
          1.       21124626818147606828212710478511552225771649871850922032539736953183588893942434650812591167574

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        200      * ALL CHANNELS = 0.5000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4834E+00      * R . M . S = 0.2184E+00
* CHISQUAR  =  0.8156E+02
```

```
    ***********************************************
    *                                             *
    * Function minimization by SUBROUTINE HFITV  *
    * Variable-metric method                      *
    * ID =          0  CHOPT = V                  *
    *                                             *
    ***********************************************
Convergence when estimated distance to minimum (EDM) .LT.  0.10E-03

PARAMETER DEFINITIONS:
   NO.   NAME        VALUE      STEP SIZE      LIMITS
    1 'P1       '    3.0000      0.90000         no limits
    2 'P2       '    1.0000      0.30000         no limits
    3 'P3       '   0.30000      0.90000E-01     no limits
    4 'P4       '   0.70000      0.21000         no limits
    5 'P5       '   0.70000E-01  0.21000E-01     no limits
    6 'P6       '   0.12000      0.36000E-01     no limits
**********
**    4 **SET PRINT  0.0000
**********
**********
**    5 **MIGRAD   1160.       1.000
**********
MACHINE ACCURACY LIMITS FURTHER IMPROVEMENT.

MIGRAD MINIMIZATION HAS CONVERGED.

MIGRAD WILL VERIFY CONVERGENCE AND ERROR MATRIX.
EIGENVALUES OF SECOND-DERIVATIVE MATRIX:
       -0.1596E+01 -0.6458E+00  0.3800E+00  0.7478E+00  0.1277E+01  0.5837E+01
MINUIT WARNING IN HESSE
============== MATRIX FORCED POS-DEF BY ADDING   1.6018     TO DIAGONAL.
MIGRAD TERMINATED WITHOUT CONVERGENCE.

FCN=   1709.709     FROM MIGRAD    STATUS=FAILED       197 CALLS      198 TOTAL
                    EDM=  0.41E+02    STRATEGY= 1      ERR MATRIX NOT POS-DEF

 EXT PARAMETER                APPROXIMATE       STEP         FIRST
 NO.   NAME       VALUE          ERROR          SIZE      DERIVATIVE
  1      P1       2.4709       0.73263E-01   0.00000       4.1109
  2      P2       1.8247       0.37237E-01   0.00000       8.5400
  3      P3      0.27725       0.24789E-02   0.00000      -125.59
  4      P4      0.70933       0.51778E-02   0.00000       132.72
  5      P5      0.90472E-01   0.47875E-02   0.00000      -302.38
  6      P6      0.21181       0.75383E-02   0.00000      -63.830

CHISQUARE = 0.9282E+00  NPFIT = 1848

 COVARIANCE MATRIX
 *****************
 0.5367E-02
 0.9472E-03   0.1387E-02
 0.4548E-05  -0.9488E-06   0.6145E-05
-0.1520E-04  -0.2581E-04   0.1647E-05   0.2681E-04
-0.2597E-03  -0.7556E-04  -0.2361E-06   0.2208E-05   0.2292E-04
 0.1100E-03  -0.3230E-04  -0.1566E-05   0.1904E-05  -0.2129E-04   0.5683E-04

    ***********************************************
    *                                             *
    * Function minimization by SUBROUTINE HFITH  *
    * Variable-metric method                      *
    * ID =          5  CHOPT =                    *
    *                                             *
    ***********************************************
```

```
 Convergence when estimated distance to minimum (EDM) .LT.  0.10E-03

 FCN=   69.87250     FROM MIGRAD    STATUS=CONVERGED     64 CALLS       65 TOTAL
                     EDM=  0.38E-05    STRATEGY= 1      ERROR MATRIX ACCURATE

  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME        VALUE          ERROR          SIZE      DERIVATIVE
   1      P1        199.30        3.5192       0.84934      -0.13509E-03
   2      P2       0.39761       0.14150E-02   0.10059E-02   -1.6362
   3      P3       0.98783E-01   0.10313E-02   0.24990E-03   -1.7442

 CHISQUARE = 0.1075E+01  NPFIT =   68
```

```
EXAMPLE NO = 5
--------------


HBOOK     ID =        5                                 DATE  18/05/92             NO =    17

     230                                              -
     220                                           -  I
     210                                           I  I
     200                                           ****** -
     190                                         **I  I--*I-
     180                                        *I I    I *I
     170                                       * I-I    I-I*
     160                                      *I-I         I*
     150                                     *I             I*
     140                                     -I              I*
     130                                   -*I               I *--
     120                                   *-I               I--*I
     110                                  *I                     I
     100                                 *I                      *-
      90                                *I                        *
      80                               *I                         I*
      70                              *I                          I-*
      60                             *-I                           I *--
      50                            *-I                            I-I*I
      40                          -*I                                  **-
      30                        -**                                    I-**
      20                      ***                                        I-***
      10      ****************I                                              I************************************

CHANNELS 100  0                                                                                                  1
          10  0         1         2         3         4         5         6         7         8         9         0
           1  1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                              111111111211211121111111
          10                1 112233456889131356586199288608541122964655231111
          1.    1    2224268062313614000760053587389243868095597245890427768955738341  11        1

LOW-EDGE  1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0  0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =       5000      * ALL CHANNELS = 0.5000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.3984E+00      * R . M . S = 0.9985E-01
* CHISQUAR  =  0.6987E+02
```

Example of parametrization and smoothing

```
      SUBROUTINE HEXAM6
*.==========>
*.           PARAMETRIZATION      -     SMOOTHING
*..=========> ( R.Brun )
      DOUBLE PRECISION COEFF
      DIMENSION ITERM(15),COEFF(15)
*.___________________________________________
*
*            Get hist 110 from data base
*
      CALL HRGET(110,'hexam.dat',' ')
*
*       Find best parametrization of histogram in terms of powers
*       of shifted Tchebychev polynomials
*       also produces the corresponding fortran function (here on
*       standard output)
*
*
      CALL HCOPY(110,1,' ')
      CALL HSETPR('PNBX',15.)
      CALL HSETPR('PNCX',15.)
      CALL HSETPR('PLUN',31.)
      CALL HPARAM(1,3011,1.,14,COEFF,ITERM,NCO)
      CALL HPRINT(1)
*
*        ID=2 is smoothed with B-splines
*        statistical errors (sqrt of contents) are drawn
*
      CALL HCOPY(110,2,' ')
      CALL HSPLI1(2,2,14,3,CHI2)
      CALL HIDOPT(2,'ERRO')
      CALL HPHIST(2,'HIST',1)
      END
```

Output Generated

```
****************************************
*                                      *
*   MULTIDIMENSIONAL PARAMETRIZATION   *
*                                      *
****************************************

FIT CHARACTERISTICS AND OPTIONS
*******************************

ID =   1
DIM =  1
WORKING SPACE IN /PAWC/ =    5045
 0 USER-DEFINED BASIC FUNCTIONS
 0 USER-DEFINED ELEMENTARY FUNCTIONS
MAX NUMBER OF REGRESSORS = 15
MAX POWERS OF POLYNOMIALS IN  EACH DIM = 14
AMOUNT OF OUTPUT = 1
WEIGHTING TYPE = 0
CLASS OF POLYNOMIALS = 3
CLASS OF BASIC FUNCTIONS = 0
BASIC FUNCTION SELECTION MODE = 0
REGRESSION MODE = 0
X-NORMALIZATION TYPE = 0
POWER LIMITOR =  1.00
F-TEST LEVEL =   1.00
PARAMETRIZATION SUPERIMPOSED ON HISTOGRAM
FORTRAN CODE FPARAM WRITTEN ON UNIT 31

FITTING PROCESS WILL STOP WHEN THE RESIDUAL VARIANCE HITS A MINIMUM

 15 CANDIDATE BASIC FUNCTIONS WERE RETAINED FOR THE FIT
NUMBER OF POINTS TO FIT =    95
SUM OF SQUARES OF Y-VALUES =   5000.0
MACHINE PRECISION =  0.22E-15


FITTING PROCESS STOPPED AS RESIDUAL VARIANCE HITS MINIMUM
R2 =  0.98543      12 REGRESSORS INCLUDED

FINAL RESULTS OF THE FIT
************************

ITERATION       RSS       R2ADJ     REGRESSOR  COEFF. VALUE   TERM OF PARAMETRIZATION

   13        72.841       0.98350       1        40.320         0
                                        2       -32.156        20
                                        3        29.461        60
                                        4       -20.018        80
                                        5        7.7912       100
                                        6       -18.482        50
                                        7       -7.0469       110
                                        8       -9.0691        10
                                        9        4.4675       130
                                       10        6.4382        90
                                       11       -3.9874       140
                                       12        3.1189        30
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 REGRESSOR  STANDARD DEVIATION     CONFIDENCE INTERVAL
     1          0.70650        [  39.144    ,  41.495    ]
     2           1.0509        [ -33.904    , -30.407    ]
     3          0.85147        [  28.044    ,  30.877    ]
     4          0.90853        [ -21.530    , -18.506    ]
     5          0.82336        [  6.4213    ,  9.1611    ]
     6           1.0259        [ -20.189    , -16.775    ]
     7          0.78401        [ -8.3514    , -5.7425    ]
     8           1.0731        [ -10.854    , -7.2836    ]
     9          0.68036        [  3.3355    ,  5.5995    ]
    10          0.83660        [  5.0463    ,  7.8301    ]
    11          0.85716        [ -5.4135    , -2.5612    ]
    12           1.1372        [  1.2267    ,  5.0110    ]
      DOUBLE PRECISION FUNCTION FPARAM (X)
      DOUBLE PRECISION COEFF,P,P0,P1,P2,HELEFT,HBASFT
      DIMENSION X(1),COEFF(12),IBASFT( 1,12)
      DATA COEFF/ 0.40319615E+02,-0.32155589E+02, 0.29460772E+02,
     +-0.20017895E+02, 0.77912196E+01,-0.18481896E+02,
     +-0.70469122E+01,-0.90690550E+01, 0.44674803E+01,
     + 0.64381900E+01,-0.39873663E+01, 0.31188760E+01
     +/
      DATA IBASFT/  0, 20, 60, 80,100, 50,110, 10,130, 90,140, 30
     +/
      FPARAM=0.
      DO 25 K=1,12
      P=1.
      DO 15 I=1, 1
      NUM=IBASFT(I,K)/10
      ITYP=IBASFT(I,K)-NUM*10
      IF (NUM.NE.0) THEN
      IF (ITYP.EQ.0) THEN
      P0=1.
      P1=2*X (I)-1.
      DO 10 J=2,NUM
      P2=2*(2*X (I)-1.)*P1-P0
      P0=P1
   10 P1=P2
      P=P*P1
      END IF
      IF (ITYP.EQ.1) P=P*HELEFT(NUM,X (I))
      IF (ITYP.EQ.2) THEN
      P=HBASFT(NUM,X )
      GOTO 20
      END IF
      END IF
   15 CONTINUE
   20 FPARAM=FPARAM+COEFF(K)*P
   25 CONTINUE
      RETURN
      END
```

