Computing lecture 2

Histograms, n-tuples, etc.

I. CERNLIB and its successors

II. Histograms in general

III. Histograms in FORTRAN/C++/PAW

IV. n-tuples

The CERN program library (CERNLIB)

- Web site: `http://wwwinfo.cern.ch/asd/index.html`
- CERNLIB contains FORTRAN subprograms for:

  numerical analysis

  Monte Carlo

  data handling (histograms, search, sort, . . .)

  event generators, detector simulation, particle kinematics, . . .
- Anaphe (LHC++): replace CERNLIB with OO (e.g. C++) libraries

  only partially complete, rapid state of flux
- Provisional solution for C++:

  call CERNLIB routines from C++ using `cfortran.h`, see

  `http://wwwinfo.cern.ch/asdcgi/listpawfaqs.pl/21`
- To use, include at end of link command:

  `‘cernlib‘` or if more libraries needed, try e.g.

  `‘cernlib graflib mathlib kernlib packlib‘`
- Some other libraries (see links on course web site):

  Statlib (Carnegie Mellon)

  Netlib (University of Tennessee)

  Numerical Algorithms Group (NAG)

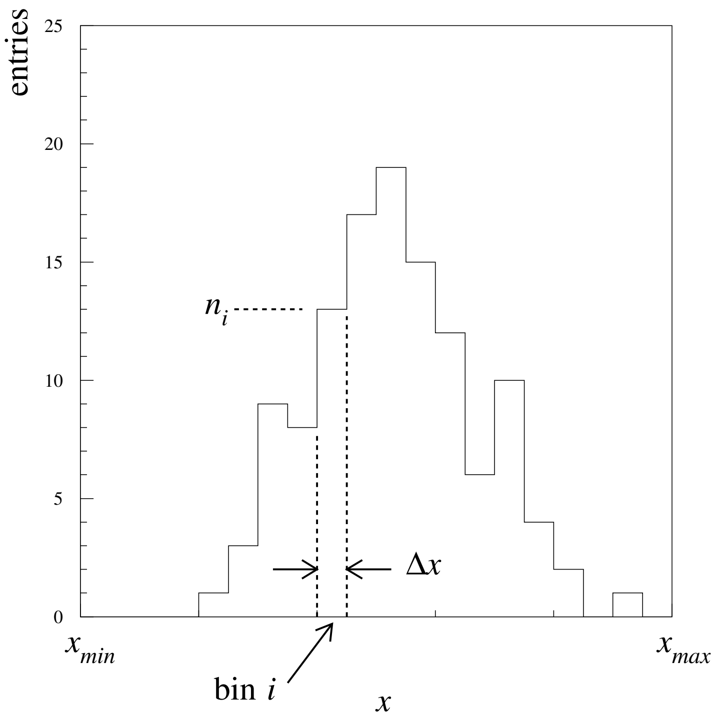
  Numerical Recipes (Press et al.)

  Datenanalyse (Brandt)

Histograms

- Consider a data sample $\vec{x} = (x_1, \ldots, x_m)$ (m can be large)

$\rightarrow$ summarize information as a histogram (N bins)



- Generic computer implementation:

  I. Define bins, e.g. N bins of width Δx from x_{min} to x_{max}.

  II. Declare variables to hold $n_1, \ldots, n_N$, initialize all n_i to 0.

  III. Loop over $x_1, \ldots, x_m$; if x value in bin i, $n_i \rightarrow n_i + 1$.

- In practice, not trivial $\Rightarrow$ use packages HBOOK, HTL, ...

Histograms with HBOOK

- The HBOOK package (from CERN): user-callable FORTRAN subroutines for creating/manipulating:

  histograms (1-dimensional)
  scatter-plots (2-dimensional)
  n-tuples

- The basic steps to get a histogram:

  I. 'Book' histogram: define bins, allocate memory for $n_1, \ldots, n_N$.

```
call HBOOK1(17, 'x values', 100, xmin, xmax, 0.)
```

  id number — title — number of bins

  II. 'Fill' the histogram:

```
do i = 1, m
  call HF1(17, x(i), 1.)
end do
```

  'weight' (usually 1.0)

- Steps also needed to set up output file and store results (see example on next page)

A FORTRAN program using HBOOK

```
      program TEST_HBOOK

c   Glen Cowan
c   5 October, 1999
c   Test program for using HBOOK

      implicit        NONE

c   Needed for HBOOK routines

      integer         hsize
      parameter       (hsize = 100000)
      integer         hmemor (hsize)
      common  /pawc/  hmemor

c   Local variables

      character*80    outfile
      integer         i, icycle, istat, num_values
      integer         seed         / 12345 /
      real            x

c   Initialize HBOOK, open histogram file, book histograms.

      call HLIMIT (hsize)
      outfile = 'test_hbook.his'
      call HROPEN (20, 'histog', outfile, 'N', 1024, istat)
      call HBOOK1 (17, 'x values', 100, 0., 10., 0.)

c   Get x values and enter into histogram.

      write (*, *) 'enter number of x values to generate'
      read (*, *) num_values
      do i = 1, num_values
        x = RANDOM (seed)           ! returns a random number
        call HF1 (17, x, 1.)
      end do

c   Store histogram and close.

      call HROUT (0, icycle, ' ')
      call HREND ('histog')

      stop
      END
```

Calling CERNLIB routines from C++ programs

- For details see

  http://wwwinfo.cern.ch/asdcgi/listcernlibfaqs.pl/10

  and example `test_radom.cc` on SDA web site.

