mFOAM-1.02: A Compact Version of the Cellular Event Generator FOAM

S. Jadach
Institute of Nuclear Physics, Academy of Sciences, ul. Radzikowskiego 152, 31-342 Cracow, Poland, and
CERN Department of Physics, Theory Division
CH-1211 Geneva 23, Switzerland

and

P. Sawicki
Institute of Nuclear Physics, Academy of Sciences, ul. Radzikowskiego 152, 31-342 Cracow, Poland

Abstract
The general-purpose self-adapting Monte Carlo (MC) event generator/simulator mFOAM (standing for mini-FOAM) is a new compact version of the FOAM program, with a slightly limited functionality with respect to its parent version. On the other hand, mFOAM is easier to use for the average user. This new version is fully integrated with the ROOT package, the C++ utility library used widely in the particle physics community. The internal structure of the code is simplified and the very valuable feature of the persistency of the objects of the mFOAM class is improved. With the persistency at hand, it is possible to record very easily the complete state of a MC simulator object based on mFOAM and ROOT into a disk-file at any stage of its use: just after object allocation, after full initialization (exploration of the distribution), or at any time during the generation of the long series of MC events. Later on the MC simulator object can be easily restored from the disk-file in the “ready to go” state. Objects of TFoam class can be used as a stand-alone solution to many everyday problems in the area of the Monte Carlo simulation, or as building blocks in large-scale MC projects, taking full advantage of the object-oriented technology and persistency.

Keywords: Monte Carlo (MC) simulation and generation, particle physics, phase space.

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PROGRAM SUMMARY

Title of the program:
mFOAM (mini FOAM), version 1.02.

Computer:
Most Unix workstations, supercomputers and PC.

Operating system:
Most UNIX systems, Linux and Windows.

Application programs were thoroughly tested under Red Hat Linux 7.x, CERN Scientific Linux 3.02, Fedora Linux FC3, UNIX IRIX-6.5.

At present mFOAM is distributed with the ROOT package (version 4.04 and later).

Programming languages used:
ANSI C++.

High-speed storage required:
Depends on the complexity of the problem. For the default 2000 cells it is about 25 MB while for 100,000 cells it allocates about 35 MB. These data are for running from CINT command line and include also memory consumption by CINT itself.

No. of lines in combined program and test deck:
mFOAM-1.02 2776 lines of C++ code.

Nature of the physical problem:
Monte Carlo integration or generation of unweighted (weight equals 1) events with a given probability distribution is a standard problem in many areas of research, ranging from high-energy physics to economy. In any library of general utilities it is highly desirable to include a general-purpose numerical tool (program) with the MC generation algorithm featuring the built-in capability of automatically adjusting generation procedure to an arbitrary pattern of singularities in the generated distribution. Our primary goal is the simulation of the differential distribution in the multiparticle Lorentz-invariant phase space for the purpose of comparison between Quantum Field Theory prediction, and experiments in the high-energy experiments. However, the solution may have a much wider area of applications.

Method of solution:
In the algorithm, a grid of cells, called “foam”, is built in the process of the binary split of the cells. The resulting foam is adapted automatically to the shape of the integrand in such a way that the resulting ratio of the average weight to maximum weight or the variance to average weight is minimized.

Restrictions on the complexity of the problem:
Consumption of computer resources depends on the complexity of the problem. The use of the program is limited to about a million of cells for a relatively small number of dimensions (≤ 20) in view of the memory and CPU time restrictions of a modern desktop computer.

Typical running time:
The CPU time necessary to build up a foam of cells depends strongly on the number of dimensions and the requested number of cells. On the PC with a 1.6 GHz Intel processor, it takes about 10 seconds to build a hyperrectangular grid of 10,000 cells for simple 3-dimensional distribution.
1 Introduction

The present program mFOAM, and the FOAM program of Refs. [1, 2], from which mFOAM is derived, are both examples of a general-purpose self-adapting Monte Carlo simulator/integrator. Let us briefly recapitulate main features of FOAM, which are shared with the present project. In the cellular algorithm of FOAM, points are generated randomly in the multi dimensional space according to an arbitrary, user-defined, unnormalized probability distribution function (PDF) $\rho(x)$. The algorithm works in two stages: exploration and generation. In the exploration stage the shape of the distribution function is explored using MC methods, dividing the integration domain into a system of cells referred to as “foam”. The foam of cells is produced in a recursive process of binary splittings of the cells starting from the root cell, which can be a single $k$-dim hyperrectangle, an $n$-dim simplex or a Cartesian product of both. In mFOAM we restrict ourselves to hyperrectangles. The PDF $\rho(x)$ is approximated by another PDF $\rho'(x)$, which is equal to a constant within each cell. The main aim of the process of the foam evolution through binary splittings is to minimize either the ratio of the variance of the weight distribution to the average weight $\sigma/\langle w \rangle$, or the ratio of the maximum weight to the average weight $w_{\text{max}}/\langle w \rangle$, where $w = \rho(x)/\rho'(x)$ is the Monte Carlo weight.

In the generation stage every single MC weighted event is generated as follows: first a cell is chosen randomly and next, within this cell, a point (MC event) is generated according to an uniform distribution equal to $\rho'$ and finally the MC weight $w = \rho(x)/\rho'(x)$ is evaluated. As usual, the rejection method may turn these weighted events into weight-one events, with a certain rejection rate (inefficiency). The main aim of the rather sophisticated cell-splitting algorithm of FOAM (exploration phase) is the reduction of $w_{\text{max}}/\langle w \rangle$, assuring a low rejection rate. Another option is the variance-reduction providing for self-adapting MC method of precise evaluation of the integrals. In either case, the value of the integrand is already known approximately from the exploration stage and can be estimated with even better precision in the generation phase.

It is instructive to compare the cellular algorithm of FOAM to algorithms used by two older programs in the family of self-adapting MC tools: VEGAS [3] and MISER [4]. VEGAS primarily implements the so-called importance sampling (variance-reducing) method. It approximates the exact distribution by a multidimensional sampling function $g$. The function $g$ is separable by construction, i.e. $g(x_1, x_2, \ldots, x_n) = g_1(x_1)g_2(x_2), \ldots, g_n(x_n)$. Owing to this feature, the function $g$ can be stored effectively in the computer memory as a collection of $n$ (one for each dimension) histograms with $K$ bins, without an explosion in the total number of bins, which would in general grow like $K^n$. The sampling distribution is constructed iteratively, step by step, by means of making a number of Monte Carlo explorations over the integration region, while inspecting $n$ 1-dimensional histograms of the projections the distribution function, each for one dimension. These histograms are used to define the new improved function $g_i$, which in turn are used to generate MC points in the next iteration. In principle, after a few iterations, one obtains the reference distribution $g$ approximating the PDF. An estimated of the value of the integral over PDF is also obtained. In practice the performance of VEGAS depends heavily on the goodness of the factorizability assumption.
for a given PDF. Generally, VEGAS turns out to be quite efficient for many distributions (integrands) featuring a single well localized peak.

