Geant4 User's Documents
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Geant4 User's Guide

- For Application Developers -

1. Introduction

1.1 Scope of this manual

The User's Guide for Application Developers is the first manual the reader should consult when learning about Geant4 or developing a Geant4-based detector simulation program. This manual is designed to:

- introduce the first-time user to the Geant4 object-oriented detector simulation toolkit,
- provide a description of the available tools and how to use them, and
- supply the practical information required to develop and run simulation applications which may be used in real experiments.

This manual is intended to be an overview of the toolkit, rather than an exhaustive treatment of it. Related physics discussions are not included unless required for the description of a particular tool. Detailed discussions of the physics included in Geant4 can be found in the Physics Reference Manual. Details of the design and functionality of the Geant4 classes can be found in the User's Guide for Toolkit Developers, and a complete list of all Geant4 classes is given in the Software Reference Manual.

Geant4 is a completely new detector simulation toolkit written in the C++ language. The reader is assumed to have a basic knowledge of object-oriented programming using C++. No knowledge of earlier FORTRAN versions of Geant is required. Although Geant4 is a fairly complicated software system, only a relatively small part of it needs to be understood in order to begin developing detector simulation applications.

1.2 How to use this manual

A very basic introduction to Geant4 is presented in **Chapter 2, "Getting Started with Geant4 - Running a Simple Example"**. It is a recipe for writing and running a simple Geant4 application program. New users of Geant4 should read this chapter first. It is strongly recommended that this chapter be read in conjunction with a Geant4 system installed and running on your computer. It is helpful to run the provided examples as they are discussed in the manual. To install the Geant4 system on your computer, please refer to the Installation Guide for Setting up Geant4 in Your Computing Environment.

Chapter 3, "Toolkit Fundamentals" discusses general Geant4 issues such as class categories and the physical units system. It goes on to discuss runs and events, which are the basic units of a simulation.

Chapter 4, "Detector Definition and Response" describes how to construct a detector from customized materials and geometric shapes, and embed it in electromagnetic fields. It also describes how to make the detector sensitive to particles passing through it and how to store this information.

How particles are propagated through a material is treated in **Chapter 5, "Tracking and Physics"**. The Geant4 "philosophy" of particle tracking is presented along with summaries of the physics processes provided by the toolkit. The definition and implementation of Geant4 particles is discussed and a list of particle properties is provided.

Chapter 6, "User Actions" is a description of the "user hooks" by which the simulation code may be customized to perform special tasks.

Chapter 7, "Communication and Control" provides a summary of the commands available to the user to control the execution of the simulation. After Chapter 2, Chapters 6 and 7 are of formeost importance to the new application developer.

The display of detector geometry, tracks and events may be incorporated into a simulation application by using the tools described in **Chapter 8, "Visualization"**.

Chapter 9, "Examples" provides a set of novice and advanced simulation codes which may be compiled and run "as is" from the Geant4 source code. These examples may be used as educational tools or as base code from which more complex applications are developed.

About the authors

2. Getting Started with Geant4 - Running a Simple Example

2.1 How to Define the main() Program

2.1.1 A Sample `main()` Method

The contents of `main()` will vary according to the needs of a given simulation application and therefore must be supplied by the user. The Geant4 toolkit does not provide a `main()` method, but a sample is provided here as a guide to the beginning user. Source listing 2.1.1 is the simplest example of `main()` required to build a simulation program.

```
#include "G4RunManager.hh"
#include "G4UImanager.hh"

#include "ExN01DetectorConstruction.hh"
#include "ExN01PhysicsList.hh"
#include "ExN01PrimaryGeneratorAction.hh"

int main()
{
  // construct the default run manager
  G4RunManager* runManager = new G4RunManager;

  // set mandatory initialization classes
  runManager->SetUserInitialization(new ExN01DetectorConstruction);
  runManager->SetUserInitialization(new ExN01PhysicsList);

  // set mandatory user action class
  runManager->SetUserAction(new ExN01PrimaryGeneratorAction);

  // initialize G4 kernel
  runManager->initialize();

  // get the pointer to the UI manager and set verbosities
  G4UImanager* UI = G4UImanager::GetUIpointer();
  UI->ApplyCommand("/run/verbose 1");
  UI->ApplyCommand("/event/verbose 1");
  UI->ApplyCommand("/tracking/verbose 1");

  // start a run
  int numberOfEvent = 3;
  runManager->BeamOn(numberOfEvent);

  // job termination
  delete runManager;
  return 0;
}
```

Source listing 2.1.1

The `main()` method is implemented by two toolkit classes, *G4RunManager* and *G4UImanager*, and three classes, *ExN01DetectorConstruction*, *ExN01PhysicsList* and *ExN01PrimaryGeneratorAction*, which are derived from toolkit classes. Each of these are explained in the following sections.

2.1.2 *G4RunManager*

The first thing `main()` must do is create an instance of the *G4RunManager* class. This is the only manager class in the Geant4 kernel which should be explicitly constructed in the user's `main()`. It controls the flow of the program and manages the event loop(s) within a run. When *G4RunManager* is created, the other major manager classes are also created. They are deleted automatically when *G4RunManager* is deleted. The run manager is also responsible for managing initialization procedures, including methods in the user initialization classes. Through these the run manager must be given all the information necessary to build and run the simulation, including

1. how the detector should be constructed,
2. all the particles and all the physics processes to be simulated,
3. how the primary particle(s) in an event should be produced and
4. any additional requirements of the simulation.

In the sample `main()` the lines

```
    runManager->SetUserInitialization(new ExN01DetectorConstruction);
    runManager->SetUserInitialization(new ExN01PhysicsList);
```

create objects which specify the detector geometry and physics processes, respectively, and pass their pointers to the run manager. *ExN01DetectorConstruction* is an example of a user initialization class which is derived from *G4VUserDetectorConstruction*. This is where the user describes the entire detector setup, including

- its geometry,
- the materials used in its construction,
- a definition of its sensitive regions and
- the readout schemes of the sensitive regions.

Similarly *ExN01PhysicsList* is derived from *G4VUserPhysicsList* and requires the user to define

- the particles to be used in the simulation,
- the range cuts for these particles and
- all the physics processes to be simulated.

The next instruction in `main()`

```
    runManager->SetUserAction(new ExN01PrimaryGeneratorAction);
```

creates an instance of a particle generator and passes its pointer to the run manager. *ExN01PrimaryGeneratorAction* is an example of a user action class which is derived from *G4VUserPrimaryGeneratorAction*. In this class the user must describe the initial state of the primary event. This class has a public virtual method named `generatePrimaries()` which will be invoked at the beginning of each event. Details will be given in Section 2.6. Note that Geant4 does not provide any default behavior for generating a primary event.

The next instruction

```
    runManager->initialize();
```

performs the detector construction, creates the physics processes, calculates cross sections and otherwise sets up the run. The final run manager method in `main()`

```
    int numberOfEvent = 3;
    runManager->beamOn(numberOfEvent);
```

begins a run of three sequentially processed events. The `beamOn()` method may be invoked any number of times within `main()` with each invocation representing a separate run. Once a run has begun neither the detector setup nor the physics processes may be changed. They may be changed between runs, however, as described in Section 3.4.4. More information on *G4RunManager* in general is found in Section 3.4.

As mentioned above, other manager classes are created when the run manager is created. One of these is the user interface manager, *G4UImanager*. In `main()` a pointer to the interface manager must be obtained

```
      G4UImanager* UI = G4UImanager::getUIpointer();
```

in order for the user to issue commands to the program. In the present example the `applyCommand()` method is called three times to direct the program to print out information at the run, event and tracking levels of simulation. A wide range of commands is available which allows the user detailed control of the simulation. A list of these commands can be found in Section 7.1.

2.1.3 User Initialization and Action Classes

Mandatory User Classes

There are three classes which must be defined by the user. Two of them are user initialization classes, and the other is a user action class. They must be derived from the abstract base classes provided by Geant4: *G4VUserDetectorConstruction, G4VuserPhysicsList*

and *G4VuserPrimaryGeneratorAction*. Geant4 does not provide default behavior for these classes. *G4RunManager* checks for the existence of these mandatory classes when the `initialize()` and `BeamOn()` methods are invoked.

As mentioned in the previous section, *G4VUserDetectorConstruction* requires the user to define the detector and *G4VUserPhysicsList* requires the user to define the physics. Detector definition will be discussed in Sections 2.2 and 2.3. Physics definition will be discussed in Sections 2.4 and 2.5. The user action class *G4VuserPrimaryGeneratorAction* requires that the initial event state be defined. Primary event generation will be discussed in Section 2.6.

Optional User Action Classes

Geant4 provides five user hook classes:

- *G4UserRunAction*
- *G4UserEventAction*
- *G4UserStackingAction*
- *G4UserTrackingAction*
- *G4UserSteppingAction*

There are several virtual methods in each of these classes which allow the specification of additional procedures at all levels of the simulation application. Details of the user initialization and action classes are provided in Section 6.

2.1.4. *G4UImanager* and UI Command Submission

Geant4 provides a category named **intercoms**. *G4UImanager* is the manager class of this category. Using the functionalities of this category, you can invoke **set** methods of class objects of which you do not know the pointer. In Source listing 2.1.1, the verbosities of various Geant4 manager classes are set. Detailed mechanism description and usage of **intercoms** will be given in the next chapter, with a list of available commands. Command submission can be done all through the application.

```
#include "G4RunManager.hh"
#include "G4UImanager.hh"
#include "G4UIterminal.hh"

#include "N02VisManager.hh"
#include "N02DetectorConstruction.hh"
#include "N02PhysicsList.hh"
#include "N02PrimaryGeneratorAction.hh"
#include "N02RunAction.hh"
#include "N02EventAction.hh"
#include "N02SteppingAction.hh"

#include "g4templates.hh"

int main(int argc,char** argv)
{
  // construct the default run manager
  G4RunManager * runManager = new G4RunManager;

  // set mandatory initialization classes
  N02DetectorConstruction* detector = new N02DetectorConstruction;
  runManager->SetUserInitialization(detector);
  runManager->SetUserInitialization(new N02PhysicsList);

  // visualization manager
  G4VisManager* visManager = new N02VisManager;
  visManager->initialize();

  // set user action classes
  runManager->SetUserAction(new N02PrimaryGeneratorAction(detector));
  runManager->SetUserAction(new N02RunAction);
  runManager->SetUserAction(new N02EventAction);
  runManager->SetUserAction(new N02SteppingAction);

  // get the pointer to the User Interface manager
  G4UImanager* UI = G4UImanager::GetUIpointer();

  if(argc==1)
  // Define (G)UI terminal for interactive mode
  {
    G4UIsession * session = new G4UIterminal;
    UI->ApplyCommand("/control/execute prerun.g4mac");
    session->sessionStart();
    delete session;
  }
  else
  // Batch mode
  {
    G4String command = "/control/execute ";
    G4String fileName = argv[1];
    UI->ApplyCommand(command+fileName);
  }

  // job termination
  delete visManager;
  delete runManager;

  return 0;
}
```

Source list 2.1.2
An example of `main()` using interactive terminal and visualization. Code modified from 2.1.1. are shown in blue.

2.1.5 *G4cout* and *G4cerr*

Although not yet included in the above examples, output streams will be needed. *G4cout* and *G4cerr* are **iostream** objects defined by Geant4. The usage of these objects is exactly the same as the ordinary *cout* and *cerr*, except that the output streams will be handled by *G4UImanager*. Thus, output strings may be displayed on another window or stored in a file. Manipulation of these output streams will be described in Section 7.2.4. These objects should be used instead of the ordinary *cout* and *cerr*.

About the authors

2.2 How to Define a Detector Geometry

2.2.1 Basic Concepts

A detector geometry in Geant4 is made of a number of volumes. The largest volume is called the **World** volume. It must contain all other volumes in the detector geometry. The other volumes are created and placed inside previous volumes, included in the World volume.

Each volume is created by describing its shape and its physical characteristics, and then placing it inside a containing volume.

When a volume is placed within another volume, we call the former volume the daughter volume and the latter the mother volume. The coordinate system used to specify where the daughter volume is placed, is the coordinate system of the mother volume.

To describe a volume’s shape, we use the concept of a solid. A solid is a geometrical object that has a shape and specific values for each of that shape’s dimensions. A cube with a side of 10 centimeters and a cylinder of radius 30 cm and length 75 cm are examples of solids.

To describe a volume’s full properties, we use a logical volume. It includes the geometrical properties of the solid, and adds physical characteristics: the material of the volume; whether it contains any sensitive detector elements; the magnetic field; etc.

We have yet to describe how to position the volume. To do this you create a physical volume, which places a copy of the logical volume inside a larger, containing, volume.

2.2.2 Create a Simple Volume

What do you need to do to create a volume?

- Create a solid.
- Create a logical volume, using this solid, and adding other attributes.

2.2.3 Choose a Solid

To create a simple box, you only need to define its name and its extent along each of the Cartesian axes. You can find an example how to do this in Novice Example N01.

In the detector description in the source file `ExN01DetectorConstruction.cc`, you will find the following box definition:

```
  G4double expHall_x = 3.0*m;
  G4double expHall_y = 1.0*m;
  G4double expHall_z = 1.0*m;

  G4Box* experimentalHall_box
     = new G4Box("expHall_box",expHall_x,expHall_y,expHall_z);
```

Source listing 2.2.1
Creating a box.

This creates a box named "expHall_box" with extent from -3.0 meters to +3.0 meters along the X axis, from -1.0 to 1.0 meters in Y, and from -1.0 to 1.0 meters in Z.

It is also very simple to create a cylinder. To do this, you can use the *G4Tubs* class.

```
  G4double innerRadiusOfTheTube = 0.*cm;
  G4double outerRadiusOfTheTube = 60.*cm;
  G4double hightOfTheTube = 50.*cm;
  G4double startAngleOfTheTube = 0.*deg;
  G4double spanningAngleOfTheTube = 360.*deg;

  G4Tubs* tracker_tube
    = new G4Tubs("tracker_tube",
                 innerRadiusOfTheTube,
                 outerRadiusOfTheTube,
                 hightOfTheTube,
                 startAngleOfTheTube,
                 spanningAngleOfTheTube);
```

Source listing 2.2.2
Creating a cylinder.

This creates a full cylinder, named "tracker_tube", of radius 60 centimeters and length 50 cm.

2.2.4 Create a Logical Volume

To create a logical volume, you must start with a solid and a material. So, using the box created above, you can create a simple logical volume filled with argon gas (see materials) by entering:

```
 G4LogicalVolume* experimentalHall_log
    = new G4LogicalVolume(experimentalHall_box,Ar,"expHall_log");
```

This logical volume is named "expHall_log".

Similarly we create a logical volume with the cylindrical solid filled with aluminium

```
  G4LogicalVolume* tracker_log
    = new G4LogicalVolume(tracker_tube,Al,"tracker_log");
```

and named "tracker_log"

2.2.5 Place a Volume

How do you place a volume? You start with a logical volume, and then you decide the already existing volume inside of which to place it. Then you decide where to place its center within that volume, and how to rotate it. Once you have made these decisions, you can create a physical volume, which is the placed instance of the volume, and embodies all of these atributes.

2.2.6 Create a Physical Volume

You create a physical volume starting with your logical volume. A physical volume is simply a placed instance of the logical volume. This instance must be placed inside a mother logical volume. For simplicity it is unrotated:

```
  G4double trackerPos_x = -1.0*meter;
  G4double trackerPos_y =  0.0*meter;
  G4double trackerPos_z =  0.0*meter;

  G4VPhysicalVolume* tracker_phys
    = new G4PVPlacement(0,                         // no rotation
                        G4ThreeVector(trackerPos_x,trackerPos_y,trackerPos_z),
                                                   // translation position
                        tracker_log,               // its logical volume
                        "tracker",                 // its name
                        experimentalHall_log,      // its mother (logical) volume
                        false,                     // no boolean operations
                        0);                        // its copy number
```

Source listing 2.2.3
A simple physical volume.

This places the logical volume `tracker_log` at the origin of the mother volume `experimentalHall_log`, unrotated. The resulting physical volume is named "tracker" and has a copy number of 0.

An exception exists to the rule that a physical volume must be placed inside a mother volume. That exception is for the World volume, which is the largest volume created, and which contains all other volumes. This volume obviously cannot be contained in any other. Instead, it must be created as a *G4PVPlacement* with a null mother pointer. It also must be unrotated, and it must be placed at the origin of the global coordinate system.

Generally, it is best to choose a simple solid as the World volume, and in Example N01, we use the experimental hall:

```
  G4VPhysicalVolume* experimentalHall_phys
      = new G4PVPlacement(0,                       // no rotation
                          G4ThreeVector(0.,0.,0.), // translation position
                          experimentalHall_log,    // its logical volume
                          "expHall",               // its name
                          0,                       // its mother volume
                          false,                   // no boolean operations
                          0);                      // its copy number
```

Source listing 2.2.4
The World volume from Example N01.

2.2.7 Coordinate Systems and Rotations

In Geant4, the rotation matrix associated to a placed physical volume represents the rotation of the reference system of this volume with respect to its mother.

A rotation matrix is normally constructed as in CLHEP, by instantiating the identity matrix and then applying a rotation to it. This is also demonstrated in Example N04.

About the authors

2.3 How to Specify Materials in the Detector

2.3.1 General Considerations

In nature, general materials (chemical compounds, mixtures) are made of elements, and elements are made of isotopes. Therefore, these are the three main classes designed in Geant4. Each of these classes has a table as a static data member, which is for keeping track of the instances created of the respective classes.

The *G4Element* class describes the properties of the atoms:

- atomic number,
- number of nucleons,
- atomic mass,
- shell energy,
- as well as quantities such as cross sections per atom, etc.

The *G4Material* class describes the macroscopic properties of matter:

- density,
- state,
- temperature,
- pressure,
- as well as macroscopic quantities like radiation length, mean free path, dE/dx, etc.

The *G4Material* class is the one which is visible to the rest of the toolkit, and is used by the tracking, the geometry, and the physics. It contains all the information relative to the eventual elements and isotopes of which it is made, at the same time hiding the implementation details.

2.3.2 Define a Simple Material

In the example below, liquid argon is created, by specifying its name, density, mass per mole, and atomic number.

```
  G4double density = 1.390*g/cm3;
  G4double a = 39.95*g/mole;
  G4Material* lAr = new G4Material(name="liquidArgon", z=18., a, density);
```

Source listing 2.3.1
Creating liquid argon.

The pointer to the material, *lAr*, will be used to specify the matter of which a given logical volume is made:

```
  G4LogicalVolume* myLbox = new G4LogicalVolume(aBox,lAr,"Lbox",0,0,0);
```

2.3.3 Define a Molecule

In the example below, the water, *H2O*, is built from its components, by specifying the number of atoms in the molecule.

```
a = 1.01*g/mole;
G4Element* elH  = new G4Element(name="Hydrogen",symbol="H" , z= 1., a);

a = 16.00*g/mole;
G4Element* elO  = new G4Element(name="Oxygen"  ,symbol="O" , z= 8., a);

density = 1.000*g/cm3;
G4Material* H2O = new G4Material(name="Water",density,ncomponents=2);
H2O->AddElement(elH, natoms=2);
H2O->AddElement(elO, natoms=1);
```

Source listing 2.3.2
Creating water by defining its molecular components.

2.3.4 Define a Mixture by Fractional Mass

In the example below, air is built from nitrogen and oxygen, by giving the fractional mass of each component.

```
a = 14.01*g/mole;
G4Element* elN  = new G4Element(name="Nitrogen",symbol="N" , z= 7., a);

a = 16.00*g/mole;
G4Element* elO  = new G4Element(name="Oxygen"  ,symbol="O" , z= 8., a);

density = 1.290*mg/cm3;
G4Material* Air = new G4Material(name="Air  ",density,ncomponents=2);
Air->AddElement(elN, fractionmass=70*perCent);
Air->AddElement(elO, fractionmass=30*perCent);
```

Source listing 2.3.3
Creating air by defining the fractional mass of its components.

2.3.5 Print Material Information

```
G4cout << H2O;                                \\ print a given material
G4cout << *(G4Material::GetMaterialTable());  \\ print the list of materials
```

Source listing 2.3.4
Printing information about materials.

In `examples/novice/N03/N03DetectorConstruction.cc`, you will find examples of all possible ways to build a material.

About the authors

2.4 How to Specify Particles

The *G4VuserPhysicsList* class is one of the base classes for the "user mandatory classes" (see Section 2.1), in which you have to specify all particles and physics processes which will be used in your simulation. In addition, the cut-off parameter in range should be defined in this class.

A user must create his own class derived from *G4VuserPhysicsList* and implement the following pure virtual methods:

`ConstructParticle()`:	construction of particles
`ConstructProcess()`:	construct processes and register them to particles
`SetCuts()`:	setting a cut value in range to all particles

In this section are some simple examples of the `ConstructParticle()` and `SetCuts()` methods.

For `ConstructProcess()` methods, please see Section 2.5.

2.4.1 Particle Definition

Geant4 provides various types of particles used in simulations:

- ordinary particles, such as electron, proton, and gamma
- resonant particles with very short life, such as vector mesons, and delta baryons
- nuclei, such as deuteron, alpha, and heavy ions
- quarks, di-quarks, and gluons

The *G4ParticleDefinition* class is provided to represent particles, and each particle has its own class derived from *G4ParticleDefinition*.

There are 6 major particle categories:

- lepton
- meson
- baryon

- boson
- shortlived
- ion

Particles in these categories are defined in sub-directories under `geant4/source/particles`, and there is a corresponding granular library for each particle category.