- Need C++ header files in `/cern/pro/include/cfortran`

- To call a FORTRAN CERNLIB routine from C++,

  (1) Include the necessary header files:

```
#include "cfortran/cfortran.h"
#include "cfortran/hbook.h"
```

  (2) Call routine (name in capitals) with same parameters:

```
main(){
              ⋮
   HBOOK (1, "test histogram", 100, 0., 1., 0.);
   for (int i = 1; i<1000; i++){
      float x = random(seed);
      HF1 (1, x, 1.);
   }
              ⋮
}
```

- Special flags needed to compile/link (see documentation on web)

A C++ program using HBOOK

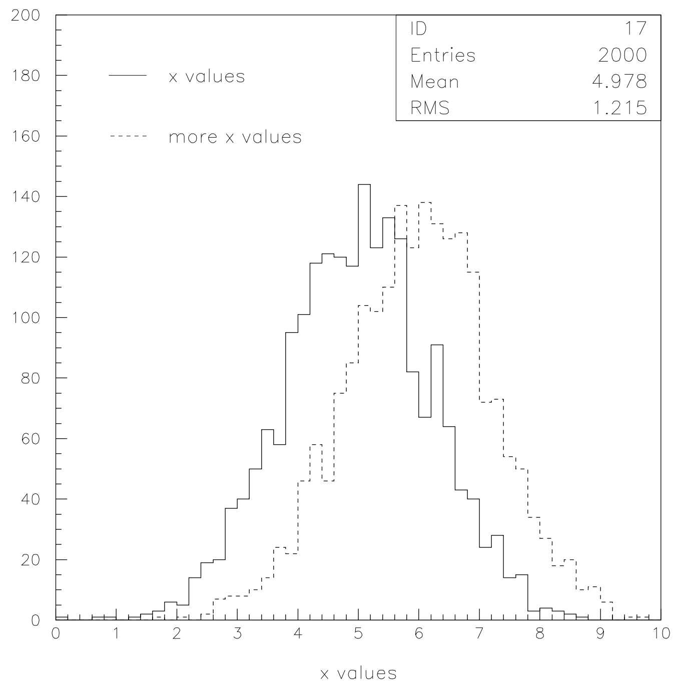
```
#include <stdlib.h>
#include <iostream>
#include "cfortran/cfortran.h"
#include "cfortran/hbook.h"
#include "random.h" // prototype for random function used below

// define array used for hbook memory
#define PAWC_SIZE 50000
float pawc_[PAWC_SIZE];

int main(){

  // Initialize HBOOK and open histogram file
  HLIMIT(PAWC_SIZE);
  int lun = 20;
  int istat = 0;
  int lrec = 1024;
  char* outfile = "test_hbook.his";
  HROPEN (lun, "histog", outfile, "N", lrec, istat);
  if (istat != 0){
    std::cout << "HROPEN error, istat = " << istat << std::endl;
    exit(istat);
  }

  HBOOK1 (1, "uniform", 100, 0., 1., 0.);

  int num_values;
  cout << "Enter number of values to generate" << endl;
  cin >> num_values;
  int seed = 12345;
  for (int i = 0; i<num_values; i++){
    float x = random(seed);
    HF1(17, x, 1.);
  }

  int icycle=0;
  HROUT (0, icycle, " ");
  HREND ("histog");

  return 0;
}
```

Looking at the histograms with PAW

- Running the sample program creates the file `test_hbook.his`.

  To view/manipulate the histograms with PAW,

```
h/file 1 test_hbook.his        ← read in file
h/list                         ← show list of histograms
===> Directory :
17 (1) x values
23 (1) more x values
h/pl 17                        ← plot histogram 17
h/pl 23 s                      ← put 23 on same plot
```



- See documentation for details on commands like:

  `opt stat, set dmod, h/set max, key, ...`

Two-dimensional histograms (scatter plots)

- Bins are now cells in 2-d plane. HBOOK routines similar to 1-d:

I. To book:

id number — title

```
   call HBOOK2 (37, 'y vs. x', nx, xmin, xmax,
& ny, ymin, ymax, 0.)
```