The MISER program\(^1\) is based on the idea of the “recursive stratified sampling” and employs the technique of variance reduction similar to that in FOAM. It explores the PDF until a fixed maximal number of available function evaluations \(N\) is exhausted. In the very beginning \(N\) is allocated to the root cell being a hypercube and later on redistributed among the daughter cells. In the simplest variant the starting hypercube is divided by bisecting it across one of the edges into two sub-cells of equal volume\(^2\). The division plane is chosen by examining all possible \(n\) bisections of the \(n\)-dimensional cell and selecting the one that minimizes the resulting total variance of the two cells. Similarly as in FOAM, the variances are estimated cell by cell during a short MC survey with a small fraction of “allocated” events for this cell. The remaining pool of unexploited function calls is allocated to the resulting sub-cells in a proportion that fulfills the condition for minimum variance. The whole procedure is repeated for each of the two sub-cells and continues recursively until the number of “allocated function calls” in a given cell falls below some predefined limit. In each cell the estimation of the integral is obtained by means of the plain MC method. At the end, the results for all cells are combined together to obtain the final value of the integrand and the error estimate.

FOAM employs a combination of both techniques: importance and stratified sampling. Contrary to VEGAS, there is no assumption in the FOAM algorithm about the factorizability of the distribution (integrand). In the variance reduction mode FOAM resembles MISER, but it employs a different, far more sophisticated cell division algorithm; the division plane of the cell is not at the half-point of the edge, but is optimized. The algorithm of FOAM has passed many practical tests and proved its efficiency in several problems in high-energy physics; see for instance [6, 7]. The foundations of the FOAM algorithm are well consolidated and our current work concentrates mainly on the updates of earlier implementations and improvements of the efficiency and functionality. For a detailed description of the algorithm of FOAM version 2.05 we refer the interested reader to Refs. [1] and [2].

The use of the original FOAM program [2] has been mainly limited by the memory consumption. FOAM v.2.05 divides the \(n\)-dimensional parameter space into hyperrectangular or simplical cells. Final MC efficiency increases mainly with the requested maximum number of cells \(N_c\), so it is very important to economize on the memory used by single cell in order reach a higher number of cells. For the hyperrectangular grid of cells a memory saving arrangement algorithm of coding cells in the memory was found [1]. It reduces memory consumption down to a mere 80 bytes/cell, independently of space dimension \(n\). The present version, limited to hyperrectangles, profits from this memory-saving algorithm of recording the cell parameters. We would like to mention, that in the mean-time a similar memory-saving algorithm has been also found and implemented for simplices. It will be included in the forthcoming version 2.06 of the FOAM [8].

The unspoken assumption in mFOAM is that the calculation of the PDF is cheap in terms

\(^{1}\)Unfortunately, the MISER algorithm was overlooked in the previous papers on the FOAM project.

\(^{2}\)A quite similar 2-dimensional algorithm is also present in the MC program LESKO, of ref. [5], and in other programs; see ref. [2] for more references.
of CPU time. This is often true in practice. If not, then mFOAM may be used to model the main features of the singularities in the PDF and the fine details, which can be CPU-costly, are then added by extra MC weight during the MC run, after the exploration. However, in order to deal better with the cases of PDFs which are costly in terms of CPU and feature relatively mild peaks, one should introduce in the future development of mFOAM the possibility to limit the total number of PDF calls, in addition to limiting the number of cells.

The paper is organized as follows: Section 2 describes changes in basic classes and their functionality. Section 3 describes the configuration of mFOAM. Section 4 discusses the usage of mFOAM classes under the ROOT system. Conclusions follow.

2 Description of mFOAM code

mFOAM (mini FOAM) is a new version of FOAM with slightly limited functionality, well integrated with ROOT [9]. Our principal aim is to provide a compact and easy to use tool, for numerical Monte Carlo generation and integration of PDFs with arbitrarily complicated structure of peaks, in the number dimensions limited up to say 20. With the increasing popularity of ROOT in high-energy community we believe that this implementation tied up with ROOT will attract the interest of the new users who already exploit ROOT in their daily work.

Let us comment on our decision of removing the simplical cells from the mFOAM algorithm and the code. It was done because of an empirical observation (based on practical experience with the wide range of the distributions) that the use of simplical cells was usually giving rise to worse MC efficiency than that of hyperrectangular cells. In addition, maintaining simplical cells increases complexity of the source code.

The main motivation for the closer integration of mFOAM with the ROOT system was to profit fully from the persistency mechanism for its objects and help users who already use ROOT daily. Also, thanks to the closer integration with ROOT, the code of mFOAM gets more compact, since the internal histogramming and other low-level structures are replaced by the well tested ROOT facilities. Altogether, we have managed to reduce significantly the total size of code (by about 50%) and its complexity as well, with respect to the original FOAM, at the same time improving its stability.

Obviously, the above improvements and gains are purely technical, nevertheless they are very important, if object of the mFOAM class are to be used as “rock solid” building blocks in any more complex, large scale, Monte Carlo projects.

mFOAM, like its ancestor, is written fully in the object-oriented programming (OOP) style in the C++ programming language. The classes of the mFOAM program are listed in Table 1. Some classes present in FOAM-2.05 have been removed, because they are needed only for the simplical cells. The remaining classes changed their names to comply with the ROOT naming conventions. For the same reason, names of preserved data members now begin with the letter “f”. Two basic classes, TFoam and TFoamCell, are greatly simplified by removing all of simplical structure. All other remaining classes have the same functionality as in FOAM version 2.05. In particular, an abstract base class TFoamIntegrand provides the
user interface to any user-provided PDF. Classes TFoamVect and TFoamMaxwt are unmodified auxiliary utility classes. In mFOAM we use the library of random generators of ROOT; the TPSEMAR class of FOAM is removed. All classes of mFOAM inherit I/O capabilities from ROOT’s TObject class.

As already advertised, we have payed special attention to the persistency issue. Generally, it is not trivial to get full persistency for the mFOAM and FOAM classes, mainly because of the intensive use of the pointers in the coding of the linked binary trees of the foam cells. All these problems are now solved efficiently with the help of the ROOT pointer classes. Consequently, any object of the mFOAM class can be written more easily at any time into disk and restored later on, with the help of the “automatic streamers” generated by ROOT. In this way, generation of the MC events can be easily stopped and resumed. When the MC generation of the series of events is resumed, then MC generation continues as if there was no disk-read and disk-write in the meantime.

A simple persistent abstract class (interface) representing any user-defined PDF is available. We refer the reader to Section 4 for a number of explicit examples/templates how to exploit it.

Let us now characterize briefly the role of most important classes in the implementation of the mFOAM algorithm.