2.4.1.1 *G4ParticleDefinition* class

The *G4ParticleDefinition* class has properties to characterize individual particles, such as, name, mass, charge, spin, and so on. Most of these properties are "read-only" and can not be changed by users without rebuilding libraries.

2.4.1.2 How to access a particle

Each particle class type represents an individual particle type, and each class has a single static object. (There are some exceptions. Please see Section 5.3 for details.)

For example, the *G4Electron* class represents the "electron" and `G4Electron::theElectron` is the only object, a so-called singleton, of the *G4Electron* class. You can get the pointer to this "electron" object by using the static method `G4Electron::ElectronDefinition()`.

More than 100 types of particles are provided by default, to be used in various physics processes. In normal applications, users do not need to define particles for themselves.

Particles are static objects of individual particle classes. This means that these objects will be instantiated automatically before the `main()` routine is executed. However, you must explicitly declare the particle classes you want somewhere in your program, otherwise the compiler can not recognize which classes you need, and no particle classes will be instantiated.

2.4.1.3 Dictionary of particles

The *G4ParticleTable* class is provided as a dictionary of particles. Various utility methods are provided, such as:

`FindParticle(G4String name)`:	find the particle by name
`FindParticle(G4int PDGencoding)`:	find the particle by PDG encoding

G4ParticleTable is also defined as a singleton object, and the static method `G4ParticleTable::GetParticleTable()` gives you its pointer.

Particles are registered automatically in construction. You do not need (and can not) execute registration by yourself.

2.4.1.4 Construct particles

The `ConstructParticle()` method is a pure virtual method, in which you should call the static member functions for all the particles you want. This ensures that objects of these particles will be created.

For example, suppose you need a proton and a geantino, which is a virtual particle used for simulation and which does not interact with materials. The `ConstructParticle()` method is implemented as below:

```
void ExN01PhysicsList::ConstructParticle()
{
  G4Proton::ProtonDefinition();
  G4Geantino::GeantinoDefinition();
}
```

Source listing 2.4.1
Construct a proton and a geantino.

The total number of particles pre-defined in Geant4 is more than 100, and it can be cumbersome to list all particles by this method. Some utility classes can be used if you want all the particles of some Geant4 particle category. There are 6 classes provided which correspond to the 6 particle categories.

- *G4BosonConstructor*
- *G4LeptonConstructor*
- *G4MesonConstructor*
- *G4BarionConstructor*
- *G4IonConstructor*
- *G4ShortlivedConstructor*

You can see an example of this in *ExN05PhysicsList*, as listed below.

```
void ExN05PhysicsList::ConstructLeptons()
{
  // Construct all leptons
  G4LeptonConstructor pConstructor;
  pConstructor.ConstructParticle();
}
```

Source listing 2.4.2
Construct all leptons.

2.4.2 Range Cuts

Each particle has a suggested threshold below which secondary particles will not be produced. In *G4ParticleDefinition*, this threshold is a distance, or range, which is converted to an energy for all materials. The range threshold should be set for all particle types in the initialization phase using the `SetCuts()` method of *G4VUserPhysicsList*. Section 5.4 discusses threshold and tracking cuts in detail.

2.4.2.1 Setting the cuts

The `SetCuts()` method is a pure virtual method of the *G4VUserPhysicsList* class. Cut-off values should be set for all particles by using the `SetCuts()` method of *G4ParticleDefinition*. Construction of particles, materials, and processes should precede the invocation of `SetCuts()`. *G4RunManager* takes care of this sequence in usual applications.

This idea of a "unique cut value in range" is one of the important features of Geant4 used to handle cut values in a coherent manner. For usual applications, users need to determine only one cut value in range, and apply this value to all particles.

In such a case, you can use the `SetCutsWithDefault()` method, which is provided in the *G4VuserPhysicsList* class, which has a `defaultCutValue` member as the default cut-off value in range. This value is used in `SetCutsWithDefault()`.

You can set different cut value in range for each particle type and set different cut value in range for each material. However, you should be careful with physics outputs if you chose "different cut values in range" scheme, because Geant4 processes (especially energy loss procsses) are designed to fit with "unique cut value in range" shceme.

```
void ExN04PhysicsList::SetCuts()
{
  //   the G4VUserPhysicsList::SetCutsWithDefault() method sets
  //   the default cut value for all particle types
  SetCutsWithDefault();
}
```

Source listing 2.4.3
Set cut values by using the default cut value.

The `defaultCutValue` is set to 1.0 mm by default. Of course, you can set the new default cut value in the constructor of your physics list class as shown below.

```
ExN04PhysicsList::ExN04PhysicsList():  G4VUserPhysicsList()
{
  // default cut value  (1.0mm)
  defaultCutValue = 1.0*mm;
}
```

Source listing 2.4.4
Set the default cut value.

You can also use the `SetDefaultCutValue()` method in the *G4VUserPhysicsList*. In addition, you can use "/run/particle/setCut" commnad to change the default cut value interactively.

DO NOT change cut values inside the event loop. You can change cut values for run by run.

If you want to set different cut values for different particles, you need to be aware of the order of the particle types in setting the cut vales, because some particles require the cut values of other particle types in the calculation of the cross section tables. The rule of ordering follows:

1. gamma
2. electron
3. positron
4. proton and antiproton
5. others

In order to ease the implementation of your `SetCuts()` method, the *G4VuserPhysicsList* class provides some utility methods such as:

- `SetCutValue(G4double cut_value, G4String particle_name)`
- `SetCutValueForOthers(G4double cut_value)`
- `SetCutValueForOtherThan(G4double cut_value, G4ParticleDefinition* a_particle)`

An example implementation of `SetCuts()` is shown below:

```
void ExN03PhysicsList::SetCuts()
{
  // set cut values for gamma at first and for e- second and next for e+,
  // because some processes for e+/e- need cut values for gamma
  SetCutValue(cutForGamma, "gamma");
  SetCutValue(cutForElectron, "e-");
  SetCutValue(cutForElectron, "e+");

  // set cut values for proton and anti_proton before all other hadrons
  // because some processes for hadrons need cut values for proton/anti_proton
  SetCutValue(cutForProton, "proton");
  SetCutValue(cutForProton, "anti_proton");

  SetCutValueForOthers(defaultCutValue);
}
```

Source listing 2.4.5
Example implementation of the `SetCuts()` method.

2.4.2.2 Get the cut values

Cut values in range set by using the `SetCuts()` method. Then, by invocation of the `SetCuts()` method for each particle type, this cut-off value in range will be converted to the cut-off energies for all materials defined in the geometry.

You can get the cut value in range for any particle type for a material by using the `GetRangeThreshold( const G4Material* )` method, which is a virtual method of *G4ParticleDefinition* class. Also, you can get the threshold energy for a material by using the

`GetEnergyThreshold( const G4Material* )` method.

You can see both range and energy cut values interactively by using "/run/particle/dumpCutValues" command.

About the authors

2.5 How to Specify Physics Processes

2.5.1 Physics Processes

Physics processes describe how particles interact with materials. Geant4 provides seven major categories of processes:

- electromagnetic,
- hadronic,
- transportation,
- decay,
- optical,
- photolepton_hadron, and
- parameterisation.

All physics processes are derived from the *G4VProcess* base class. Its virtual methods

- `AtRestDoIt`,
- `AlongStepDoIt`, and
- `PostStepDoIt`

and the corresponding methods

- `AtRestGetPhysicalInteractionLength`,
- `AlongStepGetPhysicalInteractionLength`, and
- `PostStepGetPhysicalInteractionLength`

describe the behavior of a physics process when they are implemented in a derived class. The details of these methods are described in Section 5.2.

The following are specialized base classes to be used for simple processes:

G4VAtRestProcess	- processes with only `AtRestDoIt`

G4VContinuousProcess	- processes with only `AlongStepDoIt`
G4VDiscreteProcess	- processes with only `PostStepDoIt`

Another 4 virtual classes, such as *G4VContinuousDiscreteProcess*, are provided for complex processes.

2.5.2 Managing Processes

The *G4ProcessManager* class contains a list of processes that a particle can undertake. It has information on the order of invocation of the processes, as well as which kind of `DoIt` method is valid for each process in the list. A *G4ProcessManager* object corresponds to each particle and is attached to the *G4ParticleDefiniton* class.

In order to validate processes, they should be registered with the particle's *G4ProcessManager*. Process ordering information is included by using the `AddProcess()` and `SetProcessOrdering()` methods. For registration of simple processes, the `AddAtRestProcess()`, `AddContinuousProcess()` and `AddDiscreteProcess()` methods may be used.

G4ProcessManager is able to turn some processes on or off during a run by using the `ActivateProcess()` and `InActivateProcess()` methods. These methods are valid only after process registration is complete, so they must not be used in the *PreInit* phase.

The *G4VUserPhysicsList* class creates and attaches *G4ProcessManager* objects to all particle classes defined in the `ConstructParticle()` method.

2.5.3 Specifying Physics Processes

G4VUserPhysicsList is the base class for a "mandatory user class" (see Section 2.1), in which all physics processes and all particles required in a simulation must be registered. The user must create a class derived from *G4VUserPhysicsList* and implement the pure virtual method `ConstructProcess()`.

For example, if just the *G4Geantino* particle class is required, only the transportation process need be registered. The `ConstructProcess()` method would then be implemented as follows:

```
void ExN01PhysicsList::ConstructProcess()
{
  // Define transportation process
  AddTransportation();
}
```

Source listing 2.5.1
Register processes for a geantino.

Here, the `AddTransportation()` method is provided in the *G4VUserPhysicsList* class to register the *G4Transportation* class with all particle classes. The *G4Transportation* class (and/or related classes) describes the particle motion in space and time. It is the mandatory process for tracking particles.

In the `ConstructProcess()` method, physics processes should be created and registered with each particle's instance of *G4ProcessManager*.

An example of process registration is given in the *G4VUserPhysicsList*::`AddTransportation()` method.

Registration in *G4ProcessManager* is a complex procedure for other processes and particles because the relations between processes are crucial for some processes. Please see Section 5.2 and the example codes.

An example of electromagnetic process registration for photons is shown below:

```
void MyPhysicsList::ConstructProcess()
{
  // Define transportation process
  AddTransportation();
  // electromagnetic processes
  ConstructEM();
}
void MyPhysicsList::ConstructEM()
{
   //  Get the process manager for gamma
  G4ParticleDefinition* particle = G4Gamma::GammaDefinition();
  G4ProcessManager* pmanager = particle->GetProcessManager();

  // Construct processes for gamma
  G4PhotoElectricEffect * thePhotoElectricEffect = new G4PhotoElectricEffect();
  G4ComptonScattering * theComptonScattering = new G4ComptonScattering();
  G4GammaConversion* theGammaConversion = new G4GammaConversion();

  // Register processes to gamma's process manager
  pmanager->AddDiscreteProcess(thePhotoElectricEffect);
  pmanager->AddDiscreteProcess(theComptonScattering);
  pmanager->AddDiscreteProcess(theGammaConversion);
}
```

Source listing 2.5.2
Register processes for a gamma.

About the authors

2.6 How to Generate a Primary Event

2.6.1 Generating Primary Events

G4VuserPrimaryGeneratorAction is one of the mandatory classes available for deriving your own concrete class. In your concrete class, you have to specify how a primary event should be generated. Actual generation of primary particles will be done by concrete classes of *G4VPrimaryGenerator*, explained in the following sub-section. Your *G4VUserPrimaryGeneratorAction* concrete class just arranges the way primary particles are generated.

```
#ifndef ExN01PrimaryGeneratorAction_h
#define ExN01PrimaryGeneratorAction_h 1

#include "G4VUserPrimaryGeneratorAction.hh"

class G4ParticleGun;
class G4Event;

class ExN01PrimaryGeneratorAction : public G4VUserPrimaryGeneratorAction
{
  public:
    ExN01PrimaryGeneratorAction();
    ~ExN01PrimaryGeneratorAction();

  public:
    void generatePrimaries(G4Event* anEvent);

  private:
    G4ParticleGun* particleGun;
};

#endif

#include "ExN01PrimaryGeneratorAction.hh"
#include "G4Event.hh"
#include "G4ParticleGun.hh"
#include "G4ThreeVector.hh"
#include "G4Geantino.hh"
#include "globals.hh"

ExN01PrimaryGeneratorAction::ExN01PrimaryGeneratorAction()
{
  G4int n_particle = 1;
  particleGun = new G4ParticleGun(n_particle);

  particleGun->SetParticleDefinition(G4Geantino::GeantinoDefinition());
  particleGun->SetParticleEnergy(1.0*GeV);
  particleGun->SetParticlePosition(G4ThreeVector(-2.0*m,0.0*m,0.0*m));
}

ExN01PrimaryGeneratorAction::~ExN01PrimaryGeneratorAction()
{
  delete particleGun;
}

void ExN01PrimaryGeneratorAction::generatePrimaries(G4Event* anEvent)
{
  G4int i = anEvent->get_eventID() % 3;
  switch(i)
  {
    case 0:
      particleGun->SetParticleMomentumDirection(G4ThreeVector(1.0,0.0,0.0));
      break;
    case 1:
      particleGun->SetParticleMomentumDirection(G4ThreeVector(1.0,0.1,0.0));
      break;
    case 2:
      particleGun->SetParticleMomentumDirection(G4ThreeVector(1.0,0.0,0.1));
      break;
  }

  particleGun->generatePrimaryVertex(anEvent);
}
```

Source listing 2.6.1
An example of a *G4VUserPrimaryGeneratorAction* concrete class using *G4ParticleGun*. For the usage of *G4ParticleGun* refer to 2.6.2.

2.6.1.1 Selection of the generator

In the constructor of your *G4VUserPrimaryGeneratorAction*, you should instantiate the primary generator(s). If necessary, you need to set some initial conditions for the generator(s).

In Source listing 2.6.1, *G4ParticleGun* is constructed to use as the actual primary particle generator. Methods of *G4ParticleGun* are described in the following section. Please note that the primary generator object(s) you construct in your *G4VUserPrimaryGeneratorAction* concrete class must be deleted in your destructor.

2.6.1.2 Generation of an event

G4VUserPrimaryGeneratorAction has a pure virtual method named `generatePrimaries()`. This method is invoked at the beginning of each event. In this method, you have to invoke the *G4VPrimaryGenerator* concrete class you instantiated via the `generatePrimaryVertex()` method.

You can invoke more than one generator and/or invoke one generator more than once. Mixing up several generators can produce a more complicated primary event.

2.6.2 *G4VPrimaryGenerator*

Geant4 provides two *G4VPrimaryGenerator* concrete classes. One is *G4ParticleGun*, which will be discussed here, and the other is *G4HEPEvtInterface*, which will be discussed in Section 3.6.

2.6.2.1 *G4ParticleGun*

G4ParticleGun is a generator provided by Geant4. This class generates primary particle(s) with a given momentum and position. It does not provide any sort of randomizing. The constructor of *G4ParticleGun* takes an integer which causes the generation of one or more primaries of exactly same kinematics. It is a rather frequent user requirement to generate a primary with randomized energy, momentum, and/or position. Such randomization can be achieved by invoking various set methods provided by *G4ParticleGun*. The invocation of these methods should be implemented in the `generatePrimaries()` method of your concrete *G4VUserPrimaryGeneratorAction* class before invoking `generatePrimaryVertex()` of *G4ParticleGun*. Geant4 provides various random number generation methods with various distributions (see Section 3.2).

2.6.2.2 Public methods of *G4ParticleGun*

The following methods are provided by *G4ParticleGun*, and all of them can be invoked from the `generatePrimaries()` method in your concrete *G4VUserPrimaryGeneratorAction* class.

- `void SetParticleDefinition(G4ParticleDefinition*)`
- `void SetParticleMomentum(G4ParticleMomentum)`
- `void SetParticleMomentumDirection(G4ThreeVector)`
- `void SetParticleEnergy(G4double)`
- `void SetParticleTime(G4double)`
- `void SetParticlePosition(G4ThreeVector)`
- `void SetParticlePolarization(G4ThreeVector)`
- `void SetNumberOfParticles(G4int)`

About the authors

2.7 How to Make an Executable Program

2.7.1 Building ExampleN01 in a UNIX Environment

The code for the user examples in Geant4 is placed in the directory `$G4INSTALL/examples`, where `$G4INSTALL` is the environment variable set to the place where the Geant4 distribution is installed (set by default to `$HOME/geant4`). In the following sections, a quick overview on how the GNUmake mechanism works in Geant4 will be given, and we will show how to build a concrete example, "ExampleN01", which is part of the Geant4 distribution.

2.7.1.1 How GNUmake works in Geant4

The GNUmake process in Geant4 is mainly controlled by the following GNUmake script files (`*.gmk` scripts are placed in `$G4INSTALL/config`):

`architecture.gmk`	invoking and defining all the architecture specific settings and paths which are stored in `$G4INSTALL/config/sys.`
`common.gmk`	defining all general GNUmake rules for building objects and libraries
`globlib.gmk`	defining all general GNUmake rules for building compound libraries
`binmake.gmk`	defining the general GNUmake rules for building executables
`GNUmakefile`	placed inside each directory in the Geant4 distribution and defining directives specific to build a library, a set of sub-libraries, or an executable.

Kernel libraries are placed by default in `$G4INSTALL/lib/$G4SYSTEM`, where `$G4SYSTEM` specifies the system architecture and compiler in use. Executable binaries are placed in `$G4WORKDIR/bin/$G4SYSTEM`, and temporary files (object-files and data products of the compilation process) in `$G4WORKDIR/tmp/$G4SYSTEM`. `$G4WORKDIR` (set by default to `$G4INSTALL`) should be set by the user to specify the place his/her own workdir for Geant4 in the user area.

For more information on how to build Geant4 kernel libraries and set up the correct environment for Geant4, refer to the "Installation Guide".

2.7.1.2 Building the executable

The compilation process to build an executable, such as an example from `$G4INSTALL/examples`, is started by invoking the "gmake" command from the (sub)directory in which you are interested. To build, for instance, exampleN01 in your `$G4WORKDIR` area, you should copy the module `$G4INSTALL/examples` to your `$G4WORKDIR` and do the following actions:

```
> cd $G4WORKDIR/examples/novice/N01
> gmake
```

This will create, in `$G4WORKDIR/bin/$G4SYSTEM`, the "exampleN01" executable, which you can invoke and run. You should actually add `$G4WORKDIR/bin/$G4SYSTEM` to `$PATH` in your environment.

2.7.2 Building ExampleN01 in a Windows Environment

The procedure to build a Geant4 executable on a system based on OS Windows/95-98 or Windows/NT is similar to what should be done on a UNIX based system, assuming that your system is equipped with GNUmake, MS-Visual C++ compiler and the required software to run Geant4 (see "Installation Guide").

2.7.2.1 Building the executable

See paragraph 2.7.1.

2.8 How to Set Up an Interactive Session

2.8.1 Introduction

Roles of the "intercoms" category
The "intercoms" category provides an expandable command interpreter. It is the key mechanism of Geant4 to realize user interactions of all categories without being annoyed by the dependencies among categories. The direct use of Geant4 classes in a C++ program offers a first ground level of interactivity, i.e., the batch session. As seen in the examples/novice/N01, Geant4 commands and macros are to be hard-coded in the program.

User Interfaces to steer the simulation
To avoid too much programming, the "intercoms" category provides the abstract class *G4UIsession* that captures interactive commands . The concrete implementation of the user interface and Graphical User Interfaces (GUI) is left to the interfaces category. This interfacing strategy opens an important door towards various user interface tools and allows Geant4 to utilize the state-of-the-art GUI tools such as Motif and Java, etc..The richness of the collaboration has permitted for different groups to offer various user interfaces to the Geant4 command system. Currently available are the following;

1. Character terminal (dumb terminal and tcsh(bash)-like terminal), the default user interface of Geant4,
2. Xm, Xaw, Win32, variations of the upper terminal by using a Motif, Athena or Windows widget to retrieve commands,
3. GAG, a fully Graphical User Interface of the client/server type, and
4. OPACS, an OPACS/Wo widget manager implementation in conjunction with the OPACS visualization system.

Full implementation of the character terminals (1 and 2) is included in the standard Geant4 distribution. As for the others (3 and 4) with rich GUI functionalities, their front-end classes are included in the Geant4 distribution. The corresponding GUI packages are available from the Web pages of the collaborating institutes respectively.

`GAG`	http://erpc1.naruto-u.ac.jp/~geant4
`OPACS`	http://www.lal.in2p3.fr/OPACS

2.8.2 A Short Description of Available Interface Classes

1. *G4UIterminal* and *G4UItcsh* classes

These interfaces open a session on the character terminal. *G4UIterminal* runs on all platform supported by Geant4, including *cygwin* on Windows, while *G4UItcsh* runs on Solaris and Linux. G4UItcsh supports user-friendly key bindings a-la-tcsh (or bash);

^A	move cursor to the top
^B	backward cursor ([LEFT] cursor)
^D	delete/exit/show matched list
^E	move cursor to the end
^F	forward cursor ([RIGHT] cursor)
^K	clear after the cursor
^N	next command ([DOWN] cursor)
^P	previous command ([UP] cursor)
TAB	command completion
DEL	backspace
BS	backspace

In addition, the following string substitutions are supported;

%s	current application status
%/	current working directory
%h	history number

2. *G4UIXm, G4UIXaw* and *G4UIWin32* classes

These interfaces are versions of *G4UIterminal* implemented over libraries Motif, Athena and WIN32 respectively. *G4UIXm* uses the Motif XmCommand widget, *G4UIXaw* the Athena dialog widget, and *G4UIWin32* the Windows "edit" component to do the command capturing. These interfaces are useful if working in conjunction with visualization drivers that use the Xt library or the WIN32 one.