```
THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCTION HTFUN1

HBOOK     ID =         1                                     DATE  17/12/91             NO =  18
```

```
CHANNELS 100   0                                                                                                  1
          10   0         1         2         3         4         5         6         7         8         9        0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                          1111111111111
          10                 1122246580124457554320996875432221212212334556665577766786866766645433432222221111
          1.        21124626818147606828212710478511552225771649871850922032539736953183588893942434650812591167574

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =        5000      * ALL CHANNELS = 0.5000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01       * MEAN VALUE   = 0.4834E+00      * R . M . S = 0.2184E+00
* CHISQUAR  =  0.7284E+02
```

```
THIS HISTOGRAM IS FILLED ACCORDING TO THE FUNCTION HTFUN1

HBOOK     ID =         2                                        DATE  17/12/91              NO =  19

     185                                    I
     180                                    I
     175                                    0
     170                                   II I
     165                                   IIII
     160                                   0IIII
     155                                 III I0I
     150                                 III**I0I
     145                                 00* I*II
     140                                 I*  I *0I
     135                                I*I    III
     130                               III      *I
     125                               I*        *
     120                               0I        I
     115                              I*I        I*
     110                              II          I
     105                              0           0*I
     100                             I*           III
      95                             II           I0* I                                I
      90                             *             II I                        I     I I  I
      85                             I             I *0I                       III  I0 0  I
      80                            *I                II                       0I0I***II I0II
      75                                             I*0                  I I  ****I0I***IIIII
      70                           *                 I I                  III**III0II 0 I**00I
      65                           II                0 *                  00*II I I0I I 0I **0 I
      60                           00                I  *               III*II0    I  I II I *II
      55                          *II                   0I              0I*I 0I               **   I
      50                          0 I                   I*            III*   I                0I*  I
      45                         *I                     I0*           I**I                    I 0* 0I
      40                          I                      I0          I*I                        II**0
      35                        *I                       I* I I I   *I                           00 *  I
      30                       II0                        0** 0 0I**0                            II I**0II
      25                      I*0I                        I0I*****I0I                               0I**0 I
      20                      *II                          I I 0 I0I                                I0 I**0
      15                    I*I                              0 I  I                                      0**0
      10                I0 0*I                                                                              I****0I
       5            ********                                                                                  II0**

CHANNELS 100   0                                                                                                  1
          10   0        1         2         3         4         5         6         7         8         9         0
           1   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                          1111111111111
          10                 112224658012445755432099687543222121221233455666557776678686676664543343222221111
           1.       21124626818147606828212710478511552225771649871850922032539736953183588893942434650812591167574

LOW-EDGE   1.            111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
*10**  1   0   0123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

* ENTRIES =       5000      * ALL CHANNELS = 0.5000E+04      * UNDERFLOW = 0.0000E+00      * OVERFLOW = 0.0000E+00
* BIN WID = 0.1000E-01      * MEAN VALUE   = 0.4834E+00      * R . M . S = 0.2184E+00
* CHISQUAR  =  0.9674E+02
```

Chapter 8: Memory Management and input/output Routines

8.1 Memory usage and ZEBRA

The hbook system uses the zebra data manager to store its data elements in a COMMON block /PAWC/ (shared with the kuip and higz packages, when the latter are also used, as is the case in paw). In fact the first task of a hbook user is to declare the length of this common to zebra by a call to HLIMIT, as is seen in figures 1.2 and 1.4

In the /PAWC/ data store, the hbook, higz and kuip packages have all their own **division** (see [10] for more details on the notion of divisions) as follows (see figure 8.1):

LINKS Some locations at the beginning of /PAWC/ for zebra pointers.

WORKS Working space (or division 1) used by the various packages storing information in /PAWC/

HBOOK Division 2 of the store. Reserved to hbook.

HIGZ A division reserved for the higz graphics package. This division only exists when higz is called.

KUIP A division reserved for the kuip user interface package. This division only exists when kuip is called.

SYSTEM The zebra system division. It contains some tables, as well as the Input/Output buffers for HRIN and HROUT.