## 2.1 TFoam class

TFoam is the main class. Each instance of the TFoam class is a separate, independent MC generator. In Tables 2 and 3 we provide a full list of data members of the class TFoam and their short description. Most of the methods (procedures) of the class TFoam are listed in Table 4. We omitted in this table “setters” and “getters”, which provide access to some data members, and simple inline functions, such as sqr for squaring a Double_t variable. Data members that are served by the setters and getters are marked in Tables 2 and 3 by the superscripts “s” or/and “g”. We followed closely the ROOT naming conventions and decided to use appropriate ROOT types instead of raw C number types. In this way we assure the portability of our code to the forthcoming generation of inexpensive 64-bit processors.

Below we briefly describe the functionality of the most important methods in the TFoam class.
### Table 2: Data members of the TFoam class. Associated setters and getters marked as superscripts $s$ and $g$.

| TFoam member    | Short description                                                                 |
|-----------------|-----------------------------------------------------------------------------------|
| TString fVersion$^g$ | Actual version of the mFOAM (like 1.02m)                                           |
| TString fDate    | Release date of the mFOAM                                                          |
| TString fName    | Name of a given instance of the TFoam class                                         |
| Int_t fDim$^s,g$ | Dimension of the integration space                                                 |
| Int_t fNCells$^s$ | Maximum number of cells                                                            |
| Int_t fRNmax     | Maximum number of random numbers generated at once                                 |
| Int_t fOptDrive$^s$ | Optimization =1,2 for variance or maximum weight reduction                      |
| Int_t fChat$^s$  | =0,1,2 chat level in output; =1 for normal output                                  |
| Int_t fOptRej$^s$ | =0 for weighted events; =1 for unweighted events in MC generation                 |
| Int_t fNBin$^s$  | No. of bins in edge histogram for cell MC exploration                              |
| Int_t fNSampl$^s$ | No. of MC events, when dividing (exploring) cell                                   |
| Int_t fEvPerBin$^s$ | Maximum number of effective ($w = 1$) events per bin                             |
| Double_t fMaxWtRej$^s$ | Maximum weight in rejection for getting $w = 1$ events                           |

#### 2.1.1 Constructor

The TFoam(const Char_t *) constructor creates the TFoam object whose name is given by its argument. For example the following line of code creates an instance of mFOAM generator named FoamX:

```cpp
TFoam *FoamX = new TFoam("FoamX"); // Create Simulator
```

The main role of the constructor is to initialize data members to their default values – no memory allocation is done at this stage. The principal configuration parameters can be optionally changed by using setter methods (this is described in Sect. 3).

#### 2.1.2 Setting distribution function and random number generator

The user should also provide her/his own unintegrated non-negative probability distribution function (PDF). Note that the PDF may be discontinuous. mFOAM can cope with integrable infinite singularities in the PDF. However, we do not really recommend to use it for such cases.

Two methods were available for providing a PDF object to an mFOAM object: SetRho(TFoamIntegrand *) sets the pointer of the PDF object through the abstract class TFoamIntegrand pointer (interface). The user can also provide a global PDF, making it available to the mFOAM object by calling the method SetRhoInt(void *). A detailed description of how to implement all kinds of PDFs is given in Sect. 4.1.

The random number generator (RNG) object is created by the user and set as a pointer in the SetPseRan (TRandom *) method; see explicit examples in Sect. 4.
How to organize the interrelation between the RNG and PDF objects of TRandom and TFoamIntegrand classes, serving several objects of the mFOAM class without destroying the persistency, will be discussed in Sect. 4.2.

Table 3: Data members of the TFoam class. Cont.
| **Tfoam method** | **Short description** |
|------------------|----------------------|
| Constructors and destructors | |
| `Tfoam()` | Default constructor (for ROOT streamer) |
| `Tfoam(const Char_t *)` | User constructor |
| `~Tfoam()` | Explicit destructor |
| `Tfoam(const Tfoam&)` | Copy Constructor NOT USED |
| `Tfoam& operator=(const Tfoam&)` | Substitution NOT USED |
| Initialization, foam build-up | |
| `void Initialize()` | Initialization, allocation of memory |
| `void SetRho(TfoamIntegrand *)` | Sets the pointer to distribution function |
| `void ResetRho(TfoamIntegrand *)` | Resets the pointer to distribution function |
| `void SetRhoInt(void *)` | Sets the pointer to user-defined global function |
| `void SetPseRan(TRandom*)` | Sets the pointer to r.n.g. |
| `void ResetPseRan(TRandom*)` | Resets the pointer to r.n.g. |
| `void InitCells(void)` | Initializes memory for cells and starts exploration |
| `void Grow(void)` | Adds new cells to foam, until buffer is full |
| `Int_t Divide(TfoamCell *)` | Divides cell into two daughters |
| `void Explore(TfoamCell *Cell)` | MC exploration of cell main subprogram |
| `void Carver(Int_t&,Double_t&,Double_t&)` | Determines the best edge, \( w_{\text{max}} \) reduction |
| `void Varedu (Double_t[], Int_t&,Double_t&,Double_t&)` | Determines the best edge, \( \sigma \) reduction |
| `Long_t PeekMax(void)` | Chooses one active cell, used in `Grow` |
| `void MakeAlpha(void)` | Generates rand. point inside h-rectangle |
| `Int_t CellFill(Int_t, TfoamCell*)` | Fills next cell and returns its index |
| `void MakeActiveList(void)` | Creates table of all active cells |
| `void SetInhiDiv(Int_t, Int_t )` | Sets inhibition of cell division along certain edge |
| `void SetXdivPRD(Int_t, Int_t, Double_t[])` | Sets predefined division points |
| `Double_t Eval(Double_t *)` | Evaluates value of the distribution function |
| Generation | |
| `void MakeEvent(void)` | Makes (generates) single MC event |
| `void GetMCvect(Double_t *)` | Provides generated random MC vector |
| `Double_t GetMCwt(void)` | Provides MC weight |
| `Double_t MCgenerate(Double_t *MCvect)` | All the above in single method |
| `void GenerCel2(TfoamCell *&)` | Chooses one cell with probability \( \sim R_j \) |
| Finalization, reinitialization | |
| `void Finalize(Double_t&, Double_t&)` | Prints summary of MC integration |
| `void GetIntegMC(Double_t&, Double_t&)` | Provides MC integral |
| `void GetIntNorm(Double_t&, Double_t&)` | Provides normalization |
| `void GetWtParams(const Double_t, Double_t&, Double_t&, Double_t&)` | Provides MC weight parameters |
| Debug | |
| `void CheckAll(const Int_t)` | Checks correctness of the data structure |
| `void PrintCells(void)` | Prints all cells |

Table 4: Methods of the Tfoam class.
2.1.3 Initialization step methods

To begin the process of the foam build-up, the user should invoke the `Initialize()` method. The method `InitCells` initializes the memory storage for cells and begins the exploration process starting from the root cell. The empty cells are allocated/filled using `CellFill`. The procedure `Grow` which loops over cells, picks up the cell with the biggest “driver integral” (see Ref. [1] for explanations) with the help of the `PeekMax` procedure. The chosen cell is split using the `Divide` procedure.