A command box is at disposal for entering or recalling Geant4 commands. Command completion by typing &ldquo;TAB&rdquo; key is available on the command line. The shellcommands "exit, cont, help, ls, cd..." are also supported. A menu bar could be customized through the *AddMenu* and *AddButton* method.

Ex:

```
/gui/addMenu    test Test
/gui/addButton    test Init /run/initialize
/gui/addButton    test     "Set gun"     "/control/execute gun.g4m"
/gui/addButton     test     "Run one event"    "/run/beamOn 1"
```

G4UIXm runs on Unix/Linux with Motif. *G4UIXaw*, less user friendly, runs on Unix with Athena widgets. *G4UIWin32* runs on Windows.

3. *G4UIGAG* class

GAG is a Graphical User Interface tool with which user can set parameters and execute commands. It is adaptive, since GAG reflects the internal states of Geant4 that is a state machine. GAG is based on the server-client model; GAG is the server, while Geant4 executables are clients. Hence, GAG does nothing by itself and it must invoke an executable simulation program. Geant4's front-end class *G4UIGAG* must be instantiated to communicate with GAG. This runs on Linux and Windows 2000.

GAG is written in Java and its Jar (Java Archive) file is available from the above URL. See the same pages to know how to install and run Java programs.

GAG has following functions.

- GAG Menu: The menus are to choose and run a GEANT4 executable file, to kill or exit a GEANT4 process and to exit GAG. Upon the normal exit or an unexpected death of the Geant4 process, GAG window are automatically reset to accept another GEANT4 executable.
- GEANT4 Command tree: Upon the establishment of the pipe with the GEANT4 process, GAG displays the command menu tree whose look and feel is quite similar to Windows' file browser. Disabled commands are shown opaque. GAG doesn&rsquo;t display commands that are just below the root of the command hierarchy. Direct type-in field is available for such input. Guidance of command categories and commands are displayed upon focusing . GAG has a command history function. User can re-execute a command with old parameters, edit the history, or save the history to create a macro file.
- Command Parameter panel: GAG's parameter panel is the user-friendliest part. It displays parameter name, its guidance, its type(s) (integer, double, Boolean or string), omittable, default value(s), expression(s) of its range and candidate list(s) (for example, of units). Range check is done by intercoms and the error message from it is shown in the pop-up dialog box. When a parameter component has a candidate list, a list box is automatically displayed . When a file is requested by a command, the file chooser is available.
- Logging: Log can be redirected to the terminal (xterm or cygwin window) from which GAG is invoked. It can be interrupted as will, in the middle of long session of execution. Log can be saved to a file independent of the above redirection . GAG displays warning or error messages from GEANT4 in a pop-up warning widget.

4. *G4UIOPACS* class

- OPACS as a visualization environment for Geant4: OPACS is a visualization environment based on X window and OpenGL. It has been developed in the HEP (High Energy Physic) environment to ease the writing of "Event display" programs. It is written in ANSI C and highly portable. Porting has been done on most UNIX systems, VMS and recently on a Window/NT machine having X11 installed. When using OPACS as a visualization environment, only the Geant4 kernel is used. User interface and graphic is handled directly by the OPACS. In this way the G4/source/interfaces, G4/source/visualization categories are not requested.
- OPACS as a driver to Geant4 visualization environment: *G4UIOPACS* is the front-end class to OPACS. To have Geant4 visualization environment running with OPACS, one has to install first the OPACS and follow the instruction in the Web pages above. User can test things by building the Geant4/source/visualization/tests/test19 program.

2.8.3 Building the Interface Libraries

The libraries that don't depend on external packages are made by default. They include *G4UIterminal, G4UItcsh* and *G4UIGAG* in libraries *libG4UIbasic.a/so* and *libG4UIGAG.a/so.*
To make the libraries of *G4UIXm, G4UIXaw* and *G4UIWin32,* respective environment variables

G4UI_BUILD_XM_SESSION , **G4UI_BUILD_XAW_SESSION** or **G4UI_BUILD_WIN32_SESSION** must be set explicitly. The OPACS library is made when **G4UI_BUILD_OPACS_SESSION** is set.

However, if the environment variable **G4UI_NONE** is set, no interface libraries are built at all.

Build scheme of the user interface libraries is specified in "$G4INSTALL/config/G4UI_BUILD.gmk" makefile and the dependencies on the external packages are specified in "$G4INSTALL/config/interactivity.gmk".

2.8.4 How to Use the Interface

To use a given interface (`G4UIxxx` where `xxx = terminal,Xm, Xaw, Win32, GAG, Wo`) in a user's program, he has the following lines in his main program;

- // to include the class definition in his main program:
- #include "G4Uixxx.hh"
- // to instantiate a session of his choice and start the session
- G4UIsession* session = new G4UIxxx;
- session->SessionStart();
- / /the line next to the "SessionStart" is usually to finish the session
- delete session;

For a tcsh session, the second line must be :
G4UIsession* session = new G4UIterminal(new G4UItcsh);

See the examples in "examples/novice/N0x" in which the terminal session is used.

Again, environment variable selects a given interface. But for your convenience, some of them are set defaults.

- *G4UIterminal*, *G4UItcsh* and *G4UIGAG* can be used without any environment variables. Sessions not needing external packages or libraries are always built (see "G4UI_BUILD.gmk") and linked, so the user can instantiate one of these sessions without rebuilding the libraries and without setting any environment variables. For backwards compatibility with user code, as typified by geant4/examples main programs, the C-pre-processor variables corresponding to the original environment variables for the above three (i.e., **G4UI_USE_TERMINAL**, **G4UI_USE_TCSH** and **G4UI_USE_GAG**) are set. However, if he/she sets no environment variables, then the C-pre-processor variable **G4UI_USE_TERMINAL** is set by default, although there is no need to use it.
- The environment variable **G4UI_USE_XM**, **G4UI_USE_XAW**, **G4UI_USE_WIN32** or **G4UI_USE_WO** must be set to use the respective interface. The file "$G4INSTALL/config/interactivity.gmk" resolves their dependencies on external packages.
- If the environment variable **G4UI_NONE** is set, no externa ibraries are selected. Also, for your convenience, if any **G4UI_USE_XXX** environment variable is set, then the corresponding C-pre-processor flag is also set. However, if the environment variable **G4UI_NONE** is set, no

C-pre-processor flags are set.

About the authors

2.9 How to Execute a Program

2.9.1 Introduction

A Geant4 application can be run either in

- ‘purely hard-coded‘ batch mode
- batch mode, but reading a macro of commands
- interactive mode, driven by command lines
- interactive mode via a Graphical User Interface

The last mode will be covered in Section 2.8. The first three modes are explained here.

2.9.2 ’Hard-coded’ Batch Mode

Below is an example of the main program for an application which will run in batch mode.

```
int main()
{
  // Construct the default run manager
  G4RunManager* runManager = new G4RunManager;

  // set mandatory initialization classes
  runManager->SetUserInitialization(new ExN01DetectorConstruction);
  runManager->SetUserInitialization(new ExN01PhysicsList);

  // set mandatory user action class
  runManager->SetUserAction(new ExN01PrimaryGeneratorAction);

  // Initialize G4 kernel
  runManager->Initialize();

  // start a run
  int numberOfEvent = 1000;
  runManager->BeamOn(numberOfEvent);

  // job termination
  delete runManager;
  return 0;
}
```

Source listing 2.9.1
An example of the `main()` routine for an application which will run in batch mode.

Even the number of events in the run is ‘frozen‘. To change this number you must at least recompile `main()`.

2.9.3 Batch Mode with Macro File

Below is an example of the main program for an application which will run in batch mode, but reading a file of commands.

```
int main(int argc,char** argv) {

   // Construct the default run manager
  G4RunManager * runManager = new G4RunManager;

  // set mandatory initialization classes
  runManager->SetUserInitialization(new MyDetectorConstruction);
  runManager->SetUserInitialization(new MyPhysicsList);

  // set mandatory user action class
  runManager->SetUserAction(new MyPrimaryGeneratorAction);

  // Initialize G4 kernel
  runManager->Initialize();

  //read a macro file of commands
  G4UImanager * UI = G4UImanager::getUIpointer();
  G4String command = "/control/execute ";
  G4String fileName = argv[1];
  UI->applyCommand(command+fileName);

  delete runManager;
  return 0;
}
```

Source listing 2.9.2
An example of the `main()` routine for an application which will run in batch mode, but reading a file of commands.

This example will be executed with the command:

```
 > myProgram  run1.mac
```

where `myProgram` is the name of your executable and `run1.mac` is a macro of commands located in the current directory, which could look like:

```
#
# Macro file for "myProgram.cc"
#
# set verbose level for this run
#
/run/verbose      2
/event/verbose    0
/tracking/verbose 1
#
# Set the initial kinematic and run 100 events
# electron 1 GeV to the direction (1.,0.,0.)
#
/gun/particle e-
/gun/energy 1 GeV
/run/beamOn 100
```

Source listing 2.9.3
A typical command macro.

Indeed, you can re-execute your program with different run conditions without recompiling anything.

Digression: many G4 category of classes have a verbose flag which controls the level of ’verbosity’. Usually `verbose=0` means silent. For instance

- /run/verbose is for the RunManager
- /event/verbose is for the EventManager
- /tracking/verbose is for the TrackingManager
- ...etc...

2.9.4 Interactive Mode Driven by Command Lines

Below is an example of the main program for an application which will run interactively, waiting for command lines entered from the keyboard.

```
int main(int argc,char** argv) {

  // Construct the default run manager
  G4RunManager * runManager = new G4RunManager;

  // set mandatory initialization classes
  runManager->SetUserInitialization(new MyDetectorConstruction);
  runManager->SetUserInitialization(new MyPhysicsList);

  // visualization manager
  G4VisManager* visManager = new MyVisManager;
  visManager->Initialize();

  // set user action classes
  runManager->SetUserAction(new MyPrimaryGeneratorAction);
  runManager->SetUserAction(new MyRunAction);
  runManager->SetUserAction(new MyEventAction);
  runManager->SetUserAction(new MySteppingAction);

  // Initialize G4 kernel
  runManager->Initialize();

  // Define UI terminal for interactive mode
  G4UIsession * session = new G4UIterminal;
  session->SessionStart();
  delete session;

  // job termination
  delete visManager;
  delete runManager;

  return 0;
}
```

Source listing 2.9.4
An example of the `main()` routine for an application which will run interactively, waiting for commands from the keyboard.

This example will be executed with the command:

```
> myProgram
```

where `myProgram` is the name of your executable.

The G4 kernel will prompt:

```
Idle>
```

and you can start your session. An example session could be:

Create an empty scene ("world" is default):

```
  Idle> /vis/scene/create
```

Add a volume to the scene:

```
  Idle> /vis/scene/add/volume
```

Create a scene handler for a specific graphics system. Change the next line to choose another graphic system:

```
  Idle> /vis/sceneHandler/create OGLIX
```

Create a viewer:

```
  Idle> /vis/viewer/create
```

Draw the scene, etc.:

```
  Idle> /vis/scene/notifyHandlers
  Idle> /run/verbose      0
  Idle> /event/verbose    0
  Idle> /tracking/verbose 1
  Idle> /gun/particle mu+
  Idle> /gun/energy 10 GeV
  Idle> /run/beamOn 1
  Idle> /gun/particle proton
  Idle> /gun/energy 100 MeV
  Idle> /run/beamOn 3
  Idle> exit
```

For the meaning of the machine state `Idle`, see Section 3.4.2.

This mode is useful for running a few events in debug mode and visualizing them. Notice that the *VisManager* is created in the `main()`, and the visualization system is choosen via the command:

```
  /vis/sceneHandler/create OGLIX
```

2.9.5 General Case

Most of the examples in the `$G4INSTALL/examples/` directory have the following `main()`, which covers cases 2 and 3 above. Thus, the application can be run either in batch or interactive mode.

```
int main(int argc,char** argv) {

  // Construct the default run manager
  G4RunManager * runManager = new G4RunManager;

  // set mandatory initialization classes
  N03DetectorConstruction* detector = new N03DetectorConstruction;
  runManager->SetUserInitialization(detector);
  runManager->SetUserInitialization(new N03PhysicsList);

#ifdef G4VIS_USE
  // visualization manager
  G4VisManager* visManager = new N03VisManager;
  visManager->Initialize();
#endif

  // set user action classes
  runManager->SetUserAction(new N03PrimaryGeneratorAction(detector));
  runManager->SetUserAction(new N03RunAction);
  runManager->SetUserAction(new N03EventAction);
  runManager->SetUserAction(new N03SteppingAction);

  // get the pointer to the User Interface manager
    G4UImanager* UI = G4UImanager::GetUIpointer();

  if (argc==1)   // Define UI terminal for interactive mode
    {
     G4UIsession * session = new G4UIterminal;
     UI->ApplyCommand("/control/execute prerunN03.mac");
     session->SessionStart();
     delete session;
    }
  else           // Batch mode
    {
     G4String command = "/control/execute ";
     G4String fileName = argv[1];
     UI->ApplyCommand(command+fileName);
    }

  // job termination
#ifdef G4VIS_USE
  delete visManager;
#endif
  delete runManager;

  return 0;
}
```

Source listing 2.9.5
The typical `main()` routine from the examples directory.

Notice that the visualization system is under the control of the precompiler variable `G4VIS_USE`. Notice also that, in interactive mode, few intializations have been put in the macro `prerunN03.mac` which is executed before the session start.

```
# Macro file for the initialization phase of "exampleN03.cc"
#
# Sets some default verbose flags
# and initializes the graphics.
#
/control/verbose 2
/control/saveHistory
/run/verbose 2
#
/run/particle/dumpCutValues
#
# Create empty scene ("world" is default)
/vis/scene/create
#
# Add volume to scene
/vis/scene/add/volume
#
# Create a scene handler for a specific graphics system
# Edit the next line(s) to choose another graphic system
#
#/vis/sceneHandler/create DAWNFILE
/vis/sceneHandler/create OGLIX
#
# Create a viewer
/vis/viewer/create
#
# Draw scene
/vis/scene/notifyHandlers
#
# for drawing the tracks
# if too many tracks cause core dump => storeTrajectory 0
/tracking/storeTrajectory 1
#/vis/scene/include/trajectories
```

Source listing 2.9.6
The `prerunN03.mac` macro.

Also, this example demonstrates that you can read and execute a macro interactively:

```
  Idle> /control/execute  mySubMacro.mac
```

About the authors

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2.10 How to Visualize the Detector and Events

2.10.1 Introduction

This section briefly explains how to perform Geant4 Visualization. The description here is based on the sample program `examples/novice/N03`. More details are given in Section 8 "Visualization". Example macro files can be found in `examples/novice/N03/visTutor/exN03VisX.mac`.

2.10.2 Visualization Drivers

Geant4 visualization is required to respond to a variety of user requirements. It is difficult to respond to all of these with only one built-in visualizer, therefore Geant4 visualization defines an abstract interface to any number of graphics systems. Here, a "graphics system" means either an application running as a process independent of Geant4, or a graphics library compiled with Geant4. The Geant4 visualization distribution supports concrete interfaces to several graphics systems, which are in many respects complementary to each other. A concrete interface to a graphics system is called a "visualization driver".

You need not use all visualization drivers. You can select those suitable to your purposes. In the following, for simplicity, we assume that the Geant4 libraries are built (installed) with the "OpenGL-Xlib driver" and the "DAWNFILE driver" incorporated.

In order to use the DAWNFILE driver, you need Fukui Renderer DAWN, which is obtainable from the following Web site: http://geant4.kek.jp/GEANT4/vis.

In order to use the the OpenGL drivers, you need the OpenGL library, which is installed in many platforms by default. You also need to set an environmental variable `G4VIS_BUILD_OPENGLX_DRIVER` to `1` in building (installing) Genat4 libraries, and also set another environmental variable `G4VIS_USE_OPENGLX` to `1` in compiling your Geant4 executable. You may also have to set an environmental variable `OGLHOME` to the OpenGL root directory. For example,

```
setenv G4VIS_BUILD_OPENGLX_DRIVER 1
setenv G4VIS_USE_OPENGLX 1
setenv OGLHOME /usr/X11R6
```

Some other visualization drivers depending on external libraries are also required to set the similar environmental variables, `G4VIS_BUILD_DRIVERNAME_DRIVER` and `G4VIS_USE_DRIVERNAME`, to `1`. All visualization drivers independent of external libraries, e.g. DAWNFILE and VRMLFILE drivers, need not such setting. (But you must prepare a proper visualization manager class and a proper `main()` function, anyway. See below.)

For all visualization drivers available in your Geant4 executable, the C-pre-processor flags `G4VIS_USE_DRIVERNAME` are automatically set by `config/G4VIS_USE.gmk` in compilation. Similarly, for all visualization drivers incorporated into the Geant4 libraries, the C-pre-processor flags `G4VIS_BUILD_DRIVERNAME_DRIVER` are automatically set by `config/G4VIS_BUILE.gmk` in installation.

See the document file `source/visualization/README`, for more details.

2.10.3 How to Incorporate Visualization Drivers into an Executable

You can realize (use) visualization driver(s) you want in your Geant4 executable. These can only be from the set installed in the Geant4 libraries. You will be warned if the one you request is not available.

In order to realize visualization drivers, you must do two things:

1. Write your own visualization manager, inheriting the base class *G4VisManager* defined in the `source/visualization/management` and register your selected visualization drivers. You are required to implement one pure virtual function, `void RegisterGraphicsSystems()`.
2. Instantiate and initialize the visualization manager in the `main()` function.

The implementation of `ExN03VisManager::RegisterGraphicsSystems()` demonstrates procedures for registering visualization drivers.

For example, the DAWNFILE driver and the OpenGL-Xlib drivers are registered as follows:

```
...
  RegisterGraphicsSystem (new G4DAWNFILE);
...
#ifdef G4VIS_USE_OPENGLX
  RegisterGraphicsSystem (new G4OpenGLImmediateX);
  RegisterGraphicsSystem (new G4OpenGLStoredX);
#endif
...
```

How to write the `main()` function is explained below.

2.10.4 Writing the `main()` Method to Include Visualization

Now we explain how to write a visualization manager and the `main()` function for Geant4 visualization. In order that your Geant4 executable is able to perform visualization, you must instantiate and initialize *your* Visualization Manager in the `main()` function. The typical `main()` function available for visualization is written in the following style:

```
//----- C++ source codes: main() function for visualization
// Use class ExN03VisManager to define Visualization Manager
#ifdef G4VIS_USE
#include "ExN03VisManager.hh"
#endif

.....

int main(int argc,char** argv) {

.....

  // Instantiation and initialization of the Visualization Manager
#ifdef G4VIS_USE
  // visualization manager
  G4VisManager* visManager = new ExN03VisManager;
  visManager->Initialize();
#endif

.....

  // Job termination
#ifdef G4VIS_USE
  delete visManager;
#endif

.....

  return 0;
}

//----- end of C++
```

Source listing 2.10.1
The typical `main()` routine available for visualization.

In the instantiation, initialization, and deletion of the Visualization Manager, the use of a macro is recommended. Note that it is your responsibility to delete the instantiated Visualization Manager by yourself. A complete description of a sample `main()` function is described in `examples/novice/N03/exampleN03.cc`.

2.10.5 Scene, Scene Handler, and Viewer

You can perform almost all kinds of Geant4 visualization with interactive visualization commands. In using the visualization commands, it is useful to know the concept of "scene", "scene handler", and "viewer". A "scene" is a set of visualizable raw 3D data. A "scene handler" is a graphics-data modeler, which processes raw data in a scene for later visualization. And a "viewer" generates images based on data processed by a scene handler. Roughly speaking, a set of a scene handler and a viewer corresponds to a visualization driver.

The typical steps of performing Geant4 visualization are:

Step 1. Create a scene handler and a viewer.
Step 2. Create an empty scene.
Step 3. Add raw 3D data to the created scene.
Step 4. Attach the current scene handler to the current scene.
Step 5. Set camera parameters, drawing style (wireframe/surface), etc.
Step 6. Make the viewer execute visualization.
Step 7. Declare the end of visualization for flushing.

Note that the above list does not mean that you have to execute 7 commands for visualization. You can use "compound commands" which can execute plural visualization commands at one time.

2.10.6 Sample Visualization Sessions

In this section we present typical sessions of Geant4 visualization. You can test them with the sample program geant4/examples/novice/N03. Run a binary executable "exampleN03" without an argument, and then execute the commands below in the "Idle>" state. Explanation of each command will be described later. (Note that the OpenGL-Xlib driver and the DAWNFILE driver are incorporated into the executable, and that Fukui Renderer DAWN is installed in your machine.)