```
COMMON/PAWC/NWPAW,IXPAWC,IHDIV,IXHIGZ,IXKU,FENC(5),LMAIN,HCV(9989)
DIMENSION IQ(2),Q(2),LQ(8000)
EQUIVALENCE (LQ(1),LMAIN),(IQ(1),LQ(9)),(Q(1),IQ(1))
```

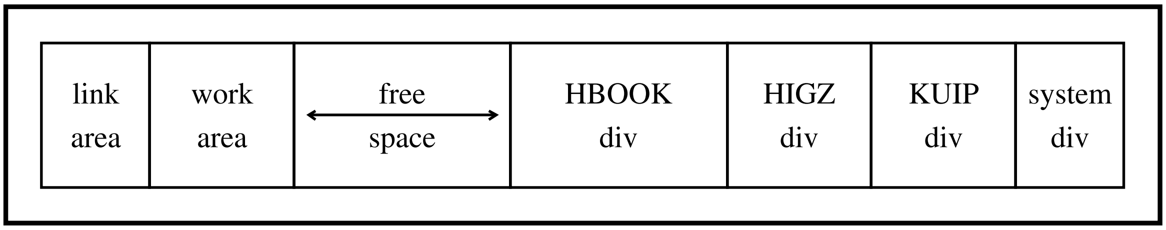


Figure 8.1: The layout of the /PAWC/ dynamic store

8.1.1 The use of ZEBRA

Inside the hbook division the various data elements are stored as a zebra data structure, one for each "identifier". In fact all identifiers (histogram or Ntuple numbers) are stored in an ordered array in a zebra bank and access to the information associated with the hbook data is via the **reference link** at the same offset as the identifier in the data part of the bank. The data structure for a given element depends on its characteristics. In any case the top bank for a given element contains the title and other constants, while the data themselves are stored in another bank hanging from the previous one. Sometimes other banks are created, e.g. for automatic binning, for storing the limits of the elements of a Ntuple and, when a Ntuple is kept in memory, for containing the overflow of the data, for **projections**, **slices** and **bands** in the 2-dim case of for containing the **errors** associated to a bin. This means that each `hbook` identifier has a whole set of **attributes** associated with its existence, and when a histogram or Ntuple is written to backup store and later reread, the **complete data structure**, containing all characteristics and attributes are retrieved. Figure 8.2 shows the `zebra` data structure for a two-dimensional histogram. The precise layout of this bank should be of no concern to the user. It is only shown here as an example of the underlying `zebra` structure of `hbook`. Note the use of the **data** part of the bank for storing attributes (e.g. title, number of bins, number of entries) as well as of the **link** part for storing the addresses to access the associated data points (scatter plot contents, X and Y projections, slices and bands and their associated errors).

8.2 Memory size control

`CALL` **HLIMIT** `(NWPAW)`

Action: Defines the maximum total size `NWPAW` of common `/PAWC/`.

Remark:

- `HLIMIT` must be called before any other `hbook` routine.
- `hbook` is compiled with a `COMMON/PAWC/` dimensioned to `10000` words. If `NWPAW<10000`, then the default value of `10000` is assumed.
- If `zebra` has already been initialised, `HLIMIT` must be called with a negative argument, e.g. `CALL HLIMIT(-NWPAW)`.

`CALL` **HLOCAT** `(ID,LOC*)`

Action: Returns the pointer in common `/PAWC/` to the `zebra` ([10]) structure, which contains the description of a given histogram.

Input parameter:

`ID` histogram identifier

Output Parameter:

`LOC` Pointer to the `zebra` bank containing the histogram information.

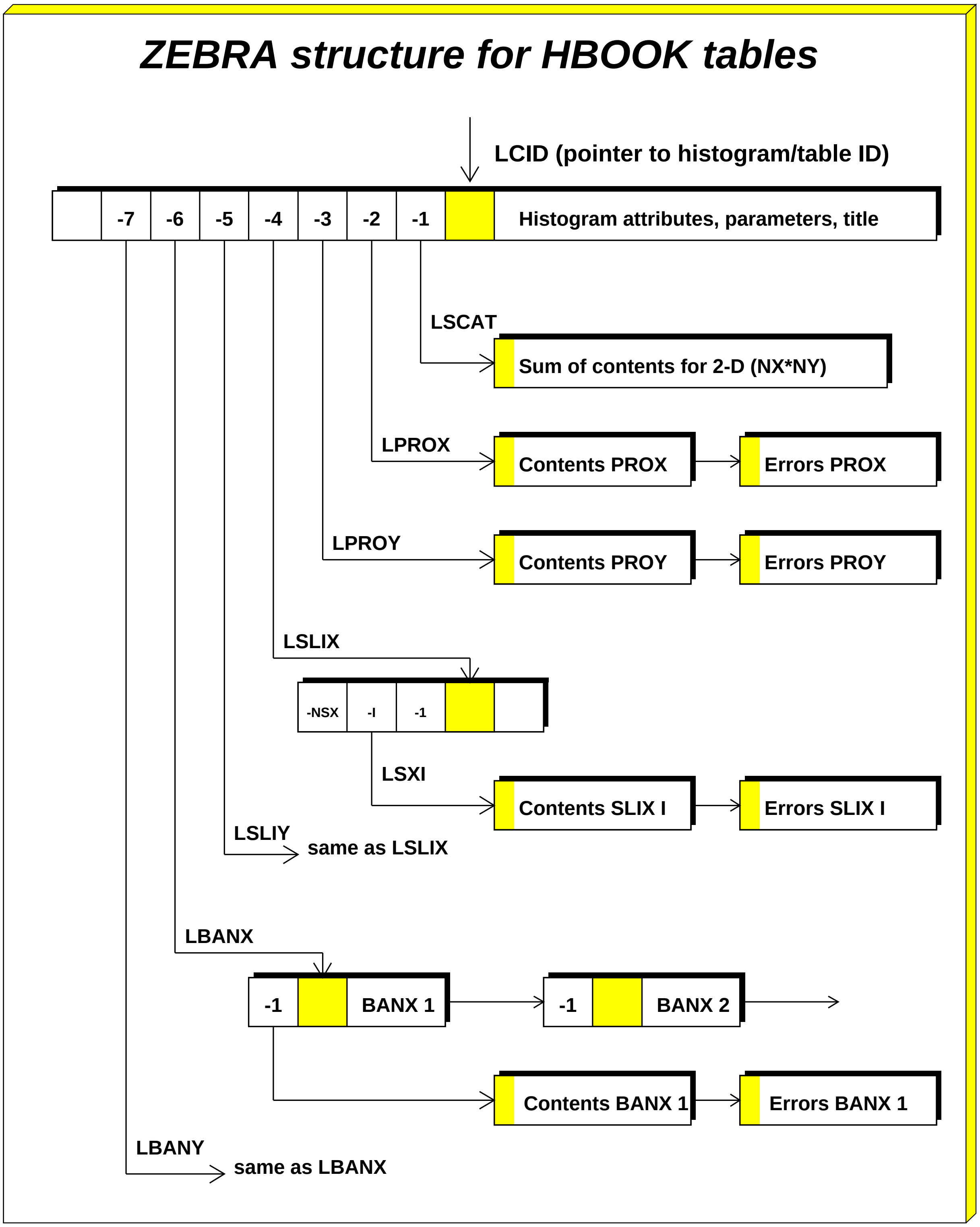
This routine can be useful to access directly the memory area of a given histogram, to extract any information that cannot be obtained with the entries previously described.

8.2.1 Space requirements

The argument `NWPAWC` must be given a value large enough to accomodate in memory all histograms (1-D and 2-D) and all Ntuple headers and buffers, i.e.

$$\mathtt{NWPAWC} > 10000 + \sum_{i=1}^{\mathtt{NF}} S_F(i) + \sum_{i=1}^{\mathtt{N1}} S_1(i) + \sum_{i=1}^{\mathtt{N2}} S_2(i) + \sum_{i=1}^{\mathtt{NT}} S_N(i)$$

Figure 8.2: The `zebra` data structure used for two-dimensional histograms



`NF` Number of open files

$S_F(i)$ 100+LREC$_i$, where LREC is the buffer size for file i, as specified in a call to `HROPEN`.

`N1` Number of 1-D histograms

$S_1(i)$ Space occupied by 1-D histogram i, i.e.
`40+(NCHAN+2)*PACK+IERR*(NCHAN+10)+IFUN*(NCHAN+10)`

- `NCHAN` Number of channels in histogram
- `PACK` Packing factor (1. by default). See parameter `VMX` of `HBOOK1`.
- `IERR` `1` if `HBARX` called, `0` otherwise.
- `IFUN` `1` if the histogram has an associated function (`HFUNC`, fits or smoothing)

`N2` Number of 2-D histograms

$S_2(i)$ Space occupied by 2-D histogram i, i.e.
`40+(NCHANX+2)*(NCHANY+2)*PACK` + space for projections, slices and bands (which are 1-D histograms).

`NT` Number of Ntuples

$S_2(i)$ Space occupied by headers and buffers of Ntuple i (see routines `HBOOKN` and `HBNT`).

8.3 Directories

`hbook` histogram data are kept in a `zebra` tree structure similar to the directory structure of the Unix file system. Note that the `zebra` RZ package uses the same conventions. (In fact, `hbook` uses the `zebra` RZ package to manage files). With this convention, all references to histograms are still made using an integer identifier, but this identifier is relative to a **directory**. `hbook` initially sets the current directory to be `//PAWC`. This directory remains the current directory until changed either explicitly or implicitly by one of the calls described below. As with the Unix file system the current directory can be a subdirectory, e.g. `//PAWC/L1`, `//PAWC/L1/L21` and `//PAWC/L1/L22`.

These `hbook` directories can reside in the local memory of the computer (i.e. the `PAWC` common, or they can be stored on a local (`//LUN1`) or remote disk file system (`//VXCRNA`). They can even be dynamically created by a "producer" in the memory of a remote computer and "shared" by that machine with the user's machine via global section (VMS) or shared memory (Unix).

```
                                                            HMDIR HCDIR HLDIR HDDIR HPDIR
--------    //PAWC                       local memory         X     X     X     X     X
|      |    //LUN1                       local disk           X     X     X     X     X
| USER |    //VXCRNA ---- telnet (rsh) remote disk            X     X     X
|      |    //GLOSEC ---- tcp/ip ---   global section(VMS)    X     X     X
--------    //SHARE  ---- tcp/ip ---   shared memory(Unix)    X     X     X
```

Figure 8.3: Different kinds of `hbook` directories

```
CALL HMDIR (CHPATH,CHOPT)
```

Action: Make a new subdirectory below the current directory. This command works with all five different kinds of directories described in figure 8.3.

Input parameters:

CHPATH Character variable or constant containing the name of the subdirectory.

CHOPT Character variable specifying the option chosen. If CHOPT='S' then the current directory is changed to the new directory.

```
CALL HCDIR (*CHPATH*,CHOPT)
```

Action: Change the current directory. This command works with all five different kinds of directories described in figure 8.3.

Input parameters:

CHPATH Character variable or constant containing the name of the directory which is to become the current directory (default action if CHOPT=' ').

CHOPT Character variable specifying the option chosen.
' ' Set new directory.
'R' Read the name of the current directory.

Output Parameter

CHPATH Character variable containing the name of the current directory (CHOPT='R').

Setting RZ directories

```
CALL HCDIR('//PAW/CDET',' ')      ! Go to directory with given absolute pathname

CALL HCDIR('TPC',' ')             ! Go to directory with given relative pathname
                                  ! we are now in //PAW/CDET/TPC

CALL HCDIR('//PAW/CDET/TPC',' ')  ! Equivalent to 1+2 above

CALL HCDIR('\',' ')               ! Go to parent directory, i.e. //PAW/CDET

CALL HCDIR('TPC',' ')             ! Go to TPC subdirectory again

CALL HCDIR ('\VERTEX',' ')        ! Go to directory //PAW/CDET/VERTEX
                                  ! i.e. one level up then one down again
```

This concept of directories also applies to the direct access files when using HRFILE, HRIN and HROUT.

```
CALL HLDIR (CHPATH,CHOPT)
```

Action: List the contents (identifiers, type of histograms and titles) of a `hbook` directory. This command works with all five different kinds of directories described in figure 8.3.

Input parameters:

`CHPATH` Character variable or constant containing the name of the directory to be listed. `CHPATH=' '` stands for the current directory.

`CHOPT` Character variable specifying the chosen option.

- `' '` List only the top directory.
- `'A'` List all Ntuple extentions.
- `'I'` `HINDEX` option selected instead of simple list.
- `'N'` List only the Ntuples.
- `'R'` List using RZ format.
- `'S'` Sort the directory entries.
- `'T'` List the complete subdirectory tree starting from the specified directory.

List all existing directories in //PAWC

```
CALL HLDIR ('//PAWC','T')
```

```
CALL HDDIR (CHPATH))
```

Action: Delete a (sub)directory from memory or local disk.

Input parameter:

`CHPATH` Character variable or constant specifying the pathname of the (sub)directory to delete. `CHPATH=' '` stands for the current directory.