Subsequently, the procedure `Explore` called by `Divide` (and by `InitCells` for the root cell) does the most important job in the mFOAM build-up: it performs a low statistics MC exploration run for each newly allocated daughter cell. It calculates how profitable the future split of the cell will be and defines the optimal cell division geometry with the help of the `Carver` or `Varedu` procedures, for maximum weight or variance optimization respectively. All essential results of the exploration are written into the explored cell object. At the very end of the foam build-up, `MakeActiveList` is invoked to create a list of pointers to all active cells, for the purpose of the quick access during the MC generation. The procedure `Explore` uses `MakeAlpha`, which provides random coordinates inside a given cell with the uniform distribution. The above sequence of the procedure calls is depicted in Fig. 1.

![Figure 1: Calling sequence of the mFOAM procedures during the foam build-up (initialization).](image)

2.1.4 MC event generation step methods

The MC generation of a single MC event is done by invoking `MakeEvent`, which chooses randomly a cell with the help of the method `GenerCell2` and, next, the internal coordinates of the point within the cell using `MakeAlpha`. 
The absolute coordinates of the MC event are calculated and stored in the data member double-precision vector \( f_{MC\text{vect}} \). The MC weight is calculated using the procedure \( \text{Eval} \), which provides the density distribution \( \rho(x) \).

The MC event (double-precision vector) and its weight are available through getters \( \text{GetMCvect} \) and \( \text{GetMCwt} \).

The user may alternatively call \( \text{MCgenerate} \), which invokes \( \text{MakeEvent} \) and provides a MC event and its weight simultaneously.

### 2.1.5 Finalize step methods

The use of the method \( \text{Finalize} \) is not mandatory. It prints statistics and calculates the estimate of the integral using the average weight from the MC run. The amount of printed information depends on the values of \( f_{\text{Chat}} \). For the normalization of the plots and integrals, the user needs to know the exact value of \( R' = \int \rho'(x)dx \), which is provided by the method \( \text{GetIntNorm} \) or \( \text{Finalize} \).

The actual value of the integrand from the MC series is provided by \( \text{GetIntegMC} \). Note that, for the convenience of the user, \( \text{GetIntNorm} \) provides \( R' \) or an MC estimate of \( R = \int \rho(x)dx \), depending on whether the MC run was with variable weight or weight = 1 events.

Another useful finalization procedure

\[
\text{GetWtParams(const Double_t eps, Double_t &AveWt, Double_t &WtMax, Double_t &Sigma)}
\]

provides three parameters that characterize the MC weight distribution: the average weight \( \text{AveWt} \), the “intelligent” maximum weight\(^3 \) \( \text{WtMax} = w_{\text{max}}^{\epsilon} \), for a given value of \( \text{eps} = \varepsilon \) and the variance \( \text{sigma} = \sigma \). In particular, in the case of \( w = 1 \) events, \( w_{\text{max}}^{\epsilon} \) can be used as an input for the next MC run.

### 2.1.6 Debug facility

The \( \text{TFoam} \) class includes method \( \text{CheckAll} \) for the debugging purposes. It checks the correctness of the pointers in the doubly linked tree of cells (this can take time for large \( N_c \)). Another debugging method \( \text{PrintCells} \) can be used at any stage of the calculation in order to print the list of all cells.

### 2.2 TFoamCell class

The \( \text{TFoamCell} \) class contains data and methods relevant to a single cell object. Data members of the class are listed in Table 5. In comparison with \( \text{FOAM} \) the number of data members is significantly reduced. Most of the methods of the \( \text{TFoamCell} \) class are setters and getters. The non-trivial methods are \( \text{GetHcub} \) and \( \text{GetHSize} \), which calculate the absolute position and size of hyperrectangles, and \( \text{CalcVolume} \), which calculates the Cartesian volume of the cell.

\(^3\)The \( \epsilon \)-dependent maximum weight is defined such that events with \( w > w_{\text{max}}^{\epsilon} \) contribute an \( \epsilon \)-fraction to the total integral. It is numerically more stable in the numerical evaluation than the one defined as the largest weight in the MC run.
| T FoamCell member | Short description |
|------------------|------------------|
| Short_t fDim     | “Static” member, the same for all cells! |
|                  | Dimension of integration space |
|                  | Linked tree organization |
| Int_t fSerial    | Serial number (index in fCells from T Foam class) |
| Int_t fStatus    | Status (active or inactive) |
| TRef fParent     | Pointer to parent cell |
| TRef fDaught0    | Pointer to daughter 1 |
| TRef fDaught1    | Pointer to daughter 2 |
|                  | The best split geometry from the MC exploration |
| Double_t fXdiv   | Factor $x$ of the cell split |
| Int_t fBest      | The best edge candidate for the cell split |
|                  | Integrals of all kinds |
| Double_t fVolume | Cartesian volume of this cell |
| Double_t fIntegral | Integral over cell (estimate from exploration) |
| Double_t fDrive  | Driver integral $R_{loss}$ for cell build-up |
| Double_t fPrimary | Primary integral $R'$ for MC generation |

Table 5: Data members of the T FoamCell class.

The linked tree structure of T FoamCell objects was not properly treated by the ROOT automatic streamers, hence in the previous version of FOAM the persistency has been achieved with the help of some workarounds – namely pointers to cells in the linked list of cells were replaced in FOAM by the integer indexes\textsuperscript{4}. In mFOAM we go back to the pointers, but instead of the raw C++ pointers we employ objects of the special class of persistent pointers T Ref of ROOT. This solution works very well, and as a consequence the method LinkCells\textsuperscript{5} from T FOAM class became obsolete. However, in the present implementation the memory consumption is increased with respect to indexing using integers; one cell now occupies 116 bytes of memory, simply because objects of the T Ref class are composite objects.

2.3 TRandom – ROOT’s collection of random-number generators

The full version 2.05 of FOAM uses its own internal random-number generator called RANMAR \textsuperscript{[10]}. In mFOAM it is replaced by the TRandom class interfacing to ROOT’s internal library of the three random-number generators. Two of them are rather simple generators, and we do not recommend their use in any serious applications. We recommend to use its Mersenne Twister generator TRandom3, which has huge period $2^{19937} - 1$ and generally very good quality \textsuperscript{[11]}. At the present moment the TRandom package does not include any random-number generator with the perfect (controllable) “randomness”, such as RANLUX \textsuperscript{[12] \textsuperscript{[13]}},

\textsuperscript{4}This workaround will be unnecessary after certain bugs have been corrected in the future implementation of the ROOT streamers.