2.10.6.1 `Visualization of detector components`

The following session visualizes detector components with the OpenGL-Xlib driver and then with the DAWNFILE driver. The former exhibits minimal visualization commands to visualize detector geometry, while the latter exhibits customized visualization (visualization of a selected physical volume, coordinate axes, texts, etc).

```
###################################################
#  vis1.mac:
#    A Sample macro to demonstrate visualization
#    of detector geometry.
#
#  USAGE:
#   Save the commands below as a macro file, say,
#   "vis1.mac", and execute it as follows:
#
#   % $(G4BINDIR)/exampleN03
#   Idle> /control/execute vis1.mac
#############################################

#############################################
# Visualization of detector geometry
#  with the OGLIX (OpenGL Immediate X) driver
#############################################

# Invoke the OGLIX driver:
#  Create a scene handler and a viewer for the OGLIX driver
/vis/open OGLIX
```

```
# Visualize the whole detector geometry
#  with the default camera parameters.
#  Command "/vis/drawVolume" visualizes the detector geometry,
#  and command "/vis/viewer/flush" declares the end of visualization.
#  (The command /vis/viewer/flush  can be omitted for the OGLIX
#   and OGLSX drivers.)
#  The default argument of "/vis/drawVolume" is "world".
/vis/drawVolume
/vis/viewer/flush

#########################################
# Visualization with the DAWNFILE driver
#########################################

# Invoke the DAWNFILE driver
#  Create a scene handler and a viewer for the DAWNFILE driver
/vis/open DAWNFILE

# Bird’s-eye view of a detector component (Absorber)
#  drawing style: hidden-surface removal
#  viewpoint  : (theta,phi) = (35*deg, 45*deg),
#  zoom factor: 1.1 of the full screen size
#  coordinate axes:
#     x-axis:red,  y-axis:green,  z-axis:blue
#     origin: (0,0,0),  length: 500 mm
#
/vis/viewer/reset
/vis/viewer/set/style          surface
/vis/viewer/zoom               1.1
/vis/viewer/set/viewpointThetaPhi  35 45
/vis/drawVolume                Absorber
/vis/scene/add/axes            0 0 0 500 mm
/vis/scene/add/text            0 0 0 mm  40 -100 -140   Absorber
/vis/viewer/flush

# Bird’s-eye view of the whole detector components
#  * "/vis/viewer/set/culling global false" makes the invisible
#    world volume visible.
#    (The invisibility of the world volume is set
#     in ExN03DetectorConstruction.cc.)
/vis/viewer/set/style     wireframe
/vis/viewer/set/culling   global false
/vis/drawVolume
/vis/scene/add/axes       0 0 0 500 mm
/vis/scene/add/text       0 0 0 mm 50 -50 -200   world
/vis/viewer/flush
################### END of vis1.mac ###################
```

2.10.6.2 Visualization of events

The following session visualizes events (tajectories) with the OpenGL-Xlib driver and then with the DAWNFILE driver. The former exhibits minimal visualization commands to visualize events, while the latter exhibits customized visualization. Note that the run action and event action classes should be described properly. (See, for example, the following classes: "examples/novice/N03/src/ExN03RunAction.cc", "examples/novice/N03/src/ExN03EventAction.cc").

```
###################################################
```

```
#  vis2.mac:
#    A Sample macro to demonstrate visualization
#    of events (trajectories).
#
#  USAGE:
#   Save the commands below as a macro file, say,
#   "vis2.mac", and execute it as follows:
#
#   % $(G4BINDIR)/exampleN03
#   Idle> /control/execute vis1.mac
#############################################

#####################################################
# Store particle trajectories for visualization
/tracking/storeTrajectory 1
#####################################################

########################################################
# Visualization with the OGLSX (OpenGL Stored X) driver
########################################################

# Invoke the OGLSX driver
#  Create a scene handler and a viewer for the OGLSX driver
/vis/open OGLSX

# Create an empty scene and add detector components to it
/vis/drawVolume

# Add trajectories to the current scene
#  Note: This command is not necessary in, e.g.,
#        examples/novice/N03, since the C++ method DrawTrajectory()
#        is described in the event action.
#/vis/scene/add/trajectories

# Set viewing parameters
/vis/viewer/reset
/vis/viewer/set/viewpointThetaPhi  10 20

# Visualize one it.
/run/beamOn 1

##########################################################
# Visualization with the DAWNFILE driver
##########################################################

# Invoke the DAWNFILE driver
#  Create a scene handler and a viewer for the DAWNFILE driver
/vis/open DAWNFILE

# Create an empty scene and add detector components to it
/vis/drawVolume

# Add trajectories to the current scene
#  Note: This command is not necessary in exampleN03,
#        since the C++ method DrawTrajectory() is
#        described in the event action.
#/vis/scene/add/trajectories

# Visualize plural events (bird’s eye view)
#  drawing style: wireframe
#  viewpoint  : (theta,phi) = (45*deg, 45*deg)
#  zoom factor: 1.5 x (full screen size)
/vis/viewer/reset
/vis/viewer/set/style  wireframe
/vis/viewer/set/viewpointThetaPhi   45 45
/vis/viewer/zoom        1.5
/run/beamOn             2

# Set the drawing style to "surface"
#  Candidates: wireframe, surface
/vis/viewer/set/style  surface

# Visualize plural events (bird’s eye view) again
#  with another drawing style (surface)
/run/beamOn             2

################### END of vis2.mac ###################
```

2.10.7 Frequently Used Visualization Commands

In this section, we explain each visualization command appeared in the above sample sessions.

2.10.7.1 `/vis/open` command

- **Command**
  `/vis/open [driver_tag_name]`
- **Argument**
  A name of (a mode of) an available visualization driver.
- **Action**
  Create a visualization driver, i.e., a set of a scene hander and a viewer.
- **Example: Create the OpenGL-Xlib driver with its immediate mode**
  `Idle> /vis/open OGLIX`
- **Additional notes**
  How to list available driver_tag_name:

  `Idle> help /vis/open`
  or
  `Idle> help /vis/sceneHandler/create`

  The list is, for example, displayed as follows:
  .....
  `Candidates : DAWNFILE OGLIX OGLSX`
  .....

2.10.7.2 `/vis/viewer/` commands

- **Command**
  `/vis/viewer/reset`

- **Action**
  Reset camera parameters and drawing style to the default values.

- **Command**
  `/vis/viewer/set/viewpointThetaPhi [<theta>] [<phi>] [<deg|rad>]`
- **Arguments**
  Arguments "theta" and "phi" are polar and azimuthal camera angles, respectively. The default unit is "degree".
- **Action**
  Set a view point in direction of (theta, phi).
- **Example: Set the viewpoint in direction of (70 deg, 20 deg)**
  `Idle> /vis/viewer/set/viewpointThetaPhi 70 20`
- **Additional notes**
  Camera parameters should be set for each viewer. They are initialized with "`/vis/viewer/reset`". This command does Step 5 of Section 2.10.5.

- **Command**
  `/vis/viewer/zoom [<scale_factor>]`
- **Argument**
  The scale factor. The command multiplies magnification of the view by this factor.
- **Action**
  Zoom up/down of view.
- **Example: Zoom up by factor 1.5**
  `Idle> /vis/viewer/zoom 1.5`
- **Additional notes**
  Camera parameters should be set for each viewer. They are initialized with "`/vis/viewer/reset`". This command does Step 5 of Section 2.10.5.

- **Command**
  `/vis/viewer/set/style [style_name]`
- **Arguments**
  Candidate values of the argument are "wireframe" and "surface". ("w" and "s" also work.)
- **Action**
  Set a drawing style to wireframe or surface.
- **Example: Set the drawing style to "surface"**
  `Idle> /vis/viewer/set/style surface`
- **Additional notes**
  Drawing style should be set for each viewer. Command "`/vis/viewer/set/style`" does Step 5 of Section 2.10.5.

- **Command**
  `/vis/viewer/flush`
- **Action**
  Declare the end of visualization for flushing.

- **Additional notes**
  Command "`/vis/viewer/flush`" should follow "/vis/drawVolume", "/vis/specify", etc in order to complete visualization, which corresponds to Step 7 of Section 2.10.5.

2.10.7.3 `/vis/drawVolume` command

- **Command**
  ```
  /vis/drawVolume [<physical-volume-name>]
  ```
- **Argument**
  A physical-volume name. The default value is "world", which is omittable.
- **Action**
  Creates a scene consisting of the given physical volume and asks the current viewer to draw it. The scene becomes current. Command "`/vis/viewer/flush`" should follow this command in order to declare end of visualization.
- **Example: Visualization of the whole world with coordinate axes**
  ```
  Idle> /vis/drawVolume
  Idle> /vis/scene/add/axes 0 0 0 500 mm
  Idle> /vis/viewer/flush
  ```
- **Additional notes**
  Command "`/vis/drawVolume`" do Steps 2, 3, 4 of Section 2.10.5. Command "`/vis/viewer/flush`" should follow in order to complete the visualization (Steps 7).

2.10.7.4 `/vis/specify` command

- **Command**
  ```
  /vis/specify [logical-volume-name]
  ```
- **Argument**
  The argument is a logical-volume name.
- **Action**
  Creates a scene consisting of the given logical volume and asks the current viewer to draw it. The scene becomes current.
- **Example (visualization of a selected logical volume with coordinate axes)**
  ```
  Idle> /vis/specify Absorber
  Idle> /vis/scene/add/axes 0 0 0 500 mm
  Idle> /vis/scene/add/text 0 0 0 mm 40 -100 -200 LogVol:Absorber
  Idle> /vis/viewer/flush
  ```
- **Additional notes**
  Command `/vis/specify` do Steps 2, 3, 4, and 6 of Section 2.10.5. Command "`/vis/viewer/flush`" should follow the command in order to complete the visualization (Step 7).

2.10.7.5 Commands to visualize events

- **Command**
  ```
  /vis/scene/add/trajectories
  ```
- **Action**

The command adds trajectories to the current scene. Trajectories are drawn at end of event when the scene in which they are added is current.

- **Example: Visualization of trajectories**
```
Idle> /tracking/storeTrajectory 1
Idle> /vis/scene/add/trajectories
Idle> /run/beamOn 10
```
- **Additional note 1**
In examples/novice/N03, command "`/vis/scene/add/trajectories`" need not be executed, since the C++ method DrawTrajectory() is explicitly described in the event action. Therefore the command need not be executed though (G)UI.
- **Additional note 2**
In order that the command visualization with /run/beamOn works, the run action and/or event action should be implemented properly. In examples/novice/N03, the following implementations are described:

```
void ExN03RunAction::BeginOfRunAction(const G4Run* aRun)
{
  .....

  if (G4VVisManager::GetConcreteInstance())
  {
    G4UImanager* UI = G4UImanager::GetUIpointer();
    UI->ApplyCommand("/vis/scene/notifyHandlers");
  }
}

void ExN03RunAction::EndOfRunAction(const G4Run* )
{
  if (G4VVisManager::GetConcreteInstance()) {
     G4UImanager::GetUIpointer()->ApplyCommand("/vis/viewer/update");
  }
}
```

2.10.8 Visualization of the Detector Geometry Tree

Geant4 also support the "tree drivers", which visualize a detector geometry tree. At present, two tree drivers are implemented:

- The ASCII tree driver
- The GAG tree driver

The ASCII tree driver visualizes the tree on display with proper indentation of physical volume names. The GAG tree driver does the same thing witin the GAG GUI (http://erpc1.naruto-u.ac.jp/~geant4). The XML tree driver, which generates the trees with the XML format, will appear soon.

Note that you have to register your selected tree drivers in your Visualization Manager class in order to use them:

```
RegisterGraphicsSystem (new G4ASCIITree);
```

```
    RegisterGraphicsSystem (new G4GAGTree  );
```

See `examples/novice/N03/src/ExN03VisManager.cc`, too.

2.10.8.1 `/vis/drawTree` command

- **Command**
  `/vis/drawTree [<physical_volume_name>] [<driver_name>]`
  The candidate driver names are "ATree" (ASCII tree, default) and "GAGTree".
- **Action**
  Visualize a detector geometry tree.
- **Arguments**
  A Physical volume of the top hierarchy of a tree, and a tree-driver name.
- **Example: Visualization of the whole geometry**

```
Idle> /vis/drawTree ! ATree
.....
"Calorimeter", copy no. 0
    "Layer", copy no. -1 (10 replicas)
        "Absorber", copy no. 0
            "Gap", copy no. 0
.....
```

- **Additional note**
  The character '!' in the above example means "the default argument". It is the convention of the Geant4 interactive commands.

2.10.8.2 `/vis/XXXTree/verbose` command

- **Command**
  `/vis/XXXTree/verbose [<verbosity>]`

  "XXX" is "`ASCIITree`" for the ASCII tree driver, and "`GAG`" for the GAG tree driver. The verbosity is from 0 (default) to 10:

```
< 10: - does not print daughters of repeated logical volumes.
      - does not repeat replicas.
>= 10: prints all physical volumes.
>=  0: prints physical volume name.
>=  1: prints logical volume name.
>=  2: prints solid name and type.
```

- **Action**
  Customize the detail level of the visualized tree.
- **Example:**

```
Idle> /vis/ASCIITree/verbose 1
Idle> /vis/drawTree ! ATree
.....
"Calorimeter", copy no. 0, belongs to logical volume "Calorimeter"
  "Layer", copy no. -1, belongs to logical volume "Layer" (10 replicas)
```

```
            "Absorber", copy no. 0, belongs to logical volume "Absorber"
              "Gap", copy no. 0, belongs to logical volume "Gap"
        .....
```

About the authors

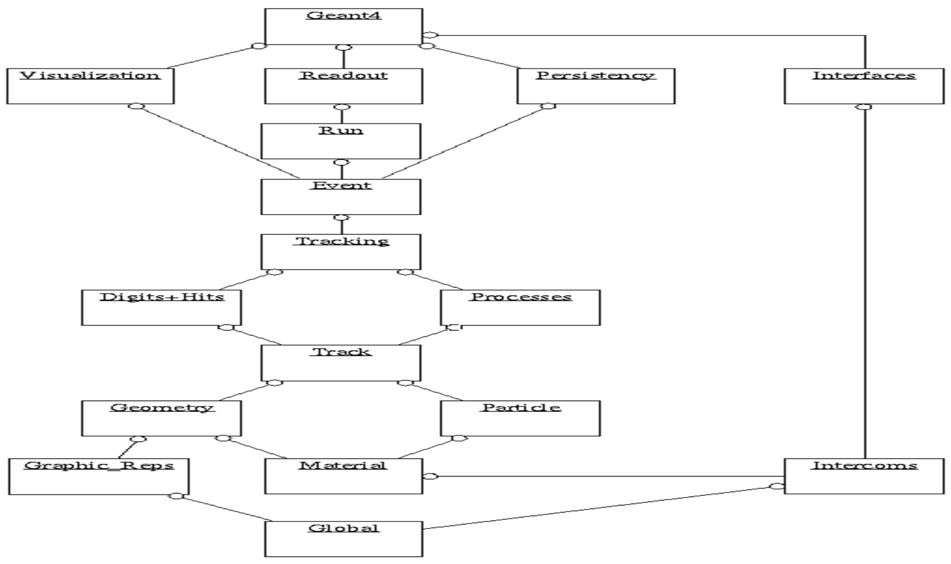
3. Toolkit Fundamentals

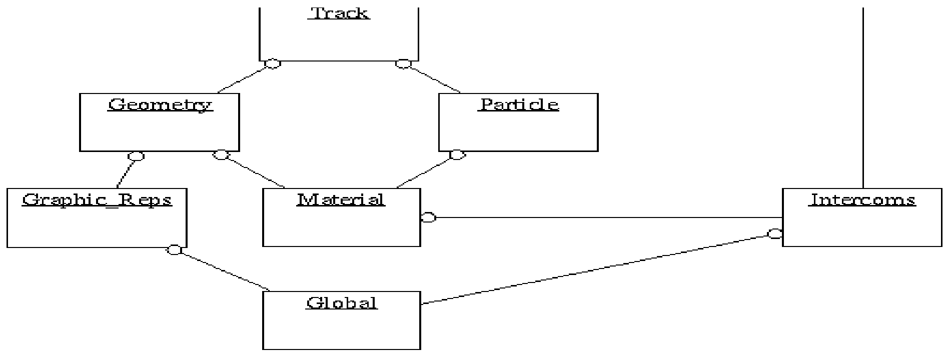
3.1 Class Categories and Domains

3.1.1 What is a class category?

In the design of a large software system such as Geant4, it is essential to partition it into smaller logical units. This makes the design well organized and easier to develop. Once the logical units are defined independent to each other as much as possible, they can be developed in parallel without serious interference.

In object-oriented analysis and design methodology by Grady Booch [1], class categories are used to create logical units. They are defined as "clusters of classes that are themselves cohesive, but are loosely coupled relative to other clusters." This means that a class category contains classes which have a close relationship (for example, the "has-a" relation). However, relationships between classes which belong to different class categories are weak, i.e., only limitted classes of these have "uses" relations. The class categories and their relations are presented by a class category diagram. The class category diagram designed for Geant4 is shown in the figure below. Each box in the figure represents a class category, and a "uses" relation by a straight line. The circle at an end of a straight line means the class category which has this circle uses the other category.





The file organization of the Geant4 codes follows basically the structure of this class cateogory. This *User's Manual* is also organized according to class categories.

In the development and maintenance of Geant4, one software team will be assigned to a class category. This team will have a responsibility to develop and maintain all classes belonging to the class category.

3.1.2 Class categories in Geant4

The following is a brief summary of the role of each class category in Geant4.

1. **Run and Event**

   These are categories related to the generation of events, interfaces to event generators, and any secondary particles produced. Their roles are principally to provide particles to be tracked to the Tracking Management.

2. **Tracking and Track**

These are categories related to propagating a particle by analyzing the factors limiting the step and applying the relevant physics processes. The important aspect of the design was that a generalized Geant4 physics process (or interaction) could perform actions, along a tracking step, either localized in space, or in time, or distributed in space and time (and all the possible combinations that could be built from these cases).

3. **Geometry, Magnetic Field and CAD-Interface**

   These three categories manage the geometrical definition of a detector (solid modeling and interactions with CAD systems) and the computation of distances to solids (also in a magnetic field). The Geant4 geometry solid modeler is based on the ISO STEP standard [7] and it is fully compliant with it, in order to be able to exchange geometrical information with CAD systems. A key feature of the Geant4 geometry is that the volume definitions are independent of the solid representation. By this abstract interface for the G4 solids, the tracking component works identically for various representations. The treatment of the propagation in the presence of fields has been provided within specified accuracy. An OO design allows us to exchange different numerical algorithms and/or different fields (not only B-field), without affecting any other component of the toolkit.

4. **Particle Definition and Matter**

   These two categories manage the the definition of materials and particles.

5. **Physics**

   This category manages all physics processes participating in the interactions of particles in matter. The abstract interface of physics processes allows multiple implementations of physics models per interaction or per channel. Models can be selected by energy range, particle type, material, etc. Data encapsulation and polymorphism make it possible to give transparent access to the cross sections (independently of the choice of reading from an ascii file, or of interpolating from a tabulated set, or of computing analytically from a formula). Electromagnetic and hadronic physics were handled in a uniform way in such a design, opening up the physics to the users.

6. **Hits and Digitization**

   These two categories manage the creation of hits and their use for the digitization phase. The basic design and implementation of the Hits and Digi had been realized, and also several prototypes, test cases and scenarios had been developed before the alpha-release. Volumes (not necessarily the ones used by the tracking) are aggregated in sensitive detectors, while hits collections represent the logical read out of the detector. Different ways of creating and managing hits collections had been delivered and tested, notably for both single hits and calorimetry hits types. In all cases, hits collections had been successfully stored into and retrieved from an Object Data Base Management System.

7. **Visualization**

   This manages the visualization of solids, trajectories and hits, and interacts with underlying graphical libraries (the Visualization class category). The basic and most frequently used graphics functionality had been implemented already by the alpha-release. The OO design of the visualization component allowed us to develop several drivers independently, such as for OpenGL and OpenInventor (for X11 and Windows), DAWN, Postscript (via DAWN) and VRML.

8. **Interfaces**

   This category handles the production of the graphical user interface (GUI) and the interactions with external software (OODBMS, reconstruction etc.).

---

[1] Grady Booch, Object-Oriented Analysis and Design with Applications The Benjamin/Cummings Publishing Co. Inc, 1994, ISBN 0-8053-5340-2

About the authors

3.2 Global Usage Classes

The "global" category in Geant4 collects all classes, types, structures and constants which are considered of general use within the Geant4 toolkit. This category also defines the interface with third-party software libraries (CLHEP, STL, etc.) and system-related types, by defining, where appropriate, `typedefs` according to the Geant4 code conventions.

3.2.1 Signature of Geant4 classes

In order to keep an homogeneous naming style, and according to the Geant4 coding style conventions, each class part of the Geant4 kernel has its name beginning with the prefix *G4*, e.g., *G4VHit, G4GeometryManager, G4ProcessVector*, etc. Instead of the raw C types, *G4* types are used within the Geant4 code. For the basic numeric types (`int, float, double,` etc.), different compilers and different platforms provide different value ranges. In order to assure portability, the use of *G4int, G4float, G4double,* which are base classes globally defined, is preferable. *G4* types implement the right generic type for a given architecture.

Basic types

The basic types in Geant4 are considered to be the following:

G4int, G4long, G4float, G4double, G4bool, G4complex and *G4String* which currently consist of simple `typedefs` to respective types defined in the **CLHEP**, **STL** or system libraries. Most definitions of these basic types come with the inclusion of a single header file, `globals.hh`. This file also provides inclusion of required system headers, as well as some global utility functions needed and used within the Geant4 kernel.

Typedefs to CLHEP classes and their usage

The following classes are `typedefs` to the corresponding classes of the **CLHEP** (**Computing Library for High Energy Physics**) distribution. For more detailed documentation please refer to the **CLHEP reference guide** [1] and the **CLHEP user manual** [2].

- *G4ThreeVector*, *G4RotationMatrix, G4LorentzVector* and *G4LorentzRotation*

  Vector classes: defining 3-component (x,y,z) vector entities, rotation of such objects as 3x3 matrices,
  4-component (x,y,z,t) vector entities and their rotation as 4x4 matrices.

- *G4Plane3D, G4Transform3D, G4Normal3D, G4Point3D,* and *G4Vector3D*

  Geometrical classes: defining geometrical entities and transformations in 3D space.