```
CALL HPDIR (CHPATH,CHOPT)
```

Action: Print the contents of a directory (This routine calls `HPRINT`). This routine works only for directories in local memory or remote RZ files accessed opened via `XZRZOP` (see the CSPACK manual [19] for more information).

Input parameters:

`CHPATH` Character variable or constant specifying the pathname of the directory to be printed. `CHPATH=' '` stands for the current directory.

`CHOPT` Character variable specifying the option chosen.

- `' '` Print the contents of the top directory.
- `'I'` Print an index.
- `'T'` Print the complete directory tree (i.e. the top directory and its subdirectories).

Printing list of histograms

```
CALL HPDIR ('//PAWC','T') ! Print list of all histograms in //PAWC

CALL HPDIR (' ',' ')      ! Print list of all histograms in current directory

CALL HPRINT(0)            ! Print histograms in current directory
```

```
CALL HLNEXT (*IDH*,CHTYPE*,CHTITL*,CHOPT)
```

Action: Scan the contents of the current directory in memory or on an RZ file.

Input parameters

`IDH` Must be zero for first call

`CHTYPE` Character variable specifying items to be scanned.

- `'1'` include 1-D histograms
- `'2'` include 2-D histograms
- `'N'` include Ntuples
- `'D'` include subdirectories
- `' '` include everything, i.e., equivalent to `'12ND'`.

Output parameters

`IDH` On return contains identifier of next histogram. When all histograms are processed, a value of zero is returned.

`CHTYPE` Character variable specifying type of histogram.

- `'1'` 1-dimensional
- `'2'` 2-dimensional
- `'N'` Ntuple
- `'D'` subdirectory
- `'?'` unknown.

`CHTYPE` Character variable containing title or subdirectory name.

Scan content of current directory

```
      IDH=0
  1   CONTINUE
      CALL HLNEXT(IDH,CHTYPE,CHTITL,CHOPT)
      IF(IDH.NE.0) THEN
         ... process
         GOTO 1
      ENDIF
```

```
CALL HRDIR (MAXDIR,CHDIR*,NDIR*)
```

Action: Returns the list of subdirectories of the current working directory. This command works with all five different kinds of directories described in figure 8.3.

Input parameter

MAXDIR Length of the character array CHPATH.

Output parameters

CHDIR* Character array which will contain the names of the subdirectories of the current working directory.

NDIR* Actual number of subdirectories present in the current working directory. If this number is greater than MAXDIR, only the first MAXDIR subdirectory names will be returned in array CHDIR.

The use of directories is illustrated below:

Example of use of directories

```
      PROGRAM MAIN
*
      COMMON/PAWC/H(20000)
      CALL HLIMIT (20000)
      CALL HBOOK1 (10,'Energy distribution',100,0.,300.,0.)
           "   "
*
      CALL USECAL
           "   "
      CALL HFILL (10,EDER,0.,1.)
           "   "
      CALL HISTDO
           "   "
      END
      SUBROUTINE USECAL
*
*        Make a new directory ECAL and set the new current directory
*
          CALL HMDIR ('ECAL','S')
*
*        Create a new histogram with ID=10 in the new directory
*
          CALL HBOOK1 (10,'My histogram',50,-5.,5.,0.)
           "   "
          CALL HFILL (10,UX,0,1.)

           "   "
*         Go back to the parent directory
*
          CALL HCDIR ('\','  ')
           "   "
      END
```

8.4 Input/Output Routines

hbook files are in fact zebra RZ files [10]. Input/output error return codes are available vin the zebra communication vector IQUEST, and the user should consult the RZ manual for their meaning. Both disk and memory resident files are supported, the latter being particularly useful in online applications, where histogram data have to be shared between different processes.

hbook files are written in Zebra exchange format and thus need not be converted when transferred between different computer systems using binary ftp (see section 8.5), or accessed over the network using a distributed file system such as AFS or NFS.

Reading and writing histograms to a direct access file

CALL **HRPUT** (ID,CHFILE,CHOPT)

Action: Write a histogram to a given direct access file. This routine cannot be used for Ntuples.

Input parameters:

ID Histogram identifier. ID=0 writes all histograms in the current directory to the output file.

CHFILE Character variable or constant defining the filename.
If CHFILE=' ' the histogram is saved in the current working directory on disk.

CHOPT Character option specifying the desired option.

- 'N' Write the histogram to a New file.
- 'T' Can be used together with ID=0. All histograms in the current directory and all subdirectories in memory are written to the output file.
- 'U' Write the histogram to an already existing hbook file. When an histogram with the same identifier already exists on the output file, then a new cycle is added.

CALL **HRGET** (ID,CHFILE,CHOPT)

Action: Read a histogram from a given direct access file. This routine cannot be used for Ntuples.

Input parameters:

ID Histogram identifier. ID=0 read all histograms into the current directory.

CHFILE Character variable or constant defining the input filename.
If CHFILE=' ' the histogram is read from the current working directory on disk.

CHOPT Character option specifying the desired option.

- 'A' Add to the current histogram in memory.
- 'T' Get a complete tree (**not yet implemented**)

Remarks:

The following remarks apply to both HRPUT and HRGET.

- HRGET and HRPUT issue automatically Fortran OPEN and CLOSE calls.
- With HRPUT the file is created with LREC=1024 machine words.
- On VM/CMS no FILEDEF statement should be given. The filename CHFILE can be given in either of the forms Filename Filetype Filemode or Filename.Filetype.Filemode
- On Unix the filename CHFILE will be translated to lowercase.
- Fortran logical unit 88 is used by these routines.
- HRPUT calls HROPEN, HROUT and HREND.
- HRGET calls HROPEN, HRIN and HREND.

Open an RZ direct access file or map a Global Section

```
CALL HROPEN (LUN,CHTOP,CHFILE,CHOPT,*LREC*,ISTAT*)
```

Action: Open a direct access hbook file. If several direct access files are opened, they are identified by the top directory only.

Input parameters:

LUN Logical unit number associated to the file.

CHTOP Character variable specifying the name of the **top** directory associated with unit LUN (maximum 8 characters). This is an arbitrary name used to identify the file on unit LUN in subsequent calls to HR.. routines.

CHFILE Character variable specifying the name of the file to be opened.

CHOPT Character variable specifying the options selected

Medium	' '	Disk (default)
	'G'	Global Section (see chapter 9)
mode	' '	Existing HBOOK file (default)
	'N'	Create a new file
	'Q'	Override default number of records for new file with contents of IQUEST(10)
	'X'	The file is/will be in exchange format
	'U'	Update an existing file

LREC Record length in machine words (recommended value is 1024). If LREC=0 the actual record length is returned on exit.

Output parameters:

ISTAT Return code. ISTAT=0 indicates success.

LREC (**Only when (LREC=0) on input**) The actual record length of the file on disk.

Remarks:

- HROPEN performs a Fortran direct access open for the file CHFILE on logical unit LUN.
- On VM/CMS no FILEDEF statement should be given. The filename CHFILE can be given in either of the forms Filename Filetype Filemode or Filename.Filetype.Filemode

- On Unix the filename `CHFILE` will be translated to lowercase.
- If `LREC=0` on input, `HROPEN` will automatically determine the record length of existing files.
- On MVS systems, the current userid prefix will be automatically added to the front of the file name unless the first character is a dot (.).
- The maximum number of records is by default 32000. You can use option `'Q'` to change this.
- A file declared with `HROPEN` must be released with `HREND`.
- `HROPEN` calls `HRFILE` internally.

`CALL` **HRFILE** `(LUN,CHTOP,CHOPT)`

Action: Establishes a temporary unique correspondance between a logical unit and a **top directory** name. Users should call `HROPEN` instead of `HRFILE`.

By default, `HROPEN` (`HRFILE`) creates new files (option `N`) with the maximum number of records set to a large number (default 32000). If this is insufficient, the user can override this value by specifying the `Q` option and setting `IQUEST(10)` to the actual number of records required (up to a maximum of 65K).

Overriding the default record allocation

```
      COMMON/QUEST/IQUEST(100)                     ! Declare IQUEST communication vector
      IQUEST(10) = 65000                           ! I require 65000 records
      CALL HROPEN(1,'FILE','file.ext','NQ',1024,ISTAT) ! Call HROPEN
```

Note that after a call to `HROPEN` (`HRFILE`) (if `CHTOP='MYDST'` for example), the current directory is set to `//MYDST`. If `LUN` is an existing file, one can change the current directory to an existing subdirectory, `SUBDIR`, using `CALL HCDIR ('SUBDIR',' ')`, setting the current directory `CD` to `//CHTOP/SUBDIR`.

- The **contents** of a directory is **listed** using routine `HLDIR`.
- A **new subdirectory** can be created with routine `HMDIR`.
- The **current directory** in memory (`//PAWC/`) and hence on the direct access files may be set by one of the routines `HCDIR` or `HMDIR`.

Note that when calling `HCDIR` or `HRFILE` on a direct access file, the current directory in memory will be **the latest current directory set**.

Writing to a file

`CALL` **HROUT** `(ID,ICYCLE*,CHOPT)`

Action: Write a histogram from the current directory in memory onto the current directory on the direct access file.

Input parameters:

`ID` Histogram identifier. `ID=0` means write all histograms from the current directory in memory.

`CHOPT` Character variable specifying the options selected.

  `'N'` Create on the direct access file the same directory tree as in memory.

'T' Write the whole directory tree hanging from the current directory (if ID=0).

Output parameter:

ICYCLE Cycle number. The first time a given histogram with identifier ID is stored on a directory on a direct access file, ICYCLE is set to 1. If the histogram identifier ID already exists on the direct access file, then the call to HROUT will increment the cycle number ICYCLE by one.

Experienced users may invoke routines from the zebra RZ package to **purge** a directory, i.e. delete all versions of an identifier but the most recent one using routine RZPURG.

Reading from a direct-access file or global section

```
CALL HRIN (ID,ICYCLE,IOFSET)
```

Action: Read a histogram from the current directory on the direct access file (or global section) into the current directory in memory.

Input parameters:

ID Histogram identifier. ID=0 means that all histograms from the current directory on the direct access file (global section) should be read into memory. If a histogram identifier ID already exists in memory a message is printed and it is deleted from memory before reading the new histogram from the file or global section.

ICYCLE Cycle number. If ICYCLE=0 then the lowest cycle is read. To read the highest cycle, use a large number, e.g. 999999. When filling an Ntuple, HBOOK creates a dummy header (ICYCLE=1) which contains only the Ntuple definition. This dummy header is used for the error recovery command (it is a fully functional header except that the number of events is not necessarily correct). For the purpose of reading Ntuples, users should always use ICYCLE=999 to ensure they receive the correct quantity of data in, for example, subsequent calls to HGNTB.

IOFSET The histogram which is read in memory will have the identifier IDN=ID+IOFSET. Specifying IOFSET different of zero permits to have in memory copies of histograms with the same identifiers ID in different files. This parameter may be very useful when HRIN is called together with routines such as HOPERA or HDIFF. **This facility also works for Ntuples.**

Merging HBOOK files into a new file

```
CALL HMERGE (NFILES,CHFIN,CHFOUT)
```

Action: Merges two or more HBOOK files with identical objects and directories into a new file. Histograms are added and Ntuples are combined. Works for CWN's and RWN's.

Input parameters:

NFILES Number of input files to be merged.

CHFIN Character array (e.g., CHARACTER*8 CHFIN(10) for 10 files whose names are not longer than 8 characters) containing the name(s) of the file(s) to be merged.

CHFOUT Character variable with the name of the output file.