\textsuperscript{5}LinkCells and integer pointers in the T FoamCell class were introduced in FOAM as a “workaround” solution for certain problems with persistency of pointers in ROOT. It is still implemented in FOAM as a void function in for the purpose of the backward compatibility in the user applications.
which is necessary for certain applications\(^6\). Generally, we have decided to use \texttt{TRandom}, because it meets our set of the minimal requirements for the library of random-number generators, which can be characterized as follows:

- Possibility to set (and reset) initial “seed” in the form of just one integer.
- Availability of a method generating single uniform random number.
- Presence of a method generating series of uniform random numbers in a single call.
- Possibility to record (disk-write) the complete status of the random-number generator and restart it using this record. (This, of course, is assured by the persistency mechanism of the ROOT.)

An advanced user of ROOT can also easily add his favourite random-number generator with the same standardized interface (using inheritance from \texttt{TRandom}).

The use of \texttt{TRandom} is rather simple. As an example lets us show the following line of code:

\begin{verbatim}
TRandom *PseRan = new TRandom3(4357); // Create random number generator
\end{verbatim}

which creates an instance of Mersenne Twister generator with the seed = 4357. Note that the \texttt{TRandom} class includes many “utility methods”, however, only a small subset of them are used in \texttt{mFOAM}. For the detailed description of the \texttt{TRandom} class we refer the interested reader to the online ROOT documentation.

How to use a single \texttt{TRandom} object for serving several objects of the \texttt{TFoam} class is described in Section 4.2.

3 Configuring \texttt{mFOAM}

At present \texttt{mFOAM} has \textit{nine principal configuration parameters}. In addition, the user may optionally (re)define certain internal configuration parameters of \texttt{mFOAM} in order to inhibit and/or predetermine the division geometry in the cell split. All of the nine principal parameters are listed in Table 6. They control all essential features of the program and are preset to some meaningful default values, appropriate for the generation of unweighted events. The new inexperienced user of \texttt{mFOAM} usually does not need to reset them. The only exception is the dimension of integration space \texttt{kDim}. It is mandatory to set \texttt{kDim} to a non-zero integer value before invoking \texttt{Initialize}.

In comparison with \texttt{FOAM-2.05} two steering parameters were completely removed: \texttt{nDim}, \texttt{OptOrd}, as relevant only for simplical cells. The other three are hidden from the users eyes, because their usefulness is rather limited. Functionality of the program was frozen for the following choice: \texttt{OptPeek=0}, \texttt{OptEdge=0} and \texttt{OptMCell=1}. Finally, the default value of another optional input parameter \texttt{OptRej} switch is now set to 1 (weight = 1 events), instead of 0.

\(^6\)However, the authors of ROOT are planning to include RANLUX in the near future.
Table 6: Nine principal configuration parameters and switches of the mFOAM program. The default values are marked with the superscript star.

If the user wants to redefine configuration parameters according to his needs, then the relevant piece of code will look as follows:

```cpp
FoamX->SetkDim(kDim);  
FoamX->SetnCells(nCells);  
FoamX->SetnSampl(nSampl);  
FoamX->SetnBin(nBin);  
FoamX->SetOptRej(OptRej);  
FoamX->SetOptDrive(OptDrive);  
FoamX->SetEvPerBin(EvPerBin);  
FoamX->SetMaxWtRej(MaxWtRej);  
FoamX->SetChat(Chat);  
```

The user of mFOAM can decide to inhibit the division in some variables. This can be done with the method `SetInhiDiv(Int t iDim, Int t InhiDiv)` of the class TFoam, where `iDim` is the index of the variable for which the inhibition is done and `InhiDiv` is the inhibition switch. This method should be used before invoking `Initialize`, after setting `kDim`. The relevant code may look as follows:

```cpp
FoamX->SetInhiDiv(0, 1); //Inhibit division of x_1  
FoamX->SetInhiDiv(1, 1); //Inhibit division of x_2  
```

The allowed values are `InhiDiv=0,1` and the default value is `InhiDiv=0`. Note that the numbering of integration variables with the index `iDim` starts from zero. The inhibited variables are generated uniformly.

The user may also predefine divisions of the root cell in certain variables using the method `SetXdivPRD(Int t iDim, Int t len, Double t xDiv[])`. The relevant piece of the user code may look as follows:
Double_t xDiv[3];
xDiv[0]=0.30; xDiv[1]=0.40; xDiv[2]=0.65;
FoamX-&SetXdivPRD(0, 3, xDiv);

Again, this should be done before invoking Initialize, after setting kDim.

4 Usage of the mFOAM package

To begin work with the mFOAM package, a user should have basic knowledge of ROOT and the CINT interpreter. Very good documentation of ROOT is available. At this moment mFOAM is already included in the ROOT standard distribution (beginning from version 4.04). The ROOT package can be obtained from ROOT’s web page. Precompiled binaries are also available as tar archive files for many major platforms: PC computers with both Linux and MS Windows systems and workstations under UNIX. All supported operating systems can be found on ROOT’s home page. The installation process is straightforward and on most UNIX-like systems amounts to unpacking the tarball file and setting environment variables: ROOTSYS, which should point to the ROOT main directory and LD_LIBRARY_PATH locating ROOT libraries.

We strongly recommend to use binaries, which exactly match the user operating system. If precompiled binaries for user system are not available, then a direct installation from source code is necessary. Source code can be obtained as a tarball or through the CVS repository. A detailed description of the configuration and compilation of the ROOT package is beyond the scope of this article. Therefore we refer the interested user to ROOT’s online documentation.

After successful installation, the shared library libFoam.so is present in the $ROOTSYS/lib directory. This library can be loaded directly to ROOT by issuing the following command from CINT command line:

```
root [] .L $ROOTSYS/lib/libFoam.so
```

From now on, the user will get an access to all mFOAM classes while interpreting/executing C++ scripts/programs under the CINT interpreter of ROOT, or simply working interactively from the command line.

4.1 Demonstration programs

The user application program can be compiled/run using one of the following three methods:

1. The user program is interpreted by CINT of ROOT. This simple method might be too slow in execution and will inhibit the use of the persistency of the mFOAM class.

---

7 See [http://root.cern.ch](http://root.cern.ch) for more information.
8 Explicit loading of the mFOAM library is really needed in rare cases, when valid system.rootmap file was not created after the compilation of source code with the help of make map command.
2. The user program is compiled/linked in flight employing the Automatic Compiler of Libraries (ACLiC) facility of CINT. This automatizes the process of compilation and linking and the persistency of the mFOAM class is available. It is the preferred mode of work for medium and small-size applications.