3.2.2 The *HEPRandom* module in CLHEP

The *HEPRandom* module, originally part of the Geant4 kernel, and now distributed as a module of **CLHEP**, has been designed and developed starting from the *Random* class of MC++, the original **CLHEP**'s *HepRandom* module and the **Rogue Wave** approach in the **Math.h++** package. For detailed documentation on the *HEPRandom* classes see the **CLHEP Reference Guide** [1] or the **CLHEP User Manual** [2].

Information written in this manual is extracted from the original manifesto [3] distributed with the *HEPRandom* package.

The *HEPRandom* module consists of classes implementing different random ‘‘engines’’ and different random ‘‘distributions’’. A distribution associated to an engine constitutes a random ‘‘generator’’. A distribution class can collect different algorithms and different calling sequences for each method to define distribution parameters or range-intervals. An engine implements the basic algorithm for pseudo-random numbers generation.

There are 3 different ways of shooting random values:

1. Using the static generator defined in the *HepRandom* class: random values are shot using static methods `shoot()` defined for each distribution class. The static generator will use, as default engine, a *HepJamesRandom* object, and the user can set its properties or change it with a new instantiated engine object by using the static methods defined in the *HepRandom* class.
2. Skipping the static generator and specifying an engine object: random values are shot using static

methods `shoot(*HepRandomEngine)` defined for each distribution class. The user must instantiate an engine object and give it as argument to the shoot method. The generator mechanism will then be by-passed by using the basic `flat()` method of the specified engine. The user must take care of the engine objects he/she instantiates.

3. Skipping the static generator and instantiating a distribution object: random values are shot using `fire()` methods (NOT static) defined for each distribution class. The user must instantiate a distribution object giving as argument to the constructor an engine by pointer or by reference. By doing so, the engine will be associated to the distribution object and the generator mechanism will be by-passed by using the basic `flat()` method of that engine.

In this guide, we'll only focus on the static generator (point 1.), since the static interface of *HEPRandom* is the only one used within the Geant4 toolkit.

***HEPRandom* engines**

The class *HepRandomEngine* is the abstract class defining the interface for each random engine. It implements the `getSeed()` and `getSeeds()` methods which return the 'initial seed' value and the initial array of seeds (if any) respectively. Many concrete random engines can be defined and added to the structure, simply making them inheriting from *HepRandomEngine*. Several different engines are currently implemented in *HepRandom*, we describe here five of them:

- *HepJamesRandom*

  It implements the algorithm described in ''F.James, Comp. Phys. Comm. 60 (1990) 329'' for pseudo-random number generation. This is the default random engine for the static generator; it will be invoked by each distribution class unless the user sets a different one.

- *DRand48Engine*

  Random engine using the `drand48()` and `srand48()` system functions from C standard library to implement the `flat()` basic distribution and for setting seeds respectively. *DRand48Engine* uses the `seed48()` function from C standard library to retrieve the current internal status of the generator, which is represented by 3 short values. *DRand48Engine* is the only engine defined in *HEPRandom* which intrinsically works in 32 bits precision. Copies of an object of this kind are not allowed.

- *RandEngine*

  Simple random engine using the `rand()` and `srand()` system functions from the C standard library to implement the `flat()` basic distribution and for setting seeds respectively. Please note that it's well known that the spectral properties of `rand()` leave a great deal to be desired, therefore the usage of this engine is not recommended if a good randomness quality or a long period is required in your code. Copies of an object of this kind are not allowed.

- *RanluxEngine*

  The algorithm for *RanluxEngine* has been taken from the original implementation in FORTRAN77 by Fred James, part of the **MATHLIB HEP** library. The initialisation is carried out using a

Multiplicative Congruential generator using formula constants of L'Ecuyer as described in ''F.James, Comp. Phys. Comm. 60 (1990) 329-344''. The engine provides five different luxury levels for quality of random generation. When instantiating a *RanluxEngine*, the user can specify the luxury level to the constructor (if not, the default value 3 is taken). For example:

```
RanluxEngine theRanluxEngine(seed,4);
// instantiates an engine with 'seed' and the best luxury-level
... or
RanluxEngine theRanluxEngine;
// instantiates an engine with default seed value and luxury-level
...
```

The class provides a `getLuxury()` method to get the engine luxury level.

The `SetSeed()` and `SetSeeds()` methods to set the initial seeds for the engine, can be invoked specifying the luxury level. For example:

```
// static interface
HepRandom::setTheSeed(seed,4);  // sets the seed to 'seed' and luxury to
HepRandom::setTheSeed(seed);    // sets the seed to 'seed' keeping
                                // the current luxury level
```

- *RanecuEngine*

  The algorithm for *RanecuEngine* is taken from the one originally written in FORTRAN77 as part of the **MATHLIB HEP** library. The initialisation is carried out using a Multiplicative Congruential generator using formula constants of L'Ecuyer as described in ''F.James, Comp. Phys. Comm. 60 (1990) 329-344''. Handling of seeds for this engine is slightly different than the other engines in *HEPRandom*. Seeds are taken from a seed table given an index, the `getSeed()` method returns the current index of seed table. The `setSeeds()` method will set seeds in the local `SeedTable` at a given position index (if the index number specified exceeds the table's size, `[index%size]` is taken). For example:

```
// static interface
const G4long* table_entry;
table_entry = HepRandom::getTheSeeds();
// it returns a pointer 'table_entry' to the local SeedTable
// at the current 'index' position. The couple of seeds
// accessed represents the current 'status' of the engine itself !
...
G4int index=n;
G4long seeds[2];
HepRandom::setTheSeeds(seeds,index);
// sets the new 'index' for seeds and modify the values inside
// the local SeedTable at the 'index' position. If the index
// is not specified, the current index in the table is considered.
...
```

  The `setSeed()` method resets the current 'status' of the engine to the original seeds stored in the static table of seeds in *HepRandom*, at the specified index.

Except for the *RanecuEngine*, for which the internal status is represented by just a couple of longs, all the other engines have a much more complex representation of their internal status, which currently can be obtained only through the methods `saveStatus()`, `restoreStatus()` and `showStatus()`, which can also be statically called from *HepRandom*. The status of the generator is needed for example to be able to reproduce a run or an event in a run at a given stage of the simulation.

RanecuEngine is probably the most suitable engine for this kind of operation, since its internal status can be fetched/reset by simply using `getSeeds()`/`setSeeds()` (`getTheSeeds()`/`setTheSeeds()` for the static interface in *HepRandom*).

The static interface in the *HepRandom* class

HepRandom a singleton class and using a *HepJamesRandom* engine as default algorithm for pseudo-random number generation. *HepRandom* defines a static private data member, `theGenerator`, and a set of static methods to manipulate it. By means of `theGenerator`, the user can change the underlying engine algorithm, get and set the seeds, and use any kind of defined random distribution. The static methods `setTheSeed()` and `getTheSeed()` will set and get respectively the ‘initial’ seed to the main engine used by the static generator. For example:

```
HepRandom::setTheSeed(seed);  // to change the current seed to ’seed’
int startSeed = HepRandom::getTheSeed();  // to get the current initial seed
HepRandom::saveEngineStatus();    // to save the current engine status on file
HepRandom::restoreEngineStatus(); // to restore the current engine to a previo
                                  // saved configuration
HepRandom::showEngineStatus();    // to display the current engine status to s
...
int index=n;
long seeds[2];
HepRandom::getTheTableSeeds(seeds,index);
  // fills ‘seeds’ with the values stored in the global
  // seedTable at position ‘index’
```

Only one random engine can be active at a time, the user can decide at any time to change it, define a new one (if not done already) and set it. For example:

```
RanecuEngine theNewEngine;
HepRandom::setTheEngine(&theNewEngine);
 ...
```

or simply setting it to an old instantiated engine (the old engine status is kept and the new random sequence will start exactly from the last one previously interrupted). For example:

```
HepRandom::setTheEngine(&myOldEngine);
```

Other static methods defined in this class are:

- `void setTheSeeds(const G4long* seeds, G4int)`
- `const G4long* getTheSeeds()`

  To set/get an array of seeds for the generator, in the case of a *RanecuEngine* this corresponds also to set/get the current status of the engine.

- `HepRandomEngine* getTheEngine()`

  To get a pointer to the current engine used by the static generator.

***HEPRandom* distributions**

A distribution-class can collect different algorithms and different calling sequences for each method to define distribution parameters or range-intervals; it also collects methods to fill arrays, of specified size, of random values, according to the distribution. This class collects either static and not static methods. A set of distribution classes are defined in *HEPRandom*. Here is the description of some of them:

- *RandFlat*

  Class to shoot flat random values (integers or double) within a specified interval. The class provides also methods to shoot just random bits.

- *RandExponential*

  Class to shoot exponential distributed random values, given a mean (default mean = 1)

- *RandGauss*

  Class to shoot Gaussian distributed random values, given a mean (default = 0) or specifying also a deviation (default = 1). Gaussian random numbers are generated two at the time, so every other time a number is shot, the number returned is the one generated the time before.

- *RandBreitWigner*

  Class to shoot numbers according to the Breit-Wigner distribution algorithms (plain or mean^2).

- *RandPoisson*

  Class to shoot numbers according to the Poisson distribution, given a mean (default = 1) (Algorithm taken from ‘‘W.H.Press et al., Numerical Recipes in C, Second Edition’’).

3.2.3 The *HEPNumerics* module

A set of classes implementing numerical algorithms has been developed in Geant4. Most of the algorithms and methods have been implemented mainly based on recommendations given in the books:

- B.H. Flowers, ‘‘An introduction to Numerical Methods In C++’’, Claredon Press, Oxford 1995.
- M. Abramowitz, I. Stegun, ‘‘Handbook of mathematical functions’’, DOVER Publications INC, New York 1965 ; chapters 9, 10, and 22.

This set of classes includes:

- *G4ChebyshevApproximation*

  Class creating the Chebyshev approximation for a function pointed by fFunction data member. The Chebyshev polynomial approximation provides an efficient evaluation of the minimax polynomial, which (among all polynomials of the same degree) has the smallest maximum deviation from the true function.

- *G4DataInterpolation*

  Class providing methods for data interpolations and extrapolations: Polynomial, Cubic Spline, ...

- *G4GaussChebyshevQ*
- *G4GaussHermiteQ*
- *G4GaussJacobiQ*
- *G4GaussLaguerreQ*

  Classes implementing the Gauss-Chebyshev, Gauss-Hermite, Gauss-Jacobi, Gauss-Laguerre and Gauss-Legendre quadrature methods. Roots of orthogonal polynomials and corresponding weights are calculated based on iteration method (by bisection Newton algorithm).

- *G4Integrator*

  Template class collecting integrator methods for generic functions (Legendre, Simpson, Adaptive Gauss, Laguerre, Hermite, Jacobi).

- *G4SimpleIntegration*

  Class implementing simple numerical methods (Trapezoidal, MidPoint, Gauss, Simpson, Adaptive Gauss, for integration of functions with signature: double f(double).

3.2.4 General management classes

The ‘global’ category defines also a set of ‘utility’ classes generally used within the kernel of Geant4. These classes include:

- *G4Allocator*

  A class for fast allocation of objects to the heap through paging mechanism. It’s meant to be used by associating it to the object to be allocated and defining for it `new` and `delete` operators via `MallocSingle()` and `FreeSingle()` methods of *G4Allocator*.

- *G4ReferenceCountedHandle*

  Template class acting as a smart pointer and wrapping the type to be counted. It performs the reference counting during the life-time of the counted object.

- *G4FastVector*

  Template class defining a vector of pointers, not performing boundary checking.

- *G4PhysicsVector*

  Defines a physics vector which has values of energy-loss, cross-section, and other physics values of a particle in matter in a given range of the energy, momentum, etc. This class serves as the base class for a vector having various energy scale, for example like 'log' (*G4PhysicsLogVector*) 'linear' (*G4PhysicsLinearVector*), 'free' (*G4PhysicsFreeVector*), etc.

- *G4LPhysicsFreeVector*

  Implements a free vector for low energy physics cross-section data. A subdivision method is used to find the energy|momentum bin.

- *G4PhysicsOrderedFreeVector*

  A physics ordered free vector inherits from *G4PhysicsVector*. It provides, in addition, a method for the user to insert energy/value pairs in sequence. Methods to retrieve the max and min energies and values from the vector are also provided.

- *G4Timer*

  Utility class providing methods to measure elapsed user/system process time.
  Uses `<sys/times.h>` and `<unistd.h>` - POSIX.1.

- *G4UserLimits*

  Class collecting methods for get and set any kind of step limitation allowed in Geant4.

- *G4UnitsTable*

  Placeholder for the system of units in Geant4.

[1] wwwinfo.cern.ch/asd/lhc++/clhep/manual/RefGuide.
[2] wwwinfo.cern.ch/asd/lhc++/clhep/manual/UserGuide.
[3] wwwinfo.cern.ch/asd/geant/geant4_public/Random.html.

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3.3 System of units

3.3.1 Basic units

Geant4 offers the user the possibility to choose and use the units he prefers for any quantity. In fact, the Geant4 kernel takes care of the units. Internally it uses a consistent set on units based on the `HepSystemOfUnits`:

```
millimeter              (mm)
nanosecond              (ns)
Mega electron Volt      (MeV)
positron charge         (eplus)
degree Kelvin           (kelvin)
the amount of substance (mole)
luminous intensity      (candela)
radian                  (radian)
steradian               (steradian)
```

All other units are defined from the basic ones.

For instance:

```
millimeter = mm = 1;
meter = m = 1000*mm;
...
m3 = m*m*m;
...
```

In the file `source/global/management/include/SystemOfUnits.h` you will find all of these definitions. That file is part of CLHEP.

Moreover, the user is free to change the system of units to be used by the kernel.

3.3.2 Input your data

Avoid ’hard coded’ data

You **must** give the units for the data you are going to introduce:

```
 G4double Size = 15*km, KineticEnergy = 90.3*GeV, density = 11*mg/cm3;
```

Indeed, the full Geant4 code is written respecting these specifications, and this makes it independent of the units chosen by the user.

If the units are not specified, it is understood that the data is implicitly in the internal G4 system, but this is strongly discouraged.

If the data set comes from an array or from an external file, it is strongly recommended to set the units as soon as the data are read, before any treatment. For instance:

```
for (int j=0, j<jmax, j++) CrossSection[j] *= millibarn;
...
my calculations
...
```

Interactive commands

Some built-in commands from the User Interface (UI) also require the units to be specified.

For instance:

```
  /gun/energy 15.2 keV
  /gun/position 3 2 -7 meter
```

If the units are not specified, or are not valid, the command is refused.

3.3.3 Output your data

You can output your data with the units you wish. To do so, it is sufficient to **divide** the data by the corresponding unit:

```
    G4cout << KineticEnergy/keV << " keV";
    G4cout << density/(g/cm3)   << " g/cm3";
```

Of course, `G4cout << KineticEnergy` will print the energy in the internal units system.

There is another way to output your data. Let Geant4 choose the most appropriate units for the actual numerical value of your data. It is sufficient to specify to which category your data belong (Length, Time, Energy, etc.). For example

```
    G4cout << G4BestUnit(StepSize, "Length");
```

`StepSize` will be printed in km, m, mm, fermi, etc. depending of its actual value.

3.3.4 Introduce new units

If you wish to introduce new units, there are two methods:

- You can complete the file `SystemOfUnits.h`

```
#include "SystemOfUnits.h"

static const G4double inch = 2.54*cm;
```

  Using this method, it is not easy to define composed units. It is better to do the following:

- You can instantiate an object of the class *G4UnitDefinition*

```
G4UnitDefinition ( name, symbol, category, value )
```

  For example: define a few units for speed

```
G4UnitDefinition ( "km/hour" , "km/h", "Speed", km/(3600*s) );
G4UnitDefinition ( "meter/ns", "m/ns", "Speed", m/ns );
```

  The category "Speed" does not exist by default in *G4UnitsTable*, but it will be created automatically.

  The class *G4UnitDefinition* is located in `source/global/management`.

3.3.5 Print the list of units

You can print the list of units with the static function: `G4UnitDefinition::PrintUnitsTable();`

or with the interactive command: `/units/list`

About the authors

3.4 Run

3.4.1 Basic concept of *Run*

In Geant4, *Run* is the largest unit of simulation. A run consists of a sequence of events. Within a run, the detector geometry, the set up of sensitive detectors, and the physics processes used in the simulation should be kept unchanged. A run is represented by a *G4Run* class object. A run starts with `beamOn()` method of *G4RunManager*.

Representation of a run

G4Run represents a run. It has a run identification number, which should be set by the user, and the number of events simulated during the run. Please note that the run identification number is not used by the Geant4 kernel, and thus it can be arbitrary number assigned for the sake of the user.

G4Run has pointers to the tables *G4VHitsCollection* and *G4VDigiCollection*. These tables are associated in case *sensitive detectors* and *digitizer modules* are simulated, respectively. The usage of these tables will be mentioned in Sections 4.4 and 4.5.

Manage the run procedures

G4RunManager manages the procedures of a run. In the constructor of *G4RunManager*, all of the manager classes in Geant4 kernel, except for some static managers, are constructed. These managers are deleted in the destructor of *G4RunManager*. *G4RunManager* must be a singleton, and the pointer to this singleton object can be obtained by the `getRunManager()` static method.

As already mentioned in Section 2.1, all of the *user initialization* classes and *user action* classes defined by the user should be assigned to *G4RunManager* before starting initialization of the Geant4 kernel. The assignments of these user classes are done by `SetUserInitialization()` and `SetUserAction()` methods. All user classes defined by the Geant4 kernel will be summarized in Section 6.

G4RunManager has several public methods, which are listed below.

`initialize()`
: Every initialization needed by the Geant4 kernel is triggered by this method. Initializations are:
  - construction of the detector geometry and set up of sensitive detectors and/or digitizer modules,
  - construction of particles and physics processes,
  - calculation of cross-section tables.

  This method is thus mandatory before proceeding to the first run. This method will be invoked automatically for the second and later runs in case some of the initialized quantities need to be updated.

`beamOn(G4int numberOfEvent)`
: This method triggers the actual simulation of a run, that is, an event loop. It takes an integer argument which represents the number of events to be simulated.

`getRunManager()`
: This static method returns the pointer to the *G4RunManager* singleton object.

`getCurrentEvent()`
: This method returns the pointer to the *G4Event* object which is currently simulating. This method is available only when an event is being processed. At this moment, the application state of Geant4, which is explained in the following sub-section, is *"EventProc"*. When Geant4 is in a state other than *"EventProc"*, this method returns `null`. Please note that the return value of this method is `const G4Event *` and thus you cannot modify the contents of the object.

`setNumberOfEventsToBeStored(G4int nPrevious)`
: For the case of simulating "pile up" of more than one event, it is essential to access to more than one event at the same moment. By invoking this method, *G4RunManager* keeps `nPrevious G4Event` objects. This method must be invoked before proceed to `beamOn()`.

`getPreviousEvent(G4int i_thPrevious)`
: The pointer to the `i_thPrevious G4Event` object can be obtained through this method. A pointer to a `const` object is returned. It is inevitable that `i_thPrevious` events must have already been simulated in the same run for getting the `i_thPrevious` event. Otherwise, this method returns `null`.

`abortRun()`
: This method should be invoked whenever the processing of a run must be stopped. It is valid for *GeomClosed* and *EventProc* states. Run processing will be safely aborted even in the midst of processing an event. However, the last event of the aborted run will be incomplete and should not be used for further analysis.

G4UserRunAction

G4UserRunAction is one of the *user action* classes from which you can derive your own concrete class. This base class has two virtual methods, as follows:

`beginOfRunAction()`
: This method is invoked at the beginning of the `beamOn()` method but after confirmation of the conditions of the Geant4 kernel. Presumable uses of this method are:
  - set a run identification number,
  - book histograms,
  - set run specific conditions of the sensitive detectors and/or digitizer modules (e.g., dead channel).

`endOfRunAction()` method
: This method is invoked at the very end of the `beamOn()` method. Typical use cases of this method are
  - store/print histograms,
  - manipulate run summaries.

3.4.2 Geant4 as a state machine

Geant4 is designed as a state machine. Some methods in Geant4 are available for only a certain state(s). *G4RunManager* controls the state changes of the Geant4 application. States of Geant4 are represented by the enumeration *G4ApplicationState*. It has six states through the life cycle of a Geant4 application.

PreInit state
: A Geant4 application starts with this state. The application needs to be initialized when it is in this state. The application occasionally comes back to this state if geometry, physics processes, and/or cut-off have been changed after processing a run.

Init state
: The application is in this state while the `initialize()` method of *G4RunManager* is being invoked. Methods defined in any *user initialization* classes are invoked during this state.

Idle state
: The application is ready for starting a run.

GeomClosed state
: When `beamOn()` is invoked, the application proceeds to this state to process a run. Geometry, physics processes, and cut-off cannot be changed during run processing.

EventProc state
: A Geant4 application is in this state when a particular event is being processed. `getCurrentEvent()` and `getPreviousEvent()` methods of *G4RunManager* are available only at this state.

Quit state
: When the destructor of *G4RunManager* is invoked, the application comes to this "dead end" state. Managers of the Geant4 kernel are being deleted and thus the application cannot come back to any other state.

Abort state
: When *G4Exception* occurs, the application comes to this "dead end" state and causes a core dump. The user still have a hook to do some "safe" opperations, e.g. storing histograms, by implementing a user concrete class of *G4VStateDependent*. The user also has a choice to suppress the occurence of *G4Exception* by a UI command */control/suppressAbortion*. When abortion is suppressed, you will still get error messages issued by G4Exception, and there is NO guarantee for the correct result after the G4Exception error message.

G4StateManager belongs to the *intercoms* category.