```
CALL HMERGIN
```

Action: Identical to `HMERGE` but the routine prompts interactively for the names of the input and output files. The `paw` command `NTUPLE/HMERGE` calls this routine.

Scratching histogram in a file

```
CALL HSCR (ID,ICYCLE,CHOPT)
```

Action: Scratch (delete) a histogram from the current directory in the direct access file.

Input parameters:

`ID` Histogram identifier. `ID=0` means scratch all histograms in the current directory.

`ICYCLE` Cycle number. If `ICYCLE=0` then all cycles are deleted.

`CHOPT` Character variable specifying options selected.

- `' '` Only possible value (not used at present)

Close a file

```
CALL HREND (CHTOP)
```

Action: Closes a direct access file if is not needed anymore or when the options `'N'` or `'U'` are specified in `HRFILE`.

Input parameter:

`CHTOP` Character variable specifying the name of the top directory associated with the file to be closed. This should correspond to the name declared with `HRFILE`. After this call, the system bank associated to this file is deleted. The call to `HREND` is obligatory when the file has been modified.

Remark:

A Fortran `CLOSE` statement should follow a call to `HREND`.

8.5 Exchange of histograms between different machines

`hbook` files are by default created in exchange mode. They can be transported between machines using the standard binary FTP or they can be NFS mounted in a heterogeneous environment.

Transfer between Unix machines with FTP

```
$ ftp remote
ftp> bin
ftp> get remote.hbook
```

Transfer from CERNVM to a Unix workstation

On CERNVM type the following:

```
CMS FTP workstation
ftp> BIN F 4096     ! block size in bytes
ftp> PUT file.hbook
```

Running FTP on a VAX/VMS systen

```
$ ftp remote
ftp> bin
ftp> get remote.hbook
ftp> quit
$ resize -s 4096 remote.hbook;1
```

The `resize` command does not copy the file. It simply changes the header information, from 512 byte records to 4096 bytes. In case the block size of the `hbook` file is not 1024 words (`LREC` parameter of routine `HROPEN`), i.e. 4096 bytes, specify the corresponding value as parameter to the `resize` command.

The `resize` tool is available on request from the CERN Program Library.

Proposed `hbook` file naming convention

Users are encouraged to name their `hbook` files with the suffix `.hbook`, so that the `paw++` browser will be able to recognize these files automatically.

8.6 RZ directories and HBOOK files

Another advantage of the use of `zebra` in `hbook` is that `zebra`'s direct access **RZ package** is available. The RZ package allows data structures to be uniquely addressed via **pathnames**, which are based on Unix file names. Related data structures are addressed from a **directory**.

Routine `HROPEN` issues a the Fortran `OPEN` statement and declares the RZ top directory.

Example of using `HROPEN`

```
      CALL HROPEN(LUN,'HISTO1','HISTOS.DAT',CHOPT,LRECL,ISTAT)
```

In this example, `HROPEN` issues a Fortran direct-access open statement for the file `HISTOS.DAT`. If, on input, `LRECL` contains the value 0, `HROPEN` will automatically determine the record length of the file, provided that the file already exists.

Each time a RZ file is opened via a call to `HROPEN` or `HRFILE`, a supplementary top directory is created with a name specified in the calling sequence. This means that the user can more easily keep track of his data and also the **same** histogram identifiers can be used in various files, what makes life easier if one wants to study various data samples with the same program, since they can be addressed by changing to the relevant file by a call to `HCDIR` first. For more information on the RZ package, see the `zebra` RZ manual.

In the case of the second call to `HROPEN`, where update mode is requested, it is the users responsibility to ensure that write-acess is enabled, i.e. the file is not on a read-only mini-disk (VM/CMS systems), or is opened with the `SHARED` attribute (VAX/VMS systems) etc.

A Fortran `CLOSE` statement is also required for each file after calling `HREND`. Further details of `hbook`'s usage of `zebra` RZ files are given below.

Defining `hbook` files

```
 CALL HROPEN(1,'HISTO1','HISTO1.DAT',' ',1024,ISTAT)    ! Open first  HBOOK RZ file (read only)
 CALL HROPEN(2,'HISTO2','HISTO2.DAT','U',1024,ISTAT)    ! Open second HBOOK RZ file (update)
 CALL HCDIR('//HISTO1',' ')                             ! Make HISTO1 current directory
 CALL HRIN(20,9999,0)                                   ! Read ID 20 on file 1
   ....
 CALL HCDIR('//HISTO2',' ')                             ! Make HISTO2 current directory
 CALL HRIN(10,9999,0)                                   ! Read ID 10 on file 2
   ....
 CALL HROUT(20,ICYCLE,' ')                              ! Write ID 20 to file 2
 CALL HREND('HISTO1')                                   ! Close file 1
 CALL HREND('HISTO2')                                   ! Close file 2
```

In the previous example (and also in figures 1.2 and 1.4) it is shown how an external file is available via a directory name inside `hbook` (and `paw`), and that one can change from one to the other file by merely **changing directory**, with `hbook` routine `HCDIR`

Using subdirectories

The use of subdirectories, both in memory and on disk, is shown in the following examples.

Example of using subdirectories

```
      PROGRAM TEST
      INTEGER    NWPAWC
      PARAMETER (NWPAWC=15000)
      COMMON/PAWC/PAW(NWPAWC)
      CHARACTER*8 CHTAGS(5)
      DIMENSION EVENT(5)
      EQUIVALENCE (EVENT(1),X),(EVENT(2),Y),(EVENT(3),Z)
      EQUIVALENCE (EVENT(4),ENERGY),(EVENT(5),ELOSS)
      DATA CHTAGS/'X','Y','Z','Energy','Eloss'/
*-- Tell HBOOK how many words are in PAWC.
      CALL HLIMIT(NWPAWC)
      CALL HROPEN(1,'EXAMPLE','EXAMPLE.DAT','N',1024,ISTAT)
      IF(ISTAT.NE.0)GO TO 99
*-- Make sub-directory on disk (as HROUT does not do this for us).
      CALL HMDIR ('US','S')
      CALL HCDIR('//PAWC',' ')
*-- Make sub-directory in memory.
      CALL HMDIR ('US','S')
      CALL HCDIR('//PAWC/US',' ')
*-- Book Ntuple + 1d histogram
      CALL HBOOKN(10,'A simple Ntuple',5,'EXAMPLE',5000,CHTAGS)
      CALL HBOOK1(100,'Energy distribution',100,0.,100.,0.)
*-- Fill the Ntuple and histogram
      DO 10 I=1,1000
         CALL RANNOR(X,Y)
         Z=SQRT(X*X+Y*Y)
         ENERGY=50. + 10.*X
         ELOSS=10.*ABS(Y)
         CALL HFN(10,EVENT)
         CALL HFILL(100,ENERGY,0.,1.)
 10   CONTINUE
*-- Juggle top directories (order of these calls is important!!).
      CALL HCDIR('//PAWC',' ')
      CALL HCDIR('//EXAMPLE',' ')
*-- Write out everything to disk
      CALL HROUT(0,ICYCLE,'T')
*-- Flush remaining buffers to disk.
      CALL HREND('EXAMPLE')
 99   CONTINUE
      END
```

Chapter 9: Global sections and shared memory

9.1 Sharing histograms in memory on remote machines

When HBOOK is used in a data acquisition system environment, **global sections** can be an interesting alternative to disk input/output. The following example is a simple illustration of this facility.

Let us assume two processes exist:

1. `PFILL`, the process **filling** some histograms in `COMMON/PAWC/` directly.
2. `PRESENT`, a process activated from time to time to **visualize** the histograms created and filled by `PFILL`.

No hand-shaking mechanism is required. A global section is created (this is system dependent). This global section is mapped to `COMMON/PAWC/` in process `PFILL` and to `COMMON/PAWMAP/PAWM(nwords)` in `PRESENT`. This process has also a `COMMON/PAWC/`, which will be used as a working space common.

A call `CALL HRFILE (PAWM,'PFILL','GN')` in process `PRESENT` will open a HBOOK global section. The **current directory** is now set to `//PFILL`. Routine `HCDIR` may be used to change the current directory to lower level directories. Using `HRIN` (described below) a histogram can now be copied from `PFILL` to `/PAWC/` of process `PRESENT` and invoke the printing or plotting routines of either `HBOOK` or `HPLOT`.

Tools exist (for example in `PAW`) to dynamically map global sections. It should be noted however that this mechanism does not allow to write (e.g. using routine `HROUT`) from process `PRESENT` into `PFILL`.

It is possible to open more than one global section (several processes `PFILL`).

9.1.1 Memory communication

`CALL` **HCOPYM** `(ID,IPAWD,IOFSET)`

Action: Copies one or more histograms from the PAW area to common `/PAWC/`.

Input parameters:

`ID`	Identifier of the histogram. `ID=0` means copy all existing histograms.
`IPAWD`	PAW area identifier.
`IOFSET`	Offset of newly created histogram(s), i.e. new histogram(s) will have identifier(s) `ID+IOFSET`.

9.2 Mapping global sections on VMS

`VALUE = ` **hcreateg** `(global_name,base_common,size)`

Action: Function to create and map a global section .

The function first opens a file with `UFO` option (using `HST_OPEN_GBL`), then creates and maps the global section using `SYS$CRMPSC`. Open the file using `SYS$SETDFPROT` to set protection loose.

Input parameters:

`global_name`	Name of the section to be mapped

`base_common` First word of `COMMON` to be mapped.

`size` size of the `COMMON` in words.

The function value returned is equal to the global section length (pages) if the procedure was successful or an errorcode `<0` if an error occurred.

`HCREATEG$DIR` is a `LOGICAL` which, if defined, gives the directory for the mapping file of the global section. In this case, the file is not deleted upon closing.

`VALUE = ` **hmapg** `(global_name,base_common,offset)`

Action: Function to dynamically map to an existing global section.

The function maps to the global section using `SYS$MGBLSC`, allocating pages in the `p0` region with the `sec$m_expreg` option.

Input parameters:

`global_name` Name of the section to be mapped

`base_common` First word of reference `COMMON` to be mapped.

`offset` Offset with respect to `BASE_COMMON` of the mapped section in words,
i.e. `BASE_COMMON(OFFSET)` is the first word.

The function value returned is equal to the global section length (pages) if the procedure was successful or is an errorcode `<0` if an error occurred.

`VALUE = ` **hfree** `(global_size,base_common,offset)`

Action: Function to dynamically delete/unmap global section space using the service `SYS$DELTVA`.

Input parameters:

`global_size` Size of the section to be freed (pages).

`base_common` First word of reference `COMMON`.

`offset` Offset with respect to `BASE_COMMON` of the mapped section in words,
i.e. `BASE_COMMON(OFFSET)` is the first word.

The function value returned is equal to the global section length (pages) if the procedure was successful or is an errorcode `<0` if an error occurred.

9.2.1 Using PAW as a presenter on VMS systems (global section)