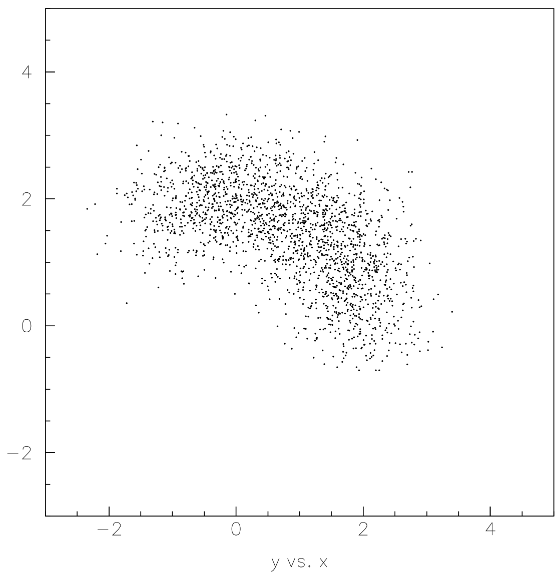
number of bins in x

same stuff for y

II. To fill:

```
   call HF2 (37, x, y, 1.)
```

- Viewing with PAW same as in 1-d case:



N.B. Exact x, y values not recorded, only numbers of entries in each bin ($N_x \times N_y$ values stored).

Access to information

- In FORTRAN (see HBOOK manual for details)

Open file and read in the histograms:

```
call HROPEN (30, ' ', 'myfile.his', ' ', lrec, istat)
call HRIN (0, icycle, 0)
```

Access contents of histograms, errors, etc.

```
  call HNOENT (id, num_entries)          ← number of entries
  call HUNPAK (id, contents, ' ', 0)     ← unpack into array
  call HGIVE (id, title, nx, xmin, xmax, ny,
& ymin, ymax, nwt, loc)                  ← get booking info
```

- In PAW (see PAW manual or online help)

Read histograms into memory, use variables and system functions, best used in macros ('kumac' files).

```
h/file 1 myfile.his
hrin 0                     ← read histograms into memory
id = 17                    ← define variable id, use brackets to evaluate.
nx = $HINFO([id],'XBINS')  ← system function HINFO
vec/create myvector([nx]) R  ← vector to hold histogram
vec/print myvector         ← show vector contents
mess 'events =' $HINFO([id],'EVENTS')   ← # entries
```

n-tuples

- An n-tuple is a matrix of numbers, e.g. m instances of an n-dimensional vector:

$$m \text{ `events' (rows)} \left\{ \begin{array}{ccc} (x_1, x_2, & \ldots & , x_n)_1 \\ (x_1, x_2, & \ldots & , x_n)_2 \\ (x_1, x_2, & \ldots & , x_n)_3 \\ & \vdots & \\ (x_1, x_2, & \ldots & , x_n)_m \end{array} \right.$$

n columns, i.e. n variables for each event

- Example: for 3-body decays of a certain type of particle, record:

$$p_{x_1}, p_{y_1}, p_{z_1}, p_{x_2}, p_{y_2}, p_{z_2}, p_{x_3}, p_{y_3}, p_{z_3}$$

- Data volume = number of events $\times$ number of columns

- Compare to histogram with n dimensions: data volume $= N_{\text{bins}}^n$

  $\Rightarrow$ for large enough n (usually 2 or more), n-tuple wins

- Use n-tuple to store event properties for use in further analysis, e.g. to make histogram of invariant mass of two of the particles

$$m_{12} = \left[(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 \right]^{1/2}$$

after making a cut on m_{23} .

n-tuples with HBOOK

- HBOOK provides two types of n-tuples:

  (1) Row wise:

  each event (row) stored sequentially;

  events have fixed length;

  only real (floating point) variables allowed;

  to book: `HBOOKN`

  to fill: `HFN`

  to read: `HGN, HGNPAR, HGNF` (or use PAW)

  (2) Column wise:

  columns stored sequentially

  → faster access if only a few columns out of many needed

  events can contain mixed variable types;

  events can contain data structures of variable length;

  to book: `HBNT, HBNAME`

  to fill: `HFNT, HFNTB`

  to read: `HGNT, HGNTB, HGNTV, HGNTF` (or use PAW)

- See examples on course web site, PAW/HBOOK documentation.

n-tuples with PAW

- The usual procedure:

  create n-tuple in analysis program, then analyze it with PAW

- Suppose we've created an n-tuple with 3 columns: x, y, z.

  Read in with **h/file** as before; suppose n-tuple id is 17.

  The basic commands:

```
ntuple/plot 17.x          ← plot histogram of x
nt/pl 17.y%x              ← make scatter plot of y vs. x
nt/print 17               ← show variable names, min/max values
nt/scan 17                ← show entire contents of n-tuple
nt/pl 17.x 2*y-z<1.5          ← histogram x after cut on y, z
nt/cut $1 2*y-z<1.5           ← define cut number 1
nt/pl 1.x $1              ← histogram of x after cut 1
```

- To set histogram properties (e.g. id=20, 100 bins from 0 to 50):

```
1dhisto 20 'histo of x' 100 0.  50.
nt/proj 20 17.x        ← project contents into histogram
h/pl 20                ← display histogram as usual
```

- More advanced features possible (loops, masks, ...) but at some point it's better to use a high level program (FORTRAN, C++).