3.4.4 Customize the run manager

Virtual methods in the run manager

G4RunManager is a concrete class and it has a complete set of functionalities for managing the Geant4 kernel. On the other hand, *G4RunManager* is the only manager class in the Geant4 kernel which has to be constructed in the `main()` function of the user's application. Thus, instead of constructing *G4RunManager*, you can construct your own *RunManager*. It is recommended that your *RunManager* inherits *G4RunManager*. For this purpose, *G4RunManager* has various virtual methods. All of the required functionalities to handle Geant4 kernel are implemented into these virtual methods. Thus, you can define some particular methods for your customization, while the remaining methods in *G4RunManager* base class can still be used. Following are the structures of the virtual methods.

```
public: virtual void initialize();
```
main entry point of Geant4 kernel initialization

```
protected: virtual void initializeGeometry();
```
geometry construction

```
protected: virtual void initializePhysics();
```
physics processes construction

```
protected: virtual void initializeCutOff();
```
build cross-section tables

```
public: virtual void beamOn(G4int n_event);
```
main entry point of the event loop

```
protected: virtual G4bool confirmBeamOnCondition();
```
check the kernel conditions for the event loop

```
protected: virtual void runInitialization();
```
prepare a run

```
protected: virtual void doEventLoop(G4int n_events);
```
manage an event loop

```
protected: virtual G4Event* generateEvent(G4int i_event);
```
generation of *G4Event* object

```
protected: virtual void analyzeEvent(G4Event* anEvent);
```
storage/analysis of an event

```
protected: virtual void runTermination();
```
terminate a run

```
public: virtual void defineWorldVolume(G4VPhysicalVolume * worldVol);
```
set the world volume to *G4Navigator*

```
public: virtual void abortRun();
```
abort the run

Customize the event loop

The virtual `doEventLoop()` method of *G4RunManager* has a `for` loop which represents the event loop. In this loop, the following steps are taken for simulating an event.

1. Construct a *G4Event* object and set primary vertex(es) and primary particles to the *G4Event* object. This is done by the virtual `generatePrimaryEvent()` method.
2. The *G4Event* object is sent to *G4EventManager* for the detector simulation. *Hits* and *trajectories* will be associated to the *G4Event* object as a consequence.
3. Book keeping of the current *G4Event* object is done by the virtual `analyzeEvent()` method.

Thus, `doEventLoop()` performs an entire simulation of an event.

On the other hand, a rather frequent use is to split the above mentioned three steps into three isolated application programs. Detector simulation for producing hits/trajectories is time consuming, whereas changing thresholds of discriminators, gate widths of ADC, and/or trigger conditions, all of which belong to digitization, can be examined for various cases. Thus, it is rather wise to store hits/trajectories and digitize them with another program. For the second program, you should prepare your own `doEventLoop()` method, getting *G4Event* objects from a file (database) and analyzing (digitizing) them.

Change the detector geometry

The detector geometry defined in your *G4VUserDetectorConstruction* concrete class can be changed during a run break (between two runs). Two different cases are considered.

The first is the case in which you want to delete the entire structure of your old geometry and build up a completely new set of volumes. For this case, you need to set the new world physical volume pointer to the *RunManager*. Thus, you should proceed in the following way.

```
  G4RunManager* runManager = G4RunManager::GetRunManager();
  runManager->defineWorldVolume( newWorldPhys );
```

Presumably this case is rather rare. The second case is more frequent for the user.

The second case is the following. Suppose you want to move and/or rotate a particular piece of your detector component. This case can easily happen for a beam test of your detector. It is obvious for this case that you need not change the world volume. Rather, it should be said that your world volume (experimental hall for your beam test) should be big enough for moving/rotating your test detector. For this case, you can still use all of your detector geometries, and just use a `Set` method of a particular physical volume to update the transformation vector as you want. Thus, you don’t need to re-set your world volume pointer to *RunManager*.

If you want to change your geometry for every run, you can implement it in the `beginOfRunAction()` method of *G4UserRunAction* class, which will be invoked at the beginning of each run, or, derive the `runInitialization()` method. Please note that, for both of the above mentioned cases, you need to let *RunManager* know "the geometry needs to be closed again". Thus, you need to invoke

```
  runManager->geometryHasBeenModified();
```

before proceeding to the next run. An example of changing geometry is given in a Geant4 tutorial in Geant4 Training kit #2.

Switch physics processes

In the `initializePhysics()` method, `G4VUserPhysicsList::Construct` is invoked in order to define particles and physics processes in your application. Basically, you can not add nor remove any particles during execution, because particles are static objects in Geant4 (see Sections 2.4 and 5.3 for details). In addition, it is very difficult to add and/or remove physics processes during execution, because registration procedures are very complex, except for experts (see Sections 2.5 and 5.2). This is why the `initializePhysics()` method is assumed to be invoked at once in Geant4 kernel initialization.

However, you can switch on/off physics processes defined in your *G4VUserPhysicsList* concrete class and also change parameters in physics processes during the run break.

You can use `ActivateProcess()` and `InActivateProcess()` methods of *G4ProcessManager* anywhere outside the event loop to switch on/off some process. You should be very careful to switch on/off processes inside the event loop, though it is not prohibited to use these methods even in the *EventProc* state.

It is a likely case to change cut-off values in a run. You can change `defaultCutValue` in *G4VUserPhysicsList* during the *Idle* state. In this case, all cross section tables need to be recalculated before the event loop. You should use the `CutOffHasBeenModified()` method when you change cut-off values in order to trigger the `InitializeCutOff()` method, which invokes the `SetCuts` method of your *PhysicsList* concrete class.

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3.5 Event

3.5.1 Representation of an event

G4Event represents an event. An object of this class contains all inputs and outputs of the simulated event. This class object is constructed in *G4RunManager* and sent to *G4EventManager*. The event currently being processed can be obtained via the `getCurrentEvent()` method of *G4RunManager*.

3.5.2 Structure of an event

A *G4Event* object has four major types of information. Get methods for this information are available in *G4Event*.

Primary vertexes and primary particles
: Details are given in Section 3.6.

Trajectories
: Trajectories are stored in G4TrajectoryContainer class objects and the pointer to this container is stored in *G4Event*. The contents of a trajectory are given in 5.1.6.

Hits collections
: Collections of hits generated by *sensitive detectors* are kept in *G4HCofThisEvent* class object and the pointer to this container class object is stored in *G4Event*. See Section 4.4 for the details.

Digits collections
: Collections of digits generated by *digitizer modules* are kept in *G4DCofThisEvent* class object and the pointer to this container class object is stored in *G4Event*. See Section 4.5 for the details.

3.5.3 Mandates of *G4EventManager*

G4EventManager is the manager class to take care of one event. It is responsible for:

- converting *G4PrimaryVertex* and *G4PrimaryParticle* objects associated with the current *G4Event* object to *G4Track* objects. All of *G4Track* objects representing the primary particles are sent to *G4StackManager*.
- Pop one *G4Track* object from *G4StackManager* and send it to *G4TrackingManager*. The current *G4Track* object is deleted by *G4EventManager* after the track is simulated by *G4TrackingManager*, if the track is marked as "killed".
- In case the primary track is "suspended" or "postponed to next event" by *G4TrackingManager*, it is sent back to the *G4StackManager*. Secondary *G4Track* objects returned by *G4TrackingManager* are also sent to *G4StackManager*.
- When *G4StackManager* returns `NULL` for the "pop" request, *G4EventManager* terminates the current processing event.
- invokes the user-defined methods `beginOfEventAction()` and `endOfEventAction()` from the *G4UserEventAction* class. See Section 6.2 for details.

3.5.4. Stacking mechanism

G4StackManager has three stacks, named *urgent*, *waiting* and *postpone-to-next-event*, which are objects of the *G4TrackStack* class. By default, all *G4Track* objects are stored in the *urgent* stack and handled in a "last in first out" manner. In this case, the other two stacks are not used. However, tracks may be routed to the other two stacks by the user-defined *G4UserStackingAction* concrete class.

If the methods of *G4UserStackingAction* have been overridden by the user, the *postpone-to-next-event* and *waiting* stacks may contain tracks. At the beginning of an event, *G4StackManager* checks to see if any tracks left over from the previous event are stored in the *postpone-to-next-event stack*. If so, it attemps to move them to the *urgent* stack. But first the `PrepareNewEvent()` method of *G4UserStackingAction* is called. Here tracks may be re-classified by the user and sent to the *urgent* or *waiting* stacks, or deferred again to the *postpone-to-next-event* stack. As the event is processed *G4StackManager* pops tracks from the *urgent* stack until it is empty. At this point the `NewStage()` method of *G4UserStackingAction* is called. In this method tracks from the *waiting* stack may be sent to the *urgent* stack, retained in the *waiting* stack or postponed to the next event.

Details of the user-defined methods of *G4UserStackingAction* and how they affect track stack management are given in Section 6.2.

About the authors

3.6 Event Generator Interface

3.6.1 Structure of a primary event

Primary vertex and primary particle

The *G4Event* class object should have a set of primary particles when it is sent to *G4EventManager* via `processOneEvent()` method. It is the mandate of your *G4VUserPrimaryGeneratorAction* concrete class to send primary particles to the *G4Event* object.

The *G4PrimaryParticle* class represents a primary particle with which Geant4 starts simulating an event. This class object has information on particle type and its three momenta. The positional and time information of primary particle(s) are stored in the *G4PrimaryVertex* class object and, thus, this class object can have one or more *G4PrimaryParticle* class objects which share the same vertex. As shown in Fig.?.?, primary vertexes and primary particles are associated with the *G4Event* object by a form of linked list.

A concrete class of *G4VPrimaryGenerator*, the *G4PrimaryParticle* object is constructed with either a pointer to *G4ParticleDefinition* or an integer number which represents P.D.G. particle code. For the case of some artificial particles, e.g., geantino, optical photon, etc., or exotic nuclear fragments, which the P.D.G. particle code does not cover, the *G4PrimaryParticle* should be constructed by *G4ParticleDefinition* pointer. On the other hand, elementary particles with very short life time, e.g., weak bosons, or quarks/gluons, can be instantiated as *G4PrimaryParticle* objects using the P.D.G. particle code. It should be noted that, even though primary particles with such a very short life time are defined, Geant4 will simulate only the particles which are defined as *G4ParticleDefinition* class objects. Other primary particles will be simply ignored by *G4EventManager*. But it may still be useful to construct such "intermediate" particles for recording the origin of the primary event.

Forced decay channel

The *G4PrimaryParticle* class object can have a list of its daughter particles. If the parent particle is an "intermediate" particle, which Geant4 does not have a corresponding *G4ParticleDefinition*, this parent particle is ignored and daughters are assumed to start from the vertex with which their parent is associated. For example, a Z boson is associated with a vertex and it has positive and negative muons as its daughters, these muons will start from that vertex.

There are some kinds of particles which should fly some reasonable distances and, thus, should be simulated by Geant4, but you still want to follow the decay channel generated by an event generator. A typical case of these particles is B meson. Even for the case of a primary particle which has a corresponding *G4ParticleDefinition*, it can have daughter primary particles. Geant4 will trace the parent particle until it comes to decay, obeying multiple scattering, ionization loss, rotation with the magnetic field, etc. according to its particle type. When the parent comes to decay, instead of randomly choosing its decay channel, it follows the "pre-assigned" decay channel. To conserve the energy and the momentum of the parent, daughters will be Lorentz transformed according to their parent's frame.

3.6.2 Interface to a primary generator

G4HEPEvtInterface

Unfortunately, almost all event generators presently in use, commonly are written in FORTRAN. For Geant4, it was decided to not link with any FORTRAN program or library, even though the C++ language syntax itself allows such a link. Linking to a FORTRAN package might be convenient in some cases, but we will lose many advantages of object-oriented features of C++, such as robustness. Instead, Geant4 provides an ASCII file interface for such event generators.

G4HEPEvtInterface is one of *G4VPrimaryGenerator* concrete class and thus it can be used in your *G4VUserPrimaryGeneratorAction* concrete class. *G4HEPEvtInterface* reads an ASCII file produced by an event generator and reproduces *G4PrimaryParticle* objects associated with a *G4PrimaryVertex* object. It reproduces a full production chain of the event generator, starting with primary quarks, etc. In other words, *G4HEPEvtInterface* converts information stored in the `/HEPEVT/` common block to an object-oriented data structure. Because the `/HEPEVT/` common block is commonly used by almost all event generators written in FORTRAN, *G4HEPEvtInterface* can interface to almost all event generators currently used in the HEP community. The constructor of *G4HEPEvtInterface* takes the file name. Source listing 3.6.1 shows an example how to use *G4HEPEvtInterface*. Note that an event generator is not assumed to give a place of the primary particles, the interaction point must be set before invoking *GeneratePrimaryVertex()* method.

```
#ifndef ExN04PrimaryGeneratorAction_h
#define ExN04PrimaryGeneratorAction_h 1

#include "G4VUserPrimaryGeneratorAction.hh"
#include "globals.hh"

class G4VPrimaryGenerator;
class G4Event;

class ExN04PrimaryGeneratorAction : public G4VUserPrimaryGeneratorAction
{
  public:
    ExN04PrimaryGeneratorAction();
    ~ExN04PrimaryGeneratorAction();

  public:
    void GeneratePrimaries(G4Event* anEvent);

  private:
    G4VPrimaryGenerator* HEPEvt;
};

#endif


#include "ExN04PrimaryGeneratorAction.hh"

#include "G4Event.hh"
#include "G4HEPEvtInterface.hh"

ExN04PrimaryGeneratorAction::ExN04PrimaryGeneratorAction()
{
  HEPEvt = new G4HEPEvtInterface("pythia_event.data");
}

ExN04PrimaryGeneratorAction::~ExN04PrimaryGeneratorAction()
{
  delete HEPEvt;
}

void ExN04PrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
  HEPEvt->SetParticlePosition(G4ThreeVector(0.*cm,0.*cm,0.*cm));
  HEPEvt->GeneratePrimaryVertex(anEvent);
}
```

Source listing 3.6.1
An example code for *G4HEPEvtInterface*.

Format of the ASCII file

An ASCII file, which will be fed by *G4HEPEvtInterface* should have the following format.

- The first line of each primary event should be an integer which represents the number of the following lines of primary particles.

- Each line in an event corresponds to a particle in the `/HEPEVT/` common. Each line has `ISTHEP`, `IDHEP`, `JDAHEP(1)`, `JDAHEP(2)`, `PHEP(1)`, `PHEP(2)`, `PHEP(3)`, `PHEP(5)`. Refer to the `/HEPEVT/` manual for the meanings of these variables.

Source listing 3.6.2 shows an example FORTRAN code to generate an ASCII file.

```
***********************************************************
      SUBROUTINE HEP2G4
*
* Convert /HEPEVT/ event structure to an ASCII file
* to be fed by G4HEPEvtInterface
*
***********************************************************
      PARAMETER (NMXHEP=2000)
      COMMON/HEPEVT/NEVHEP,NHEP,ISTHEP(NMXHEP),IDHEP(NMXHEP),
     >JMOHEP(2,NMXHEP),JDAHEP(2,NMXHEP),PHEP(5,NMXHEP),VHEP(4,NMXHEP)
      DOUBLE PRECISION PHEP,VHEP
*
      WRITE(6,*) NHEP
      DO IHEP=1,NHEP
       WRITE(6,10)
     >  ISTHEP(IHEP),IDHEP(IHEP),JDAHEP(1,IHEP),JDAHEP(2,IHEP),
     >  PHEP(1,IHEP),PHEP(2,IHEP),PHEP(3,IHEP),PHEP(5,IHEP)
10     FORMAT(4I10,4(1X,D15.8))
      ENDDO
*
      RETURN
      END
```

Source listing 3.6.2
A FORTRAN example using the `/HEPEVT/` common.

Future interface to the new generation generators

Several activities have already been started for developing object-oriented event generators. Such new generators can be easily linked and used with a Geant4 based simulation. Furthermore, we need not distinguish a primary generator from the physics processes used in Geant4. Future generators can be a kind of physics process plugged-in by inheriting *G4VProcess*.

3.6.3 Event overlap using multiple generators

Your *G4VUserPrimaryGeneratorAction* concrete class can have more than one *G4VPrimaryGenerator* concrete class. Each *G4VPrimaryGenerator* concrete class can be accessed more than once per event. Using these class objects, one event can have more than one primary event.

One possible use is the following. Within an event, a *G4HEPEvtInterface* class object instantiated with a minimum bias event file is accessed 20 times and another *G4HEPEvtInterface* class object instantiated with a signal event file is accessed once. Thus, this event represents a typical signal event of LHC overlapping 20 minimum bias events. It should be noted that a simulation of event overlapping can be done by merging hits and/or digits associated with several events, and these events can be simulated independently. Digitization over multiple events will be mentioned in Section 4.5.

About the authors

4. Detector Definition and Response

4.1 Geometry

4.1.1 Introduction

The detector definition requires the representation of its geometrical elements, their materials and electronics properties, together with visualization attributes and user defined properties. The geometrical representation of detector elements focuses on the solid models definition and their spatial position, as well as their logical relations such as the relation of containment.

Geant4 manages the representation of the detector element properties via the concept of ''Logical Volume''. Geant4 manages the representation of the detector element spatial positioning and their logical relation via the concept of ''Physical Volume''. Geant4 manages the representation of the detector element solid modeling via the concept of ''Solid''.

The Geant4 solid modeler is STEP compliant. STEP is the ISO standard defining the protocol for exchanging geometrical data between CAD systems. This is achieved by standardizing the representation of solid models via the EXPRESS object definition language, which is part of the STEP ISO standard.

4.1.2 Solids

The STEP standard supports multiple solid representations. Constructive Solid Geometry (CSG) representations and Boundary Represented Solid (BREP) are available. Different representations are suitable for different purposes, applications, required complexity, and levels of detail. CSG representations normally give a superior performance and easy-of-use, but they cannot reproduce complex solids as used in CAD systems. BREP representations allow to handle a more extended topology, reproducing the most complex solids, and thus allowing the exchange of models with CAD systems.

4.1.2.1 Constructed Solid Geometry (CSG) Solids

CSG solids are defined directly as 3D primitives. They are described by a minimal set of parameters necessary to define the shape and the size of the solid. CSG solids are Boxes, Tubes and their sections, Cones and their sections, Spheres, Wedges, and Toruses.

To create a box one can use the constructor:

```
   G4Box(const G4String& pName,
               G4double  pX,
               G4double  pY,
               G4double  pZ)
```

by giving the box a name and its half-lengths along the X, Y and Z axis:

`pX`	half length in X	`pY`	half length in Y	`pZ`	half length in Z

This will create a box that extends from `-pX` to `+pX` in X, from `-pY` to `+pY` in Y, and from `-pZ` to `+pZ` in Z.

For example to create a box that is 2 by 6 by 10 centimeters in full length, and called `BoxA` one should use the following code:

```
   G4Box* aBox= G4Box("BoxA", 1.0*cm, 3.0*cm, 5.0*cm);
```

Similarly to create a cylindrical section or tube, one would use the constructor

```
   G4Tubs(const G4String& pName,
                G4double  pRMin,
                G4double  pRMax,
                G4double  pDz,
                G4double  pSPhi,
                G4double  pDPhi);
```

giving its name `pName` and its parameters which are

`pRMin`	Inner radius	`pRMax`	Outer radius
`pDz`	half length in z	`pSPhi`	the starting phi angle in radians
`pDPhi`	the angle of the segment in radians		

Similarly to create a cone, or conical section, one would use the constructor

```
        G4Cons(const G4String& pName,
                     G4double  pRmin1, G4double pRmax1,
                     G4double  pRmin2, G4double pRmax2,
                     G4double  pDz,
                     G4double  pSPhi, G4double pDPhi);
```

giving its name `pName`, and its parameters which are

`pDz`	half length in z	`pRmin1`	inside radius at `-pDz`
`pRmin2`	inside radius at `+pDz`	`pRmax1`	outside radius at `-pDz`
`pRmax2`	outside radius at `+pDz`	`pSPhi`	starting angle of the segment in radians
`pDPhi`	the angle of the segment in radians		

A Parallelepiped is constructed using

```
          G4Para(const G4String& pName,
                       G4double  dx, G4double dy, G4double dz,
                       G4double  alpha, G4double theta, G4double phi)
```

giving its name `pName` and its parameters which are

`dx,dy,dz`	Half-length in x,y,z
`alpha`	Angle formed by the y axis and by the plane joining the centre of the faces *G4Parallel* to the z-x plane at -dy and +dy
`theta`	Polar angle of the line joining the centres of the faces at -dz and +dz in z
`phi`	Azimuthal angle of the line joining the centres of the faces at -dz and +dz in z

To construct a trapezoid use

```
   G4Trd( const G4String& pName,
                G4double  dx1, G4double dx2,
                G4double  dy1, G4double dy2,
                G4double  dz )
```

to obtain a solid with name `pName` and parameters

`dx1`	Half-length along x at the surface positioned at `-dz`
`dx2`	Half-length along x at the surface positioned at `+dz`
`dy1`	Half-length along y at the surface positioned at `-dz`
`dy2`	Half-length along y at the surface positioned at `+dz`
`dz`	Half-length along z axis

To build a generic trapezoid, the G4Trap class is provided. Here is the simplest costructor for Right Angular Wedge defined for it

```
   G4Trap( const G4String& pName,
                 G4double  pZ, G4double pY, G4double pX,
                 G4double  pLTX )
```

to obtain a solid with name `pName` and parameters

`pZ`	Length along z
`pY`	Length along y
`pX`	Length along x at the wider side
`pLTX`	Length along x at the narrower side (`plTX<=pX`)

For the complete set of constructors see the Software Reference Manual.