```
      PROGRAM PRODUCE
      PARAMETER MAXPAGES=100
      COMMON/PAWC/IPAWC(128*MAXPAGES)
      CHARACTER*8 GNAME
      INTEGER*4 HCREATEG
*
      GNAME='GTEST'
      WAIT_TIME=1.
      NUMEVT=1000
*..............           Create Global section
      NPAGES=HCREATEG(GNAME,IPAWC,128*MAXPAGES)
      IF(NPAGES.GT.0) THEN
         PRINT 1000,GNAME
 1000    FORMAT(' Global Section: ',A,' created')
      ELSE
         IERROR=-NPAGES
         PRINT 2000,IERROR
 2000    FORMAT(' Global Section Error', I6)
         GO TO 99
      ENDIF
      CALL HLIMIT(128*NPAGES)
*...............           Book histos.
      CALL HBOOK1(10,'Test1$',50,-4.,4.,0.)
      CALL HBOOK1(20,'Test2$',50,-4.,4.,0.)
*...............           Fill histos.
      DO 20 I=1,NUMEVT
         DO 10 J=1,100
            CALL RANNOR(A,B)
            CALL HFILL(10,A,0.,1.)
            CALL HFILL(20,B,0.,1.)
 10      CONTINUE
        CALL LIB$WAIT(WAIT_TIME)
 20   CONTINUE
*
 99   STOP
      END

$ fort produce
$ link produce,SYS$INPUT/OPTIONS,-
cern$library:packlib/lib,kernlib/lib
PSECT=PAWC,PAGE
```

```
PAW > edit produce
   macro produce ntimes=100
     nt=[ntimes]
     zone 1 2
     histo/plot 10 K
     histo/plot 20 K
   loop:
       histo/plot 10 U
       histo/plot 20 U
       wait ' ' 1
       nt=[nt] -1
       if nt>0 goto loop
   return
PAW > global_sect GTEST
PAW > exec produce ntimes=20
```

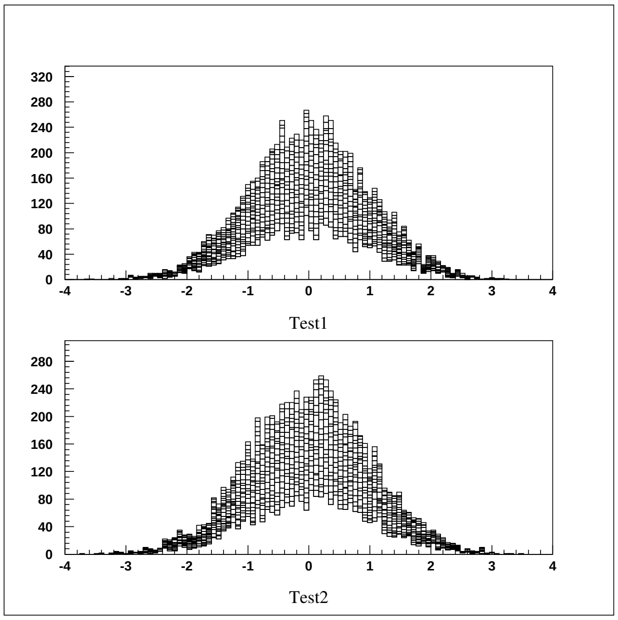


Figure 9.1: Visualise histograms in global section

In addition to the facilities described in the previous section, the standard version of PAW may be used as an online presenter on VMS systems using the mechanism of global sections. It is possible for two processes to reference the same histograms using **global sections**. For example, the first process may be a **histogram producer** (e.g. a monitoring task) and the second process **PAW**. As the histograms are being gradually filled by the first task, PAW can view them, and even reset them. To use the global sections, it is also necessary to "page align" the common which is in the global section. This is achieved in the "link step" when making the process (see example). The relevant statements are `SYS$INPUT/OPTIONS` to tell the linker that some options follow the link statement, and `PSECT=PAWC,PAGE` which is the option to page align the `/PAWC/` common.

9.3 Unix shared memory (Sun and DecStation only!)

On Unix systems, with the exception of HP-UX and SOLARIS, it is possible to communicate between processes using shared memory. In the histogram producer program, use routime `HLIMAP` instead of `HLIMIT` to initialize HBOOK. With PAW use the command `global_sect` to use shared memory.

CALL **HLIMAP** (NWORDS,CHNAME)

Action: The routine maps a file to a shared memory area.

Input parameters:

`NWORDS` Number of words for the shared area.
If `NWORDS=0` an existing shared memory is attached and becomes the current HBOOK directory. In this case `HLIMIT` must have been called previously.

`CHNAME` Character variable (`CHARACTER*4`) specifying the name given to the shared area.

All histograms, Ntuples, etc. in this area have a structure similar to the `/PAWC/` common.

Example with pre-existing shared area

```
      Program toy
      Parameter (nwpaw=100000)
      common/pawc/paw(nwpaw)
      call hlimit(nwpaw)
*
      call hlimap(0,'TEST')
*
    1 read *,id
      call hrin(id,9999,0)
      call hprint(id)
      call hdelet(id)
      if(id.ne.0)go to 1
      end
```

Note that HBOOK does not delete the shared memory when the job finishes, that reamins the user's responsability .

9.3.1 Using PAW and Unix shared memory (Sun and DecStation only)

```
      Program hserver
*
*     HBOOK program creating a "shared memory"
*     area called 'TEST'
*     Routine HLIMAP replaces HLIMIT.
*     NWORDS is the amount of space requested
*     in the shared area.
*
      parameter(nwords=50000)

      call hlimap(nwords,'TEST')
*
      call hbook1(1,'test1',100,-3.,3.,0.)
      call hcopy(1,2,'test2')
      call hcopy(1,3,'test3')
*
      do 10 i=1,100000000
         call rannor(a,b)
         call hf1(1,a,1.)
         call hf1(2,b,1.)
         call hf1(3,a**2+b**2,1.)
         if(mod(i,100000).eq.0)
     X   print *,' hserver in loop index ',i
  10  continue
*
      end

$ f77 -L... -l... -ohserver hserver.f

$ hserver
GLOBAL MEMORY CREATED,
        offset from LQ =  1037452510

 hserver in loop index   100000
 hserver in loop index   200000
 hserver in loop index   300000
 hserver in loop index   400000
 hserver in loop index   500000
 hserver in loop index   600000
 hserver in loop index   700000
```