3. Standard compile-link-run method. This method is well suited for large MC projects, which are run in the batch mode.

We tried to provide the user with examples of all possible compile/run methods. Demonstration scripts in the $ROOTSYS/tutorials directory cover the first two methods and show the basic features of mFOAM. In addition there is a collection of simple programs showing how to build and run stand-alone applications. They are distributed as a mFoam-examples-1.2.tar file which is available from the authors web page.

4.1.1 Examples in $ROOTSYS/tutorials directory

Let us now describe in more detail some demonstration scripts in the tutorials subdirectory of the ROOT distribution directory. There are 3 demonstration programs there.

The first of them, foam_demo.C, demonstrates the full power of the mFOAM compiled by ACLiC facility (scenario 2 above), showing all essential phases of its usage: initialization, the setting up of random-number generator a the distribution to be generated/integrated. The examples of setting up optional input parameters are also shown. Finally, MC generation and getting the value of the integral and other parameters after MC generation are also demonstrated. This example is a slightly modified version of the analogous program in the FOAM distribution [1]. Let us explain the content of the foam_demo.C script. After collection of headers we see the definition of the distribution to be generated/integrated:

```cpp
class TFDISTR: public TFoamIntegrand {
public:
   TFDISTR();
   Double_t Density(Int_t, Double_t *){
      .........................
   }
   ClassDef (TFDISTR,1) //Class of testing functions for FOAM
};
ClassImp(TFDISTR)

TFoamIntegrand *rho= new TFDISTR();
FoamX->SetRho(rho);
```

Class TFDISTR inherits from the abstract class TFoamIntegrand. Note the presence of the ClassImp and ClassDef statements, which tell ROOT to create an automatic streamer for this class.

The subsequent piece of the code creates the objects of the random-number generator, the integrand distribution and the mFOAM object itself:
TRandom *PseRan = new TRandom3(); // Create random number generator
PseRan->SetSeed(4357); // Set seed
TFoamIntegrand *rho= new TFDISTR(); // Create integrand distribution
TFoam *FoamX = new TFoam("FoamX"); // Create MC simulator/generator

Next, some configuration parameters of the TFoam object FoamX are redefined before it is initialized (exploration):

FoamX->SetkDim(kDim); // mandatory!
FoamX->SetnCells(nCells); // optional
FoamX->SetRho(rho); // mandatory!
FoamX->SetPseRan(PseRan) // mandatory!
FoamX->Initialize(); // Initialize MC simulator/generator

At this point the attention should be payed to the fact that just after the exploration phase the object of the mFOAM class is written to file rdemo.root:

TFile RootFile("rdemo.root","RECREATE","histograms");
.............
FoamX->Write("FoamX"); // Writing mFOAM object on the disk
.............
RootFile.Write();
RootFile.Close();

Finally, the series of MC events are generated:

for(loop=0; loop<NevTot; loop++)
{
    FoamX->MakeEvent(); // generate MC event
    FoamX->GetMCvect( MCvect); // get MC point
    MCwt=FoamX->GetMCwt(); // get MC weight
    ..........
}

The code ends up with the printouts of the value of the integral over PDF and some other statistics concerning the MC run. The user is invited to manipulate the configuration parameters of mFOAM. In particular we recommend to switch to weighted events (OptRej=0) and change the number of cells nCells in the initialization.

The foam_demo.C program is compiled, linked and executed from the CINT shell by issuing the following commands:

$ root
root [0] .L ./lib/libFoam.so
root [1] .x foam_demo.C+
Note that the suffix “+” instructs CINT to use the Automatic Compiler of Libraries (ACLIc) facility. In such a case the process of compilation and linking is completely automatized. During the compilation phase the shared library foam_demo.C.so is created, which contains the definition of the TFDISTR class, together with its automatic streamers. This is exactly what we need for testing persistency. In the stand-alone application the class of the PDF would have to be directly compiled and put in the shared library for further use. Here it is done in a simplified way.

The second small program, foam_demopers.C, demonstrates the use of the persistency of the mFOAM class. It reads the mFOAM object from the disk, checks its consistency, prints out geometry of cells and starts generation of events. It can be interpreted directly by CINT:

$ root
root [0] .x foam_demopers.C

The demo_C.so library, defining the TFDISTR class, is loaded at the run-time with the help of

gROOT->ProcessLine(".L foam_demo.C+")
in the code. The user may verify that the output from it is exactly the same as the analogous output of foam_demo.C. This illustrates the fact that the mFOAM object, the MC simulator, can be dumped into the disk at any moment and it resumes its functioning after reloading it from the disk, as if there was no disk-write and disk-read at all.

The other macro foam_kanwa.C is a simplified shorter version of foam_demo.C, without any unnecessary modification of the configuration parameters of the mFOAM (they are internally set to sensible default values). This macro might be useful for the first-time user of the mFOAM. On the other hand, this program adds a simple example of the graphics using ROOT; the 2-dimensional distribution of the produced MC events is shown dynamically on the screen, as the accumulated MC statistics grows. Notice the use of the TApplication object, in order to stabilize the picture on the screen in the execution. This macro can be executed/interpreted (scenario 1) directly by means of typing:

$ root
root [0] .x foam_kanwa.C

The example output from running foam_kanwa.C is reproduced in the appendix. Simulation will start and then a plot of the distribution function will pop-up on the graphical canvas on the screen. The execution is noticeably slower, as is always the case for the interpreted programs. The main difference with the foam_kanwa.C is in the distribution function, which is now defined simply as a global function Camel2. It is made accessible to the mFOAM object FoamX in the following line of code:

FoamX->SetRhoInt(Camel2);

Another difference is that the shared library of mFOAM is loaded with the following explicit instruction:
gSystem->Load("libFoam.so");

instead of the linking procedure. This instruction is not really needed if ROOT is already aware of the location of the mFOAM library.

In some of the above examples we could not exploit the persistency of the ROOT objects. This is because of the restrictions in CINT, which does not allow an interpreted function to inherit from the TObject class. This is the reason why, in these examples where PDF is the global function, the automatic streamer cannot be generated. Even if one would write the mFOAM object on the disk, the information about the PDF will be lost. Of course, the user may always go back to one of the compilation methods and enjoy full persistency of the mFOAM objects. In addition to better persistency, the compiled applications have the advantage of being significantly faster in the execution.

4.1.2 More advanced examples of the use of mFOAM

Let us now describe in more detail some examples of the use of mFOAM classes in stand-alone applications (scenario 3). It may be of interest to more advanced users, who plan to use mFOAM as part of their large-scale Monte Carlo projects. It is assumed that ROOT is installed and the environment variable ROOTSYS is properly set.

After unpacking the distribution file mFoam-examples-1.2.tar one should execute the configure script:

```
$ cd mFoam-examples-1.2
$ ./configure
```

which inspects the system configuration and looks up for the ROOT library, then generates the Makefile file. Version 4.04 of ROOT or later is required. The configure script can fail for many reasons. In that case the user should first check if the ROOTSYS environment variable indeed points to ROOT installation location. The default behaviour of the configure script can be changed by additional command line parameters and environment variables. It may be useful if the computer is equipped with a compiler other than gcc. A full list of available options is displayed by the ‘configure -h’ command.