To build a sphere use

```
   G4Sphere( const G4String& pName,
                   G4double  pRmin, G4double pRmax,
                   G4double  pSPhi, G4double pDPhi,
                   G4double  pSTheta, G4double pDTheta )
```

to obtain a solid with name `pName` and parameters

`pRmin`	Inner radius
`pRmax`	Outer radius
`pSPhi`	Starting Phi angle of the segment in radians
`pDPhi`	Delta Phi angle of the segment in radians
`pSTheta`	Starting Theta angle of the segment in radians
`pDTheta`	Delta Theta angle of the segment in radians

To build a torus use

```
  G4Torus( const G4String& pName,
                 G4double  pRmin, G4double pRmax,
                 G4double  pRtor, G4double pSPhi, G4double pDPhi )
```

to obtain a solid with name `pName` and parameters

`pRmin`	Inside radius
`pRmax`	Outside radius
`pRtor`	Swept radius of torus
`pSPhi`	Starting Phi angle in radians (`fSPhi+fDPhi<=2PI`, `fSPhi>-2PI`)
`pDPhi`	Delta angle of the segment in radians

In addition, the Geant4 Design Documentation shows in the Solids Class Diagram the complete list of CSG classes, and the STEP documentation contains a detailed EXPRESS description of each CSG solid.

Specific CSG Solids

Polycons (PCON) are implemented in Geant4 through the G4Polycon class:

```
   G4Polycone( const G4String& pName,
                     G4double  phiStart,
                     G4double  phiTotal,
                     G4int     numZPlanes,
               const G4double  zPlane[],
               const G4double  rInner[],
               const G4double  rOuter[])

   G4Polycone( const G4String& pName,
                     G4double  phiStart,
                     G4double  phiTotal,
                     G4int     numRZ,
               const G4double  r[],
               const G4double  z[])
```

where:

`phiStart`	Initial Phi starting angle
`phiTotal`	Total Phi angle
`numZPlanes`	Number of z planes
`numRZ`	Number of corners in r,z space
`zPlane`	Position of z planes
`rInner`	Tangent distance to inner surface
`rOuter`	Tangent distance to outer surface
`r`	r coordinate of corners
`z`	z coordinate of corners

Polyhedra (PGON) are implemented through G4Polyhedra:

```
   G4Polyhedra( const G4String& pName,
                      G4double  phiStart,
                      G4double  phiTotal,
                      G4int     numSide,
                      G4int     numZPlanes,
                const G4double  zPlane[],
                const G4double  rInner[],
                const G4double  rOuter[]  )

   G4Polyhedra( const G4String& pName,
                      G4double  phiStart,
                      G4double  phiTotal,
                      G4int     numSide,
                      G4int     numRZ,
                const G4double  r[],
                const G4double  z[] )
```

where:

`phiStart`	Initial Phi starting angle
`phiTotal`	Total Phi angle
`numSide`	Number of sides
`numZPlanes`	Number of z planes
`numRZ`	Number of corners in r,z space
`zPlane`	Position of z planes
`rInner`	Tangent distance to inner surface
`rOuter`	Tangent distance to outer surface
`r`	r coordinate of corners
`z`	z coordinate of corners

A tube with elliptical cross section (ELTU) can be defined as following:

```
   G4EllipticalTube( const G4String& pName,
                           G4double  Dx,
                           G4double  Dy,
                           G4double  Dz )
```

The equation of the surface in x/y is `1.0 = (x/dx)**2 + (y/dy)**2`

`Dx`	Half length in X	`Dy`	Half length in Y	`Dz`	Half length in Z

A tube with hyperbolic profile (HYPE) can be defined as following:

```
   G4Hype(const G4String& pName,
                G4double  innerRadius,
                G4double  outerRadius,
                G4double  innerStereo,
                G4double  outerStereo,
                G4double  halfLenZ )
```

G4Hype is shaped with curved sides parallel to the z-axis, has a specified half-length along the z axis about which it is centred, and a given minimum and maximum radius.
A minimum radius of 0 defines a filled Hype (with hyperbolical inner surface), i.e. inner radius = 0 AND inner stereo angle = 0.
The inner and outer hyperbolical surfaces can have different stereo angles. A stereo angle of 0 gives a cylindrical surface.

`innerRadius`	Inner radius
`outerRadius`	Outer radius
`innerStereo`	Inner stereo angle in radians
`outerStereo`	Outer stereo angle in radians
`halfLenZ`	Half length in Z

4.1.2.2 Solids made by boolean operations

Simple solids can be combined using boolean operations. For example, a cylinder and a half-sphere can be combined with the union boolean operation.

Creating such a new ‘‘boolean’’ solid, requires:

- Two solids
- A boolean operation: union, intersection or subtraction.
- Optionally a transformation for the second solid.

The solids used should be either CSG solids (for examples a box, a spherical shell, or a tube) or another ‘‘boolean’’ solid: the product of a previous boolean operation. An important purpose of ‘‘boolean’’ solids is to allow the description of solids with peculiar shapes in a simple and intuitive way, still allowing an efficient geometrical navigation inside them.

Note: The solids used can actually be of any type. However, in order to fully support the export of a Geant-4 solid model via STEP to CAD systems, we restrict the use of boolean operations to this subset of solids. But this subset contains all the most interesting use cases.

Note: The tracking cost for navigating in a Boolean solid (in its current implementation) is proportional to the number of constituent solids. So care must be taken to avoid extensive unecessary use of Boolean solids -- where each one is created from Boolean combinations of many other solids -- in performance critical areas of a geometry description.

Examples of the creation of the simplest ‘‘boolean’’ solids are given below:

```
  G4Box box1("Box #1",20,30,40);
  G4Tubs Cylinder1("Cylinder #1",0,50,50,0,2*M_PI);  // r:     0 -> 50
                                                     // z:   -50 -> 50
                                                     // phi:   0 ->  2 pi
  G4UnionSolid b1UnionC1("Box+Cylinder", &box1, &Cylinder1);
  G4IntersectionSolid b1IntersC1("Box Intersect Cylinder", &box1, &Cylinder1);
  G4SubtractionSolid b1minusC1("Box-Cylinder", &box1, &Cylinder1);
```

where the union, intersection and subtraction of a box and cylinder are constructed.

The more useful case where one of the solids is displaced from the origin of coordinates also exists. In this case the second solid is positioned relative to the coordinate system (and thus relative to the first). This can be done in two ways:

- Either by giving a rotation matrix and translation vector that are used to transform the coordinate system of the first solid to the coordinate system of the second solid. This is called the passive method.
- Or by creating a transformation that moves the second solid from its desired position to its standard position, e.g., a box’s standard position is with its centre at the origin and sides parallel to the three axes. This is called the active method.

In the first case, the translation is applied first to move the origin of coordinates. Then the rotation is used to rotate the coordinate system of the first solid to the coordinate system of the second.

```
    G4RotationMatrix yRot45deg;   // Rotates X and Z axes only

    yRot45deg.rotateY(M_PI/4.);
    G4ThreeVector  translation(0, 0, 50);
    G4UnionSolid  box1UnionCyl1Mv("Box1UnionCyl1Moved",
                    &box1,&Cylinder1,&yRot45deg,translation) ;
    // The new coordinate system of the cylinder is translated so that
    // its centre is at +50 on the original Z axis, and it is rotated
    // with its X axis halfway between the original X and Z axes.

    // Now we build the same solid using the alternative method
    G4RotationMatrix InvRot= yRot45deg;
    yRot45deg.invert();
    // or else InvRot.yRotate( -M_PI/4.0);
    G4Transform3D transform(InvRot,translation) ;
    G4UnionSolid  SameUnion("Box1UnionCyl1Moved2",&t1,&b3,transform) ;
```

Note that the first constructor that takes a *G4RotationMatrix* does not copy it. Therefore once used a Rotation Matrix to construct a Boolean solid, it must not be modified.

In contrast, a *G4Transform3D* is provided to the constructor by value, and its transformation is stored by the Boolean solid. The user may modify the *G4Transform3D* and use it again.

4.1.2.3 Boundary Represented (BREPS) Solids

BREP solids are defined via the description of their boundaries. The boundaries can be made of planar and second order surfaces. Eventually these can be trimmed and have holes. The resulting solids, such as polygonal, polyconical, and hyperboloidal solids are known as Elementary BREPS.

In addition, the boundary surfaces can be made of Bezier surfaces and B-Splines, or of NURBS (Non-Uniform-Rational-B-Splines) surfaces. The resulting solids are Advanced BREPS.

We have defined a few simple Elementary BREPS, that can be instantiated simply by a user in a manner similar to the construction of Constructed Solids (CSGs). We summarize their capabilities in the following section.

However most BREPS Solids are defined by creating each surface separately and tying them together. Though it is possible to do this using code, it is potentially error prone. So generally much more productive to utilize a tool to create these volumes, and the tools of choice are CAD systems. Models created in CAD systems can be exported utilizing the STEP standard.

So BREPS solids are normally defined via the use of a STEP reader. This reader allows the user to import any solid model created in a CAD system, as described in Section 4.1.10 of this document.

Specific BREP Solids

We have defined one polygonal and one polyconical shape using BREPS. The polycone provides a shape defined by a series of conical sections with the same axis, contiguous along it.

The polyconical solid *G4BREPSolidPCone* is a shape defined by a set of inner and outer conical or cylindrical surface sections and two planes perpendicular to the Z axis. Each conical surface is defined by its radius at two different planes perpendicular to the Z-axis. Inner and outer conical surfaces are defined using common Z planes.

```
  G4BREPSolidPCone( const G4String& pName,
                          G4double  start_angle,
                          G4double  opening_angle,
                          G4int     num_z_planes,    // sections,
                          G4double  z_start,
                    const G4double  z_values[],
                    const G4double  RMIN[],
                    const G4double  RMAX[]  )
```

The conical sections do not need to fill 360 degrees, but can have a common start and opening angle.

`start_angle`	starting angle
`opening_angle`	opening angle
`num_z_planes`	number of planes perpendicular to the z-axis used.
`z_start`	starting value of z
`z_values`	z coordinates of each plane
`RMIN`	radius of inner cone at each plane
`RMAX`	radius of outer cone at each plane

The polygonal solid *G4BREPSolidPolyhedra* is a shape defined by an inner and outer polygonal surface and two planes perpendicular to the Z axis. Each polygonal surface is created by linking a series of polygons created at different planes perpendicular to the Z-axis. All these polygons all have the same number of sides (`sides`) and are defined at the same Z planes for both inner and outer polygonal surfaces.

The polygons do not need to fill 360 degrees, but have a start and opening angle.

The constructor takes the following parameters:

```
  G4BREPSolidPolyhedra( const G4String& pName,
                              G4double  start_angle,
                              G4double  opening_angle,
                              G4int     sides,
                              G4int     num_z_planes,
                              G4double  z_start,
                        const G4double  z_values[],
                        const G4double  RMIN[],
                        const G4double  RMAX[]  )
```

which in addition to its name have the following meaning:

`start_angle`	starting angle
`opening_angle`	opening angle
`sides`	number of sides of each polygon in the x-y plane
`num_z_planes`	number of planes perpendicular to the z-axis used.
`z_start`	starting value of z
`z_values`	z coordinates of each plane
`RMIN`	radius of inner polygon at each plane
`RMAX`	radius of outer polygon at each plane

the shape is defined by the number of sides `sides` of the polygon in the plane perpendicular to the z-axis.

Other BREP Solids

Other solids can be created by defining their boundary surfaces. Creating these BREP Solids is complex. So they are typically built using a Computer Aided Design (CAD) program. The CAD system can create a single solid or an assembly of several solids. Importing the definition of these solids is done using a STEP interchange file, as described in another section of this guide.

4.1.3 Logical Volumes

The Logical Volume manages the information associated to detector elements represented by a given Solid and Material, independently from its physical position in the detector.

A Logical Volume knows what are the physical volumes contained in it. It is uniquely defined to be their mother volume. A Logical Volume thus represents a hierarchy of unpositioned volumes with a well defined position between themselves. By creating Physical Volumes, which are placed instances of a Logical Volume, this hierarchy or tree can be repeated.

A Logical Volume also manages the information relative to the Visualization attributes (Section 8.3) and user-defined parameters related to tracking, electro-magnetic field or cuts (through the G4UserLimits interface).

```
    G4LogicalVolume( G4VSolid*             pSolid,
                     G4Material*           pMaterial,
                     const G4String&       pName,
                     G4FieldManager*       pFieldMgr=0,
                     G4VSensitiveDetector* pSDetector=0,
                     G4UserLimits*         pULimits=0 )
```

Finally, the Logical Volume manages the information relative to the Envelopes hierarchy required for fast Monte Carlo parameterisations (Section 5.2.6).

4.1.4 Physical Volumes

Physical volumes represent the spatial positioning of the volumes describing the detector elements. Several techniques can be used. They range from the simple placement of a single copy to the repeated positioning using either a simple linear formula or a user specified function.

The simple placement involves the definition of a transformation matrix for the volume to be positioned. Repeated positioning is defined using the number of times a volume should be replicated at a given distance along a given direction. Finally it is possible to define a parameterised formula to specify the position of multiple copies of a volume. Details about these methods are given below.

4.1.4.1 Placements: single positioned copy

In this case, the Physical Volume is created by associating a Logical Volume with a Rotation Matrix and a Translation vector. The Rotation Matrix represents the rotation of the reference frame of the considered volume relatively to its mother volume's reference frame. The Translation Vector represents the translation of the current volume in the reference frame of its mother volume.

To create a Placement one must construct it using

```
    G4PVPlacement(       G4RotationMatrix*  pRot,
                   const G4ThreeVector&     tlate,
                   const G4String&          pName,
                         G4LogicalVolume*   pLogical,
                         G4VPhysicalVolume* pMother,
                         G4bool             pMany,
                         G4int              pCopyNo )
```

where

`pRot`	Rotation with respect to its mother volume
`tlate`	Translation with respect to its mother volume
`pName`	String identifier for this placement
`pLogical`	The associated Logical Volume
`pMother`	The associated mother volume
`pMany`	For future use. Can be set to false
`pCopyNo`	Integer which identifies this placement

Care must be taken because the rotation matrix is not copied by a *G4PVPlacement*. So the user must not modify it after creating a Placement that uses it. However the same rotation matrix can be re-used for many volumes.

Currently boolean operations are not implemented at the level of physical volume. So `pMany` must be false. However, an alternative implementation of boolean operations exists. In this approach a solid can be created from the union, intersection or subtraction of two solids. See Section 4.1.2.2 above for an explanation of this.

The mother volume must be specified for all volumes except a world volume.

An alternative way to specify a Placement utilizes a different method to place the volume. The solid itself is moved by rotating and translating it to bring it into the system of coordinates of the mother volume. This ‘‘active’’ method can be utilized using the following constructor:

```
    G4PVPlacement(       G4Transform3D      solidTransform,
                   const G4String&          pName,
                         G4LogicalVolume*   pLogical,
                         G4VPhysicalVolume* pMother,
                         G4bool             pMany,
                         G4int              pCopyNo )
```

An alternative method to specify the mother volume is to specify its unplaced logical volume. It can be used in either of the above methods of specifying the placement’s position and rotation.

Note that a Placement Volume can still represent multiple detector elements. This can happen if several copies exist of the mother logical volume. Then different detector elements will belong to different branches of the tree of the hierarchy of geometrical volumes.

4.1.4.2 Repeated volumes

In this case, a single Physical Volume represent multiple copies of a volume within its mother volume, allowing to save memory. This is normally done when the volumes to be positioned follow a well defined rotational or translational symmetry along a Cartesian or cylindrical coordinate. The Repeated

Volumes technique is available for volumes described by CSG solids.

Replicas

Replicas are *repeated volumes* in the case when the multiple copies of the volume are all identical. The coordinate axis and the number of replicas need to be specified for the program to compute at run time the transformation matrix corresponding to each copy.

```
G4PVReplica( const G4String&          pName,
                   G4LogicalVolume*   pLogical,
                   G4VPhysicalVolume* pMother, // OR G4LogicalVolume* pMother,
             const EAxis              pAxis,
             const G4int              nReplicas,
             const G4double           width,
             const G4double           offset=0 )
```

where

`pName`	String identifier for the replicated volume
`pLogical`	The associated Logical Volume
`pMother`	The associated mother volume
`pAxis`	The axis along with the replication is applied
`nReplicas`	The number of replicated volumes
`width`	The width of a single replica along the axis of replication
`offset`	Possible offset associated to mother offset along the axis of replication

G4PVReplica represents `nReplicas` volumes differing only in their positioning, and completely **filling** the containing mother volume. Consequently if a G4PVReplica is 'positioned' inside a given mother it **MUST** be the mother's only daughter volume. Replica's correspond to divisions or slices that completely fill the mother volume and have no offsets. For Cartesian axes, slices are considered perpendicular to the axis of replication.

The replica's positions are calculated by means of a linear formula. Replication may occur along:

- *Cartesian axes* *`(kXAxis,kYAxis,kZAxis)`*
  The replications, of specified width have coordinates of form
  `(-width*(nReplicas-1)*0.5+n*width,0,0)`
  where `n=0.. nReplicas-1` for the case of `kXAxis`, and are unrotated.
- *Radial axis (cylindrical polar)* *`(kRho)`*
  The replications are cons/tubs sections, centred on the origin and are unrotated.
  They have radii of `width*n+offset` to `width*(n+1)+offset` where `n=0..nReplicas-1`
- *Phi axis (cylindrical polar)* *`(kPhi)`*

The replications are *phi sections* or *wedges*, and of cons/tubs form.
They have `phi` of `offset+n*width` to `offset+(n+1)*width` where `n=0..nReplicas-1`

The coordinate system of the replicas is at the centre of each replica for the cartesian axis. For the radial case, the coordinate system is unchanged from the mother. For the `phi` axis, the new coordinate system is rotated such that the X axis bisects the angle made by each wedge, and Z remains parallel to the mother's Z axis.

The solid associated via the replicas' logical volume should have the dimensions of the first volume created and must be of the correct symmetry/type, in order to assist in good visualisation.
ex. For X axis replicas in a box, the solid should be another box with the dimensions of the replications. (same Y & Z dimensions as mother box, X dimension = mother's X dimension/nReplicas).

Replicas may be placed inside other replicas, provided the above rule is observed. Normal placement volumes may be placed inside replicas, provided that they do not intersect the mother's or any previous replica's boundaries. Parameterised volumes may not be placed inside.
Because of these rules, it is not possible to place any other volume inside a replication in `r`.

During tracking, the translation + rotation associated with each G4PVReplica object is modified according to the currently 'active' replication. The solid is not modified and consequently has the wrong parameters for the cases of `phi` and `r` replication and for when the cross-section of the mother is not constant along the replication.

Example:

```
G4PVReplica repX("Linear Array",
                 pRepLogical,
                 pContainingMother,
                 kXAxis, 5, 10*mm);

G4PVReplica repR("RSlices",
                 pRepRLogical,
                 pContainingMother,
                 kRho, 5, 10*mm, 0);

G4PVReplica repRZ("RZSlices",
                  pRepRZLogical,
                  &repR,
                  kZAxis, 5, 10*mm);

G4PVReplica repRZPhi("RZPhiSlices",
                     pRepRZPhiLogical,
                     &repRZ,
                     kPhi, 4, M_PI*0.5*deg, 0);
```

Source listing 4.1.1
An example of simple replicated volumes with `G4PVReplica`.

`RepX` is an array of 5 replicas of width 10*mm, positioned inside and completely filling the volume pointed by `pContainingMother`. The mother's X length must be 5*10*mm=50*mm (for example, if the mother’s solid were a Box of half lengths [25,25,25] then the replica’s solid must be a box of half lengths [25,25,5]).

If the containing mother’s solid is a tube of radius 50*mm and half Z length of 25*mm, `RepR` divides the mother tube into 5 cylinders (hence the solid associated with `pRepRLogical` must be a tube of radius 10*mm, and half Z length 25*mm); `repRZ` divides it into 5 shorter cylinders (the solid associated with `pRepRZLogical` must be a tube of radius 10*mm, and half Z length 5*mm); finally, `repRZPhi` divides it into 4 tube segments with full angle of 90 degrees (the solid associated with `pRepRZPhiLogical` must be a tube segment of radius 10*mm, half Z length 5*mm and delta phi of M_PI*0.5*deg).
No further volumes may be placed inside these replicas. To do so would result in intersecting boundaries due to the `r` replications.

Parameterised Volumes

Parameterised Volumes are *repeated volumes* in the case in which the multiple copies of a volume can be different in size, solid type, or material. The solid’s type, its dimensions, the material and the transformation matrix can all be parameterised in function of the copy number, both when a strong symmetry exist and when it does not. The user implements the desired parameterisation function and the program computes and updates automatically at run time the information associated to the Physical Volume.

An example of creating a parameterised volume exists in novice example N02. Two source files are used, `ExN02DetectorConstruction.cc` and `ExN02ChamberParameterisation.cc`.

To create a parameterised volume, one must first create its logical volume like `trackerChamberLV` below. Then one must create his own parameterisation class (*ExN02ChamberParameterisation*) and instantiate an object of this class (`chamberParam`). We will see how to create the parameterisation below.

```
//------------------------------
// Tracker segments
//------------------------------
// An example of Parameterised volumes
// dummy values for G4Box -- modified by parameterised volume
G4VSolid * solidChamber =
              new G4Box("chamberBox", 10.*cm, 10.*cm, 10.*cm);

G4LogicalVolume * trackerChamberLV
  = new G4LogicalVolume(solidChamber, Aluminum, "trackerChamberLV");
G4VPVParameterisation * chamberParam
  = new ExN02ChamberParameterisation(
                       6,            //  NoChambers,
                      -240.*cm,      //  Z of centre of first
                      80*cm,         //  Z spacing of centres
                      20*cm,         //  Width Chamber,
                      50*cm,         //  lengthInitial,
                      trackerSize*2.); //  lengthFinal

G4VPhysicalVolume *trackerChamber_phys
  = new G4PVParameterised("TrackerChamber_parameterisedPV",
                     trackerChamberLV, // Its logical volume
                     physiTracker,     // Mother physical volume
                     kZAxis,           // Are placed along this axis
                     6,                // Number of chambers
                     chamberParam);    // The parameterisation
// kZAxis is used only for optimisation in geometrical calculations
```

Source listing 4.1.2
An example of Parameterised volumes.