```
PAW > edit shared
    macro shared ntimes=100
    histo/plot 1 K
    do nt = 1,[ntimes]
       histo/plot 1 U
       wait ' ' 1
    enddo
    return
PAW > global_sect TEST
PAW > exec shared ntimes=15
```

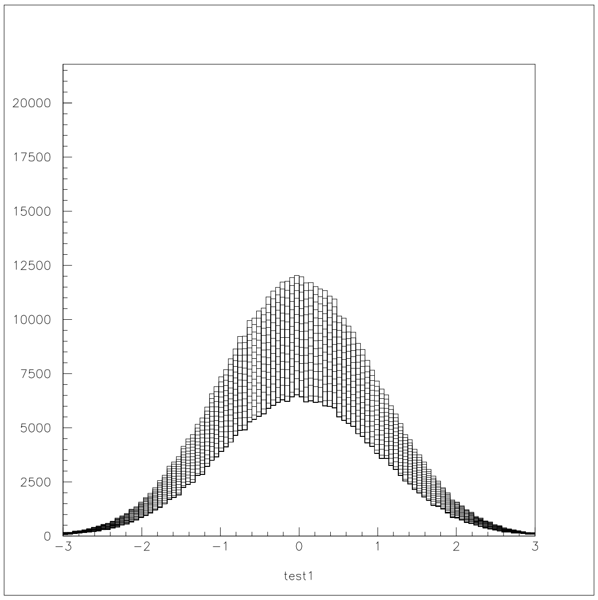


Figure 9.2: Visualise histograms in Unix shared memory

On Unix PAW can be used as an online presenter using the shared memory facility (at present on Sun and DecStation only) and the routines described in section 9.3 Figure 9.2 shows on the left hand side the program, which fills the histograms. It is compiled and linked with the `f77` command, and then started. It writes the lines shown while going through the event loop. Then PAW is started, communication is established via the command `global_sect TEST`, which declares that the area called `'MAP'` is to be shared for data communication, and the execution of the KUMAC program `shared.kumac`, shown at the top right of the figure, is initiated.

The output shown on the screen then allows one to follow interactively (using the Update option `'U'` of the plot command) how the event generator (the `hserver` program) fills histogram number one. The first fifteen iterations have been captured and are shown at the bottom right of Fig. 9.2.

9.4 Access to remote files from a PAW session

When running PAW, it is often necessary to access files (e.g. HBOOK files) which reside on a different computer. Therefore a PAW server is provided, which works using a conventional Client/Server model. The client (PAW) typically runs on a workstation. When the PAW command RLOGIN is invoked, a PAW server is automatically started on the remote machine, normally a mainframe or data server.

Once the `RLOGIN REMOTE` command has been executed, the PAW Current Directory is set to `//REMOTE`. The PAW client can now instruct the PAW server to attach a file using the `RSHELL` command (e.g. `rshell file pawtest.dat`). If an histogram with HBOOK ID=10 is on the remote file, than the PAW command `Histo/Plot 10` will plot this histogram on the local workstation. The histogram resides on `//PAWC` like other histograms coming from local files.

The `RSHELL` command may be used to communicate with the PAW server. The expression typed following `RSHELL` is passed to the server. The current implementation of the PAW server recognizes the commands:

`rshell file filename`	Server connects filename
`rshell cdir //lun11`	Server changes current directory
`rshell ld`	Server lists current directory
`rshell ld //`	Server lists all connected files
`rshell message`	Server pass message to operating system

Access to remote files from a workstation

```
PAW > rlogin CERNVM                          | connect to CERNVM
PAW > rshell file HRZTEST.HBOOK              | PAW server connects HRZTEST HBOOK A to //LUN11
PAW > histo/plot 10                          | plot histogram 10 from CERNVM
PAW > histo/fit 20 G                         | fit histo 20 with a gaussian and plot it
PAW > rlogin VXCRNA                          | connect to VXCRNA
PAW > rshell file DISK$DL:[PAW]HEXAM.DAT;3   | PAW server on VXCRNA connects file to //LUN11
PAW > histo/plot 110                         | plot histogram 110 from VXCRNA
PAW > rshell file HRZTEST.DAT                | PAW server on VXCRNA connects file to //LUN12
PAW > histo/plot 110 s                       | plot histogram 110 from HRZTEST.DAT
                                             | on VXCRNA on the existing picture
PAW > rshell ld //                           | list all files connected on VXCRNA
PAW > cdir //CERNVM                          | Change current PAW directory to CERNVM
PAW > histo/plot 110                         | plot histogram 110 from CERNVM
PAW > histo/plot //VXCRNA/110                | plot histogram 110 from VXCRNA
PAW > cdir //PAWC                            | current directory to local memory
PAW > histo/list                             | list all histograms in //PAWC
PAW > Histo/delete 0                         | delete all histograms in memory
PAW > hrin //VXCRNA/0                        | read all histograms from VXCRNA
                                             | file HRZTEST.DAT to //PAWC
PAW > cdir //CERNVM                          | change directory to CERNVM
PAW > rshell file NEW.DAT.D 1024 N           | creates a new file on the D disk
PAW > hrout 0                                | write all histograms from //PAWC
                                             | to CERNVM file NEW DAT D
```

9.5 Using PAW as a presenter on OS9 systems

The technique described in previous sections may also be used to access HBOOK histograms being filled by a monitoring task on OS9 systems from a standard PAW session running on a machine with the TCP/IP software.

```
      INDIRECT PAWC
      PROGRAM PRODUCE
*
*        Monitoring task MT1 in processor OP2.
*
      PARAMETER NWPAW=10000
      COMMON/PAWC/IPAWC(NWPAW)
*
      CALL HLIMIT(NWPAW)
*
*       Book histos.
*
      CALL HBOOK1(10,'TEST1$',50,-3.,3.,0.)
      CALL HBOOK1(20,'TEST2$',50,-3.,3.,0.)
*
*       Fill histos.
*
      NUMEVT=10000
      DO 20 I=1,NUMEVT
         DO 10 J=1,100
            CALL RANNOR(A,B)
            CALL HFILL(10,A,0.,1.)
            CALL HFILL(20,B,0.,1.)
 10      CONTINUE
 20   CONTINUE
*
 99   STOP
      END
```

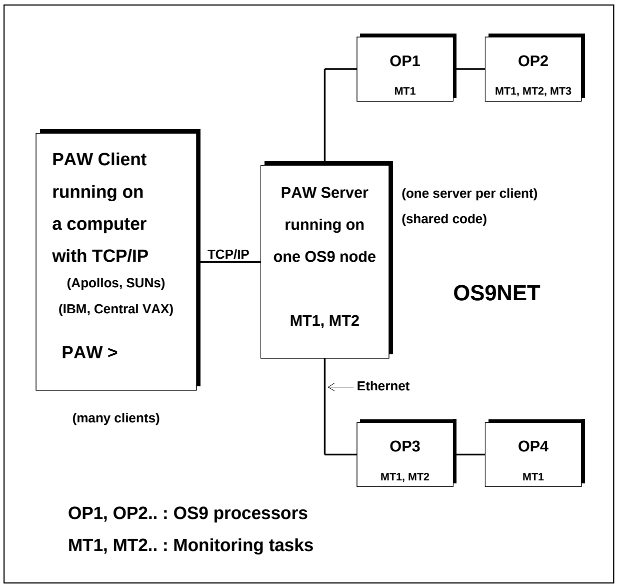


Figure 9.3: Visualising histograms on OS9 modules from PAW

Example of how to access OS9 modules from PAW