The configure script and the accompanying configuration files were generated\(^9\) using automake tools version 1.91. In case the user wants to re-create the configure script and the accompanying files, version 1.61 or later of automake is needed.

To compile and link these codes one should type the following:

```
$ make
$ make install
```

We have successfully tested the installation of mFOAM-examples on computers with several variants of the Linux operating system: CERN Scientific Linux SLC3, Red Hat Linux 7.3, Fedora Linux FC3. The code is highly portable and we think that it should compile without

\(^9\)The distribution directory with the configure script was created with the command sequence (autoreconf -i; ./configure; make dist), activating the directive AM_MAINTAINER_MODE in config.in.
any problems on all other systems supported by ROOT developers. In rare case, certain
minor modifications of the source code may be necessary.

After successful compilation one can run demonstration programs with the following
commands:

```
make kanwa
make demo
make testpers
```

The content and functionality of the programs `demo.cxx` and `kanwa.cxx` are the same
as those of their macro counterparts `foam_demo.C` and `foam_kanwa.C` described above. The
code of these programs can serve as a useful template for the user applications.

The command `make testpers` runs an advanced test of persistency with two generator
objects served by one central random generator. In this example two classes of MC event
generators `TGenMC` and `TGenMC2` are defined and the corresponding library `libTGenMC.so`
is created. An object of each MC event generator uses one own object of `mFOAM` class and one
external object of the class `TRandom` – the central RNG.

In the program `Main.cxx`, two objects of the class `TGenMC` and `TGenMC2` are created. Also
a single central RNG object is allocated and made available to both MC generators. All
three objects are written into a disk file and used to generate 200k MC events, using each of
the two MC generators.

The other program `MainW.cxx` reads all three objects from the disk file, reassigns the
central RNG to `mFOAM` objects inside the two MC event generators; again, 200k MC events
are generated, using each of the two MC generators. Since the disk-write in `Main` was done
after initialization and before MC generation, the MC series of the events from `MainW` should
be the same as from `Main`. This is checked by “diffing” two files which record first 15 events
from `Main` and `MainW` correspondingly. We find that their content is identical, and this
provides an empirical proof that this complicated setup of the two MC event generators
using two `mFOAM` objects and single central RNG is surviving the disk-write and disk-read
operations without any loss of its functionality.

The compile–link–execute chain for the tandem of `Main` and `MainW` programs and “diffing”
output files is realized by the single command ‘`make testpers`’.

The above example of organization with the single central RNG is well suited for any
large Monte Carlo projects with many `mFOAM` objects and many Monte Carlo sub-generators
served by the single central RNG.

The other interesting feature of the above examples is the implementation of the PDF
as the `Density` method of the `TGenMC2` class. In our example the `TGenMC2` class inherits
from `TFoamIntegrand`. Consequently, the `Density` function is provided to the `mFOAM`
object (which is the member of the `TGenMC2` class) as `this`. In the other MC generator of the class
`TGenMC`, the PDF is defined in an object of the separate class `TFDISTR` and the PDF of this
class is allocated and its pointer is assigned to the `mFOAM` object in the `TGenMC` object during
its initialization.

The above test demonstrates a few fairly complicated examples of how to organize the
relation between several `mFOAM` objects, RNGs and PDFs within the MC project. However,
it does not cover all possible situations. In the next section we shall discuss this issue in a general case and we shall argue that object of the mFOAM class are able to cope with all possible scenarios in an efficient and transparent way.

4.2 External RNG and PDF objects and the implementation of persistency

Persistency is undoubtedly a very valuable feature of the objects of the class TFoam, and of ROOT objects in general. It is therefore worthwhile to clarify certain features of its implementation, which the user should know and consider before attempting to exploit the persistency of mFOAM objects in any advanced/sophisticated applications.

As we have seen in the explicit examples of the previous section, the critical issue in this context is the treatment of the two external objects, which every given object of the class TFoam needs in order to function properly: the object of random number generator (RNG) and the object providing the probability distribution function (PDF). These two objects have to be provided to the object of the class TFoam. In the previous section, we have shown most typical case, when one deals with only one instance (object) of the above classes – this was quite straightforward to organize.

In more advanced applications we have to be prepared to deal with the situations in which we deal with many (hundreds) of objects of the class TFoam, all of them using single central RNG object (or a few of them) and possibly generating many different PDFs. In this case if one wants to profit fully from the persistency, such a complicated set of interrelated objects of the three types has to emerge fully operational after the disk-write and disk-read operations. This turns out to be a nontrivial task to realize in practice.

We claim that the way we interface an object of the class TFoam with the two “satellite” RNG and PDF objects of the TRandom and T FoamIntegrand classes allows us to deal with any arbitrarily complicated set of interrelated object, while correctly implementing the persistency in all such situations.

First of all, the two external objects, RNG and PDF, are external in this sense that the new operator allocating them is placed outside the TFoam code and the object of the class TFoam knows only their pointers. Hence, the important question related to the persistency implementation using ROOT (the problem is however more general) can be immediately formulated: Whose responsibility is to re-create these two objects in the process of the disk-read? First possible solution is that this task is handled by the automatic streamer of the object of the class TFoam, which would re-create the objects RNG and PDF\textsuperscript{10}. Their actual pointer should then be exported to any other objects, which need legitimately an access to them. This second possibility is to inhibit the re-creation of the objects RNG and PDF by the streamers of the class TFoam. ROOT allows this to be done\textsuperscript{11}. In the latter case it would be the sole responsibility of the user to store the two external objects RNG and PDF into

\textsuperscript{10}With the help of their own streamers.

\textsuperscript{11}It is done by means of adding the comment `\\!' at the end of the line in which the pointer to an object is defined.
disk separately, read them separately, and provide their pointers to the object of the class T Foam after the disk-read operation.

The first option looks attractive because of its simplicity. It is definitely an optimal one in the most common case of just three objects – hence we would like to implement this scenario as the basic one. However, this solution will fail when several objects of the T Foam class are served by the single RNG object, a quite common case in any bigger MC projects. In this case, the disk-read operation (done by ROOT streamers) will clone many independent identical RNG objects, each one for every object of the class T Foam. This is clearly undesirable.

The situation with a set of several PDF objects serving one or more T Foam objects is even more subtle. On the one hand, one may argue that since the distribution of a given PDF object is essentially memorized inside a given T Foam object, a genuine one-to-one association among them should be maintained. Hence, the PDF object should be “owned” by the T Foam object, during the disk-write and disk-read, as in the first scenario. On the other hand, we shall sometimes deal with the situations with a single PDF object serving several T Foam objects; either because it needs huge memory, or it is very slow in execution (its execution is a two-step process), or it is not a genuine C++ object, but rather a “wrapper” to another non-OOP (Fortran) program. In such a case it is better to handle PDF objects outside the T Foam object, as in the second scenario. Summarizing, the treatment of the RNG and PDF objects should be quite similar, and the possibility of keeping/controlling both of them outside the T Foam object should be optionally available. In other words, we would ideally need both above solution for both RNG and PDF objects: The first solutions, for simple applications and the second one for advanced applications.