```
PAW > rlogin O-OPAL01                    | connect to an OS9 machine
PAW > rshell module OP2/MT1              | PAW server connects to OP2/MT1
                                         | (Processor OP2, Monitoring Task MT1)
PAW > histo/plot 10                      | plot histogram 10
PAW > hrin 0                             | read all histograms into //PAWC
PAW > Histo/File 1 local.dat 1024 N      | create a new file local.dat
                                         | on the client machine
PAW > hrout 0                            | save all histograms from //PAWC
                                         | to the local file
PAW > rshell module OP3/MT2              | PAW server connects to another
                                         | OS9 monitoring task
PAW > Output 56 os9.listing              | Change output file on client
PAW > rshell ldir                        | list all histograms in MT2
                                         | on file os9.listing
PAW > Output -56                         | Change output file to default (unit 6)
                                         | file os9.listing is closed
```

Chapter 10: HBOOK Tabular Overview

Table 10.1: HBOOK Routine calling sequences

Calling Sequence	page
CALL HARRAY (ID,NWORDS,LOC*)	58
CALL HBANDX (ID,YMI,YMA,VMX)	55
CALL HBANDY (ID,XMI,XMA,VMX)	55
CALL HBARX (ID)	56
CALL HBARY (ID)	56
CALL HBAR2 (ID)	56
CALL HBFUN1 (ID,CHTITL,NX,XMI,XMA,FUN)	57
CALL HBFUN2 (ID,CHTITL,NX,XMI,XMA,NY,YMI,YMA,FUN)	57
CALL HBIGBI (ID,NCOL)	82
CALL HBINSZ ('YES'/'NO')	54
CALL HBNAMC (ID,CHBLOK,IADDR,CHFORM)	25
CALL HBNAME (ID,CHBLOK,IADDR,CHFORM)	25
CALL HBNT (ID,CHTITL,CHOPT)	24
CALL HBOOKB (ID,CHTITL,NCX,XBINS,VMX)	53
CALL HBOOKN (ID,CHTITL,NVAR,CHRZPA,NPRIME,CHTAGS)	20
CALL HBOOKNC (ID,CHTITL,NVAR,BLOCK,TUPLE,CHTAGS)	28
CALL HBOOK1 (ID,CHTITL,NX,XMI,XMA,VMX)	14
CALL HBOOK2 (ID,CHTITL,NX,XMI,XMA,NY,YMI,YMA,VMX)	14
CALL HBPRO (ID,VMX)	54
CALL HBPROF (ID,CHTITL,NCX,XLOW,XUP,YMIN,YMAX,CHOPT)	53
CALL HBPROX (ID,VMX)	55
CALL HBPROY (ID,VMX)	55
CALL HBSET (OPTION,IVAL,IERR*)	24
CALL HBSLIX (ID,NSLI,VMX)	55
CALL HBSLIY (ID,NSLI,VMX)	55
CALL HCDIR (*CHPATH*,CHOPT)	163
CALL HCOMPA (IDVECT,N)	83
CALL HCONVOL (ID1,ID2,ID3,IERROR*)	40
CALL HCOPY (ID1,ID2,CHTITL)	16
CALL HCOPYM (ID,IPAWD,IOFSET)	175
CALL HCOPYR (ID1,ID2,CHTITL,IBINX1,IBINX2,IBINY1,IBINY2,CHOPT)	17
variab = hcreateg(global_name,base_common,size)	175
CALL HDDIR (CHPATH)	164
CALL HDELET (ID)	17
CALL HDERIV (DERIV)	118

Table 10.1: HBOOK Routine calling sequences (cont.)

Calling Sequence	**page**
CALL HDIFF (ID1,ID2,PROB*,CHOPT)	103
CALL HDIFFB (ID1,ID2,TOL,NBINS,CHOPT,NBAD*,DIFFS*)	106
CALL HDUMP (ID)	100
CALL HERMES (LERR)	87
LOGVAR = HEXIST (ID)	94
CALL HFC1 (ID,IBIN,CLAB,W,CHOPT)	63
CALL HFC2 (ID,IBINX,CLABX,IBINY,CLABY,W,CHOPT)	63
CALL HFF1 (ID,NID,X,WEIGHT)	61
CALL HFF2 (ID,NID,X,Y,W)	61
CALL HFILL (ID,X,Y,WEIGHT)	15
CALL HFINAM (ID,CHPNAM,NPAR)	116
CALL HFITEX (ID,AA*,BB*,CHI2*,IC,SIG*)	125
CALL HFITGA (ID,C*,AV*,SD*,CHI2*,IC,SIG*)	125
CALL HFITH (ID,FUN,CHOPT,NP,PARAM*,STEP,PMIN,PMAX,SIGPAR*,CH2*)	113
CALL HFITHN (ID,CHFUN,CHOPT,NP,*PAR*,STEP,PMIN,PMAX,SIGPAR*,CHI2*)	114
CALL HFITL (ID,FUN,NP,*P*,CHI2*,IC,SIG*,COV*,ST,PMI,PMA)	124
CALL HFITN (X,Y,EY,NPTS,N1,NVAR,FUN,NP,*P*,CHI2*,IC,SIG*,COV*	124
CALL HFITPO (ID,NP,A*,CHI2*,IC,SIG*)	125
CALL HFITS (ID,FUN,NP,*P*,CHI2*,IC,SIG*)	124
CALL HFITV (N,NDIM,NVAR,X,Y,EY,FUN,CHOPT,NP,PARAM,STEP,PMIN,PMAX,SIGPAR,CHI2)	115
CALL HFIT1 (X,Y,EY,N,FUN,NP,*P*,CHI2*,IC,SIG*)	125
CALL HFN (ID,X)	20
CALL HFNOV (ID,X)	21
CALL HFNT (ID)	29
CALL HFNTB (ID,CHBLOK)	29
CALL HFPAK1 (ID,NID,V,N)	61
CALL HFUNC (ID,FUN)	57
variab = hfree(global_size,base_common,offset)	176
CALL HF1 (ID,X,WEIGHT)	60
CALL HF1E (ID,X,WEIGHT,ERRORS)	60
CALL HF2 (ID,X,Y,WEIGHT)	61
CALL HGFIT (ID,NFPAR,NPFITS,FITCHI,FITPAR,FITSIG,FITNAM)	117
CALL HGIVE (ID,CHTITL*,NX*,XMI*,XMA*,NY*,YMI*,YMA*,NWT*,LOC*)	101
CALL HGIVEN (ID,CHTITL,*NVAR*,CHTAG*,RLOW*,RHIGH*)	33
CALL HGN (ID,*IDN*,IDNEVT,X*,IERROR*)	33
CALL HGNF (ID,IDNEVT,X*,IERROR*)	33
CALL HGNPAR (ID,CHROUT)	34

Table 10.1: HBOOK Routine calling sequences (cont.)

Calling Sequence	page
CALL HGNT (ID,IROW,IERR*)	35
CALL HGNTB (ID,CHBLOK,IROW,IERR*)	36
CALL HGNTF (ID,IROW,IERR*)	37
CALL HGNTV (ID,CHVAR,NVAR,IROW,IERR*)	36
VARIAB = HI (ID,I)	96
CALL HIDALL (IDVECT*,N*)	94
CALL HIDOPT (ID,CHOPT)	80
CALL HID1 (IDVECT*,N*)	94
CALL HID2 (IDVECT*,N*)	94
VARIAB = HIE (ID,I)	97
VARIAB = HIF (ID,I)	98
VARIAB = HIJ (ID,I,J)	96
VARIAB = HIJE (ID,I,J)	98
CALL HIJXY (ID,I,J,X*,Y*)	99
CALL HINDEX	80
CALL HIPAK1 (ID,NID,IV,N)	62
CALL HISTDO	16
CALL HIX (ID,I,X*)	99
CALL HKIND (ID,KIND*,CHOPT)	95
CALL HLABEL (ID,NLAB,*CLAB*,CHOPT)	59
CALL HLDIR (CHPATH,CHOPT)	164
CALL HLIMAP (NWORDS,CHNAME)	178
CALL HLIMIT (NWPAW)	160
CALL HLNEXT (*IDH*,CHTYPE*,CHTITL*,CHOPT)	165
CALL HLOCAT (ID,LOC*)	160
variab = hmapg(global_name,base_common,offset)	176
VARIAB = HMAX (ID)	99
CALL HMAXIM (ID,FMAX)	83
CALL HMCINI (IDDATA,IDMC,IDWT,NSRC,CHOPT,IERR)	142
VARIAB = HMCLNL (FRAC)	142
CALL HMCMLL (IDD,IDM,IDW,NSRC,CHOPT,IFIX,FRAC,FLIM,START,STEP,UP,PAR*,DPAR*)	141
CALL HMDIR (CHPATH,CHOPT)	163
CALL HMERGE (NFILES,CHFIN,CHFOUT)	170
CALL HMERGIN	171
VARIAB = HMIN (ID)	99
CALL HMINIM (ID,FMIN)	83
CALL HNOENT (ID,NOENT*)	94

Table 10.1: HBOOK Routine calling sequences (cont.)

Calling Sequence	page
CALL HNORMA (ID,XNORM)	84
CALL HNTDUP (ID1,ID2,NEWBUF,CHTITL,CHOPT)	40
CALL HNTVDEF (ID1,IVAR,CHTAG,BLOCK,ITYPE)	37
CALL HOPERA (ID1,CHOPER,ID2,ID3,C1,C2)	102
CALL HOUTPU (LOUT)	87
CALL HPAGSZ (NLINES)	85
CALL HPAK (ID,CONTEN)	62
CALL HPAKAD (ID,CONTEN)	62
CALL HPAKE (ID,ERRORS)	62
CALL HPARAM (ID,IC,R2MIN,MAXPOW,COEFF*,ITERM*,NCO*)	128
CALL HPARMN (X,Y,EY,NP,NVAR,IC,R2MIN,MAXPOW,COEFF*,ITERM*,NCO*)	131
CALL HPCHAR (CHOPT,CHAR)	82
CALL HPDIR (CHPATH,CHOPT)	164
CALL HPHIST (ID,CHOICE,NUM)	85
CALL HPHS (ID)	86
CALL HPHST (ID)	86
CALL HPONCE	87
CALL HPRINT (ID)	16
CALL HPRNT (IDN)	29
CALL HPROJ1 (ID,IDN,ISEL,FUN,IFROM,ITO,IVARX)	32
CALL HPROJ2 (ID,IDN,ISEL,FUN,IFROM,ITO,IVARX,IVARY)	33
CALL HPROT (ID,CHOICE,NUM)	86
CALL HPSCAT (ID)	86
CALL HPTAB (ID)	86
CALL HQUAD (ID,CHOPT,MODE,SENSIT,SMOOTH,NSIG*,CHISQ*,NDF*,FMIN*,FMAX*,IERR*)	133
CALL HRDIR (MAXDIR,CHDIR*,NDIR*)	166
CALL HREBIN (ID,X*,Y*,EX*,EY*,N,IFIRST,ILAST)	99
CALL HRECOV (ID,CHOPT)	29
CALL HRENAME (ID1,CHOLD,CHNEW)	40
CALL HREND (CHTOP)	171
CALL HRENID (IDOLD,IDNEW)	17
CALL HRESET (ID,CHTITL)	17
CALL HRFILE (LUN,CHTOP,CHOPT)	169
CALL HRGET (ID,CHFILE,CHOPT)	167
CALL HRIN (ID,ICYCLE,IOFSET)	170
VARIAB = HRNDM1 (ID)	135
CALL HRNDM2 (ID,RX*,RY*)	135

Table 10.1: HBOOK Routine calling sequences (cont.)

Calling Sequence	**page**
CALL HROPEN (LUN,CHTOP,CHFILE,CHOPT,LREC,ISTAT*)	168
CALL HROUT (ID,ICYCLE*,CHOPT)	169
CALL HRPUT (ID,CHFILE,CHOPT)	167
CALL HSCALE (ID,FACTOR)	84
CALL HSCR (ID,ICYCLE,CHOPT)	171
CALL HSETPR (CHNAME,VALUE)	130
CALL HSMOOF (ID,ICASE,CHI2*)	132
VARIAB = HSPFUN (ID,X,N,K)	133
CALL HSPLI1 (ID,IC,N,K,CHI2*)	132
CALL HSPLI2 (ID,NX,NY,KX,KY)	133
CALL HSQUEZ ('YES'/'NO')	85
CALL HSTAF (CHOPT)	82
VARIAB = HSTATI (ID,ICASE,CHOICE,NUM)	101
VARIAB = HSUM (ID)	100
CALL HTITLE (CHGTIT)	80
CALL HUNPAK (ID,CONTEN*,CHOICE,NUM)	96
CALL HUNPKE (ID,CONTEN*,CHOICE,NUM)	97
CALL HUWFUN (LUN,ID,CHFUN,CHFILE,ITRUNC,CHOPT)	37
VARIAB = HX (ID,X)	96
VARIAB = HXE (ID,X)	97
CALL HXI (ID,X,I*)	98
VARIAB = HXY (ID,X,Y)	96
VARIAB = HXYE (ID,X,Y)	98
CALL HXYIJ (ID,X,Y,I*,J*)	98

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