The actual method of handling the RNG and PDF external objects in the T Foam class allows the user to implement both above scenarios. It is done in the following way: the RNG and PDF objects are always created for the first time outside the T Foam object, as already described. Their pointers are transferred into the T Foam object as the arguments of Initialize(RNG,PDF). Alternatively it is done with the help of the two dedicated setters SetPseRan(RNG) and SetRho(PDF), before invoking Initialize(). At first sight, it seems that we follow the first solution, especially that we do not inhibit the re-creation of the “private copy” of the objects RNG and PDF by the T Foam object (by its streamer) during the disk-read. Indeed the first solution is available in this way. Restricting the discussion to RNG objects, the second scenario can be implemented as follows: first, disk-write and disk-read of the RNG object is done by the user, then, after the disk-read of all T Foam objects, the pointers of the RNG object inside T Foam objects are reassigned to the RNG object, using a dedicated setter method, see also the examples of section 4.1.2. In order to avoid a memory leak, the setter which is used to reassign the pointer to external RNG has to destroy the existing “ghost” RNG object, which has been unnecessarily created during the disk-read operation of every T Foam object. The method ResetPseRan(RNG) is introduced exactly for this purpose. The analogous setter method of destroying the existing PDF object and reassigning its pointer is the method ResetRho(PDF) of the T Foam class. Obviously, the RNG and PDF objects are treated in the same way.

The above solution is efficient, transparent and useful in almost all cases. It will not be
satisfactory in the case where creating and destroying a PDF object takes an extremely long time and/or huge memory (no such problem with the RNG objects). In such a case a simple modification of the source code of the TFoam class (inhibiting the storage of the PDF object) will be a more economic solution; however, it requires recompiling the TFoam library.

5 Conclusions

We present all users of the FOAM package with its new version mFOAM. We have payed special attention to making it more user-friendly, so that it provides with less effort solutions of many every-day problems in the MC simulation. This may, hopefully, attract new users, especially those who already use ROOT in their work. We also hope for feedback from them, to be used in the further improvements in the user interface to both FOAM and mFOAM.

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A APPENDIX

The code of the example macro foam\_kanwa.C looks like:

```cpp
//
// This program can be executed from the command line:
//
// root -l foam\_kanwa.C
//
_____________________________________________________________________________

Int_t kanwa(){
  cout<<"--- kanwa started ---"<<endl;
  gSystem->Load("libFoam.so");
  TH2D *hst\_xy = new TH2D("hst\_xy" , "x-y plot", 50,0,1.0, 50,0,1.0);
  Double_t *MCvect = new Double_t[2]; // 2-dim vector generated in the MC run
  TRandom *PseRan = new TRandom3(); // Create random number generator
  PseRan->SetSeed(4357); // Set seed
  TFoam *FoamX = new TFoam("FoamX"); // Create Simulator
  FoamX->SetDim(2); // No. of dimensions, obligatory!
  FoamX->SetCells(500); // No. of cells, can be omitted, default=2000
  FoamX->SetRhoInt(Camel2); // Set 2-dim distribution, included below
  FoamX->SetPseRan(PseRan); // Set random number generator
  FoamX->Initialize(); // Initialize simulator, may take time...
  // From now on FoamX is ready to generate events according to Camel2(x,y)
  for(Long_t loop=0; loop<100000; loop++){
    FoamX->MakeEvent(); // generate MC event
    FoamX->GetMCvect( MCvect); // get generated vector (x,y)
    Double_t x=MCvect[0];
    Double_t y=MCvect[1];
    if(loop<10) cout<<"(x,y) = ( \"<< x <<\", \"<< y <<\")"<<endl;
    hst\_xy->Fill(x,y);
  } // loop
  Double_t MCresult, MCerror;
  FoamX->GetIntegMC( MCresult, MCerror); // get MC integral, should be one
  cout " MCresult= " MCresult << " +- " MCerror <<endl;
  // now hst\_xy will be plotted, visualizing generated distribution
  TCanvas *cKanwa = new TCanvas(\"cKanwa\",\"Canvas for plotting\",600,600);
  cKanwa->cd();
  hst\_xy->Draw(\"lego2\"); // From now on FoamX is ready to generate events according to Camel2(x,y)
  cout<<"--- kanwa ended ---"<<endl;
}
//kanwa
_____________________________________________________________________________

Double_t sqr(Double_t x){return x*x;};
Double_t Camel2(Int_t nDim, Double_t *Xarg){
 // 2-dimensional distribution for Foam, normalized to one (within 1e-5)
  Double_t x=Xarg[0];
  Double_t y=Xarg[1];
  Double_t GamSq= sqr(0.100e0);
  Double_t Dist= 0;
  Dist +=exp(-sqr(x-1./3) +sqr(y-1./3))/GamSq/GamSq/TMath::Pi();
  Dist +=exp(-sqr(x-2./3) +sqr(y-2./3))/GamSq/GamSq/TMath::Pi();
  return 0.5*Dist;
}
// Camel2
_____________________________________________________________________________
```

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Macro \texttt{foam\_kanwa.C} produces the following output:

--- kanwa started ---

| Description          | Value                      |
|----------------------|----------------------------|
| Version              | 1.02M                      |
| kDim                 | 2                          |
| nCells               | 500                        |
| nSamp1               | 200                        |
| nBin                 | 8                          |
| EvPerBin             | 25                         |
| OptDrive             | 2                          |
| OptRej               | 1                          |
| MaxWtRej             | 1.1                        |
| XPrime               | 1.3922344                  |
| XDiver               | 0.39314276                 |
| MCresult             | 0.99909163                 |
| (x,y)                | (0.26506687, 0.37983892)    |
| (x,y)                | (0.65874831, 0.76719268)    |
| (x,y)                | (0.6405293, 0.73329734)     |
| (x,y)                | (0.29933616, 0.37537068)    |
| (x,y)                | (0.31228105, 0.39614503)    |
| (x,y)                | (0.71258758, 0.64969589)    |
| (x,y)                | (0.34830539, 0.38099167)    |
| (x,y)                | (0.26990382, 0.42078097)    |
| (x,y)                | (0.35661486, 0.41847364)    |
| (x,y)                | (0.5557375, 0.62757837)     |
| MCresult=            | 1.0004446 +0.00080837425   |

--- kanwa ended ---
In addition the same script `foam_kanwa.C` produces the following plot (canvas), which pops up on the screen.