The general constructor is:

```
G4PVParameterised( const G4String&              pName,
                         G4LogicalVolume*       pLogical,
                         G4VPhysicalVolume*     pMother, // OR G4LogicalVolume*
                   const EAxis                  pAxis,
                   const G4int                  nReplicas,
                         G4VPVParameterisation* pParam )
```

Note that for a parameterised volume the user must alway specify a mother volume. So the world volume can never be a parameterised volume. The mother volume can be specified either as a physical or a logical volume.

The power of a parameterised volume is created by the parameterisation class and its methods. Every parameterisation must create two methods:

- `ComputeTransformation` defines where one of the copies is placed,
- `ComputeDimensions` defines the size of one copy, and
- a constructor that initializes any member variables that are required.

An example is *ExN02ChamberParameterisation* that parameterizes a series of boxes of different sizes

```
class ExN02ChamberParameterisation : public G4VPVParameterisation
{
  ...
  void ComputeTransformation(const G4int       copyNo,
                             G4VPhysicalVolume *physVol) const;

  void ComputeDimensions(G4Box&              trackerLayer,
                         const G4int             copyNo,
                         const G4VPhysicalVolume *physVol) const;
  ...
}
```

Source listing 4.1.3
An example of Parameterised boxes of different sizes.

These methods works as follows:

The `ComputeTransformation` method is called with a copy number for the instance of the parameterisation under consideration. It must compute the transformation for this copy, and set the physical volume to utilize this transformation:

```
void ExN02ChamberParameterisation::ComputeTransformation
(const G4int copyNo,G4VPhysicalVolume *physVol) const
{
  G4double      Zposition= fStartZ + copyNo * fSpacing;
  G4ThreeVector origin(0,0,Zposition);
  physVol->SetTranslation(origin);
  physVol->SetRotation(0);
}
```

Note that the translation and rotation given in this scheme are those for the frame of coordinates (the passive method.) They are **not** for the active method, in which the solid is rotated into the mother frame of coordinates.

Similarly the `ComputeDimensions` method is used to set the size of that copy.

```
void ExN02ChamberParameterisation::ComputeDimensions
(G4Box & trackerChamber, const G4int copyNo,
 const G4VPhysicalVolume * physVol) const
{
  G4double  halfLength= fHalfLengthFirst + (copyNo-1) * fHalfLengthIncr;
  trackerChamber.SetXHalfLength(halfLength);
  trackerChamber.SetYHalfLength(halfLength);
  trackerChamber.SetZHalfLength(fHalfWidth);
}
```

The user must ensure that the type of the first argument of this method (in this example *G4Box &*) corresponds to the type of object the user give to the logical volume of parameterised physical volume.

More advanced usage allows the user:

- to change the type of solid by creating a `ComputeSolid` method, or

- to change the material of the volume by creating a `ComputeMaterial` method

for his parameterisation.

Note that currently for many cases it is not possible to add daughter volumes to a parameterised volume. In particular only parameterised volumes in which all the solids have the same size are currently guaranteed to allow the addition of daughter volumes. When the size or type of solid varies it is not possible currently to add daughters.

So the full power of parameterised volumes can be used only for ‘‘leaf’’ volumes, which contain no other volumes.

4.1.5 Touchables: Uniquely identifying a volume

Introduction to Touchables

A Touchable Volume serves the purpose of providing a unique identification for a detector element. This can be useful for description of the geometry alternative to the one used by the Geant4 tracking system, such as a Sensitive Detectors based read-out geometry, or a parameterised geometry for fast Monte Carlo. In order to create a Touchable Volume, several techniques can be implemented: for example, in Geant4 Touchables are implemented as Solids associated to a Transformation Matrix in the global reference system, or as a hierarchy of Physical Volumes up to the root of the geometrical tree.

A touchable is a geometrical volume (solid) which has a unique placement in a detector description. It an abstract base class which can be implemented in a variety of ways. Each way must provide the capabilities of obtaining the transformation and solid that is described by the touchable.

What can a Touchable do ?

All *G4VTouchable* implementations must respond to the two following ‘‘requests’’:

1. `GetTranslation` and `GetRotation` that return the components of the volume’s transformation
2. `GetSolid` that gives the solid of this touchable.

Additional capabilities are available from implementations with more information. These have a default implementation that causes an exception.

Several capabilities are available from touchables with physical volumes:

3. `GetVolume` gives the physical volume.
4. `GetReplicaNumber` gives the replica number of the physical volume, if it is replicated.

Touchables that store volume hierarchy (history) have the whole stack of parent volumes available. Thus it is possible to add a little more state in order to extend its functionality. We add a ‘‘pointer’’ to a level and a member function to move the level in this stack. Then calling the above member functions for another level the information for that level can be retrieved.

The top of the history tree is, by convention, the world volume.

5. `GetHistoryDepth` gives the depth of the history tree.
6. `MoveUpHistory( num )` moves the current pointer inside the touchable to point `num` levels up the history tree. Thus, e.g., calling it with `num=1` will cause the internal pointer to move to the mother of the current volume.
   WARNING: this function changes the state of the touchable and can cause errors in tracking if applied to Pre/Post step touchables.

An update method, with different arguments is available, so that the information in a touchable can be updated:

7. `UpdateYourself` takes a physical volume pointer and can additionally take a `NavigationHistory`.

Touchable history holds stack of geometry data

As shown in Sections 4.1.3 and 4.1.4, a logical volume represents unpositioned detector elements, and a physical volume can represent multiple detector elements. On the other hand, touchables provide a unique identification for a detector element. In particular, the Geant4 transportation process and the tracking system exploit touchables as implemented in *G4TouchableHistory*. The touchable history is the minimal set of information required to specify the full genealogy of a given physical volume (up to the root of the geometrical tree). These touchable volumes are made available to the user at every step of the Geant4 tracking in *G4VUserSteppingAction*.

To create a *G4TouchableHistory* the user must message the Navigator

```
  G4TouchableHistory* CreateTouchableHistory() const;
```

which will create one (the user is then responsible to delete it).

The methods that differentiate it from other touchables, because they have meaning for this type, are:

```
  G4int GetHistoryDepth()  const;
  G4int MoveUpHistory( G4int num_levels = 1 );
```

The first method is used to find out how many levels deep in the geometry tree the current volume is. The second method asks the touchable to eliminate its deepest level.

Note in particular that `MoveUpHistory` significantly modifies the state of a touchable.

4.1.6 Creating an assembly of volumes

`G4AssemblyVolume` is a helper class which allows to combine several logical volumes together in an arbitrary way in the 3D space. The result is a placement of a normal logical volume, but where final physical volumes are many.

An *assembly* volume, however, does not act as a real mother volume, being an envelope for its daughter volumes. Its role is over at the time the placement of the logical assembly volume is done. The physical volume objects become independent copies of each of the assembled logical volumes.

This class is particularly useful when there's a need to create a regular pattern in space of a complex component which consists of different shapes and can't be obtained by using replicated volumes or parametrised volumes (see also figure 4.1.0). Careful usage of `G4AssemblyVolume` must be considered though, in order to avoid cases of "proliferation" of physical volumes all placed in the same mother.

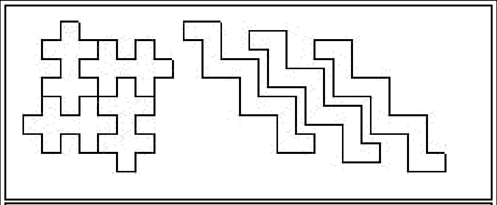


Figure 4.1.0
Examples of *assembly* of volumes.

Filling an assembly volume with its "daughters"

Participating logical volumes are represented as a triplet of of <logical volume, translation, rotation> (`G4AssemblyTriplet` class).
The adopted approach is to place each participating logical volume with respect to the assembly's coordinate system, according to the specified translation and rotation.

Assembly volume placement

An assembly volume object is composed of a set of logical volumes; imprints of it can be made inside a mother logical volume.

Since the assembly volume class generates physical volumes during each imprint, the user has no way to specify identifiers for these. An internal counting mechanism is used to compose uniquely the names of the physical volumes created by the invoked `MakeImprint(...)` method(s).
The name for each of the physical volume is generated with following format:

```
av_WWW_impr_XXX_YYY_ZZZ
```

where:

- **WWW** - assembly volume instance number
- **XXX** - assembly volume imprint number
- **YYY** - the name of the placed logical volume
- **ZZZ** - the logical volume index inside the assembly volume

Destruction of an assembly volume

At destruction all the generated physical volumes and associated rotation matrices of the imprints will be destroyed. A list of physical volumes created by MakeImprint() method is kept, in order to be able to cleanup the objects when not needed anymore. This requires the user to keep the assembly objects in memory during the whole job or during the life-time of the `G4Navigator`, logical volume store and physical volume store may keep pointers to physical volumes generated by the assembly volume.
At destruction of a `G4AssemblyVolume`, all its generated physical volumes and rotation matrices will be freed.

Example

This example shows how to use the `G4AssemblyVolume` class. It implements a layered detector where each layer consists of 4 plates.

In the code below, at first the world volume is defined, then solid and logical volume for the plate are created, followed by the definition of the assembly volume for the layer.
The assembly volume for the layer is then filled by the plates in the same way as normal physical volumes are placed inside a mother volume.
Finally the layers are placed inside the world volume as the imprints of the assembly volume (see source listing 4.1.4).

```
 static unsigned int layers = 5;

 void TstVADetectorConstruction::ConstructAssembly()
 {
   // Define world volume
   G4Box* WorldBox = new G4Box( "WBox", worldX/2., worldY/2., worldZ/2. );
   G4LogicalVolume*   worldLV  = new G4LogicalVolume( WorldBox, selectedMaterial, '
   G4VPhysicalVolume* worldVol = new G4PVPlacement(0, G4ThreeVector(), "WPhys", wor

   // Define a plate
   G4Box* PlateBox = new G4Box( "PlateBox", plateX/2., plateY/2., plateZ/2. );
   G4LogicalVolume* plateLV = new G4LogicalVolume( PlateBox, Pb, "PlateLV", 0, 0, 0

   // Define one layer as one assembly volume
   G4AssemblyVolume* assemblyDetector = new G4AssemblyVolume();

   // Rotation and translation of a plate inside the assembly
   G4RotationMatrix Ra;
   G4ThreeVector Ta;

   // Rotation of the assembly inside the world
   G4RotationMatrix Rm;

   // Fill the assembly by the plates
   Ta.setX( caloX/4. ); Ta.setY( caloY/4. ); Ta.setZ( 0. );
   assemblyDetector->AddPlacedVolume( plateLV, Ta, Ra );

   Ta.setX( -1*caloX/4. ); Ta.setY( caloY/4. ); Ta.setZ( 0. );
   assemblyDetector->AddPlacedVolume( plateLV, Ta, Ra );

   Ta.setX( -1*caloX/4. ); Ta.setY( -1*caloY/4. ); Ta.setZ( 0. );
   assemblyDetector->AddPlacedVolume( plateLV, Ta, Ra );

   Ta.setX( caloX/4. ); Ta.setY( -1*caloY/4. ); Ta.setZ( 0. );
   assemblyDetector->AddPlacedVolume( plateLV, Ta, Ra );

   // Now instantiate the layers
   for( unsigned int i = 0; i < layers; i++ )
   {
     // Translation of the assembly inside the world
     G4ThreeVector Tm( 0,0,i*(caloZ + caloCaloOffset) - firstCaloPos );
     assemblyDetector->MakeImprint( worldLV, Tm, Rm );
   }
}
```

Source listing 4.1.4
An example of usage of the `G4AssemblyVolume` class.

The resulting detector will look as in figure 4.1.1, below:

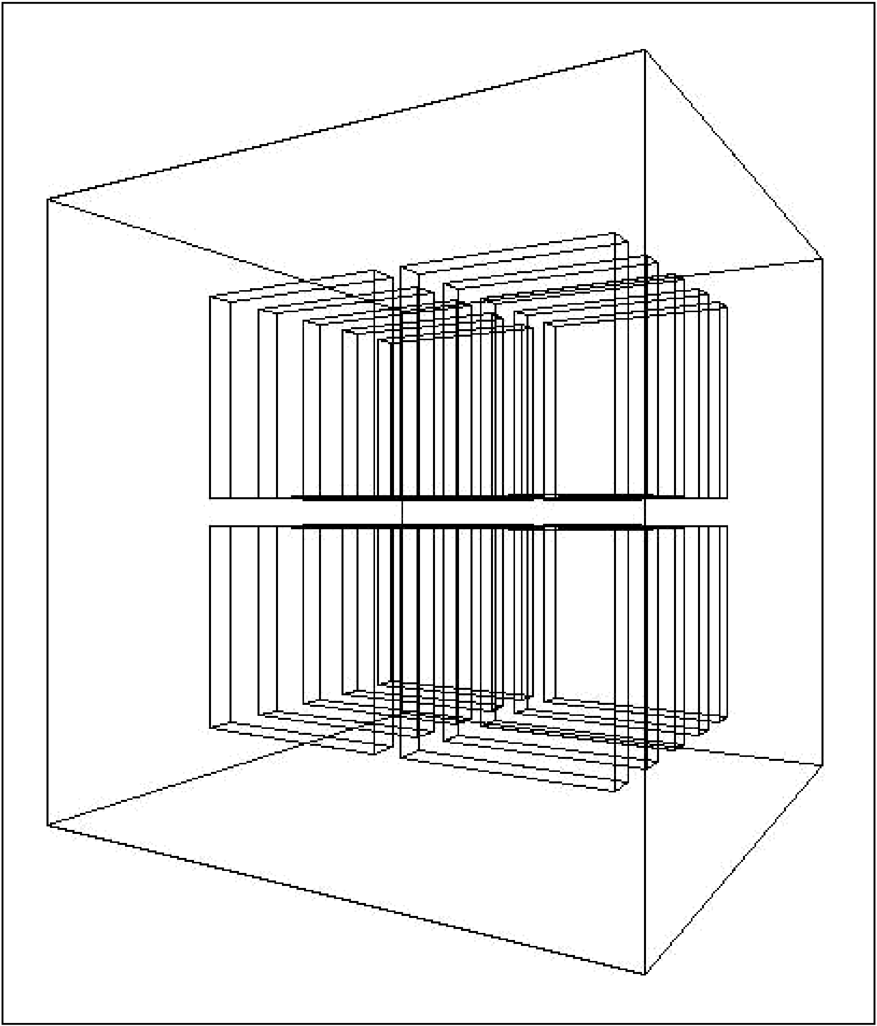


Figure 4.1.1
The geometry corresponding to source listing 4.1.4.

4.1.7 Reflecting hierarchies of volumes

Hierarchies of simple placements (`G4PVPlacement`) based on CSG solids can be reflected by means of the `G4ReflectionFactory` class and `G4ReflectedSolid`, which implements a solid that has been shifted from its original reference frame to a new 'reflected' one. The reflection transformation is applied as a decomposition into rotation and translation transformations.
The factory is a singleton object which provides the following methods:

```
   G4PhysicalVolumesPair Place(const G4Transform3D&   transform3D,
                               const G4String&        name,
                                     G4LogicalVolume* LV,
                                     G4LogicalVolume* motherLV,
                                     G4bool           isMany,
                                     G4int            copyNo)
```

```
  G4PhysicalVolumesPair Replicate(const G4String&        name,
                                        G4LogicalVolume* LV,
                                        G4LogicalVolume* motherLV,
                                        EAxis            axis,
                                        G4int            nofReplicas,
                                        G4double         width,
                                        G4double         offset=0)
```

The method `Place()` used for placements, evaluates the passed transformation; in case the transformation contains reflection, the factory will act as following:

1. Performs the transformation decomposition.
2. Creates a new reflected solid and logical volume, or retrieves them from a map if the reflected object was already created.
3. Transforms the daughters (if any) and place them in the given mother.

If successful, the result is a pair of physical volumes, where the second physical volume is a placement in a reflected mother.
The method `Replicate()` creates replicas in the given mother. If successful, the result is a pair of physical volumes, where the second physical volume is a replica in a reflected mother.

```
#include "G4ReflectionFactory.hh"

// Calor placement with rotation

G4double calThickness = 100*cm;
G4double Xpos = calThickness*1.5;
G4RotationMatrix* rotD3 = new G4RotationMatrix();
rotD3->rotateY(10.*deg);

G4VPhysicalVolume* physiCalor =
    new G4PVPlacement(rotD3,                     // rotation
                      G4ThreeVector(Xpos,0.,0.), // at (Xpos,0,0)
                      logicCalor,     // its logical volume (defined elsewhere)
                      "Calorimeter",  // its name
                      logicHall,      // its mother volume (defined elsewhere)
                      false,          // no boolean operation
                      0);             // copy number

// Calor reflection with rotation
//
G4Translate3D translation(-Xpos, 0., 0.);
G4Transform3D rotation = G4Rotate3D(*rotD3);
G4ReflectX3D  reflection;
G4Transform3D transform = translation*rotation*reflection;

G4ReflectionFactory::Instance()
         ->Place(transform,     // the transformation with reflection
                 "Calorimeter", // the actual name
                 logicCalor,    // the logical volume
                 logicHall,     // the mother volume
                 false,         // no boolean operation
                 1);            // copy number

// Replicate layers
//
G4ReflectionFactory::Instance()
         ->Replicate("Layer",    // layer name
                     logicLayer, // layer logical volume (defined elsewhere)
                     logicCalor, // its mother
                     kXAxis,     // axis of replication
                     5,          // number of replica
                     20*cm);     // width of replica
```

Source listing 4.1.5
An example of usage of the `G4ReflectionFactory` class.

4.1.8 The geometry navigator

The navigation through the geometry at tracking time is implemented by the class `G4Navigator`. The navigator is used to locate points in the geometry and compute distances to geometry boundaries. At tracking time, the navigator is intended to be the only point of interaction with tracking.
Internally, the G4Navigator has several private helper/utility classes:

- **G4NavigationHistory** - to store the compounded transformations, replication/parameterisation information and volume pointers at each level of the hierarchy to the current location. The volume types at each level are also stored - whether normal (placement), replicated or parameterised.
- **G4NormalNavigation** - Provides location \& distance computation functions for geometries containing 'placement' volumes, with no voxels.
- **G4VoxelNavigation** - Provides location \& distance computation functions for geometries containing 'placement' physical volumes with voxels. Internally a stack of voxel information is maintained. Private functions allow for isotropic distance computation to voxel boundaries and for computation of the 'next voxel' in a specified direction.
- **G4ParameterisedNavigation** - Provides location \& distance computation functions for geometries containing parameterised volumes with voxels. A voxel information is maintained similarly to `G4VoxelNavigation`, but the computations are simpler because the voxels are guaranteed to be one level deep only (*unrefined*)
- **G4ReplicaNavigation** - Provides location \& distance computation functions for replicated volumes.

In addition the navigator maintains a set of flags for exiting/entry optimisation. A navigator is not a singleton class, this is mainly to allow a design extension in future (e.g geometrical event biasing). At the current time, no two navigator objects should be used at the same time.

Navigation and Tracking

The main functions required for tracking in the geometry are described below. Additional functions are provided to return the net transformation of volumes and for the creation of touchables. None of the functions implicitly requires that the geometry be described hierarchically.

- **SetWorldVolume()**
  Sets the first volume in the hierarchy. It must be unrotated and untranslated from the origin.
- **LocateGlobalPointAndSetup()**
  Locates the volume containing the specified global point. This involves a traverse of the hierarchy, requiring the computation of compound transformations, testing replicated and parameterised volumes (etc). To improve efficiency this search may be performed relative to the last, and this is the recommended way of calling the function. A 'relative' search may be used for the first call of the function which will result in the search defaulting to a search from the root node of the hierarchy. Searches may also be performed using a `G4TouchableHistory`.
- **LocateGlobalPointAndUpdateTouchableHandle()**
  First, search the geometrical hierarchy like the above method `LocateGlobalPointAndSetup()`. Then use the volume found and its navigation history to update the touchable.
- **ComputeStep()**
  Computes the distance to the next boundary intersected along the specified unit direction from a specified point. The point must be have been located prior to calling `ComputeStep()`.
  When calling `ComputeStep()`, a proposed physics step is passed. If it can be determined that the first intersection lies at or beyond that distance then `kInfinity` is returned. In any case, if the returned step is greater than the physics step, the physics step must be taken.
- **SetGeometricallyLimitedStep()**
  Informs the navigator that the last computed step was taken in its entirety. This enables entering/exiting optimisation, and should be called prior to calling `LocateGlobalPointAndSetup()`.

- **CreateTouchableHistory()**
  Creates a `G4TouchableHistory` object, for which the caller has deletion responsibility. The 'touchable' volume is the volume returned by the last Locate operation. The object includes a copy of the current NavigationHistory, enabling the efficient relocation of points in/close to the current volume in the hierarchy.

As stated previously, the navigator makes use of utility classes to perform location and step computation functions. The different navigation utilities manipulate the `G4NavigationHistory` object.
In `LocateGlobalPointAndSetup()` the process of locating a point breaks down into three main stages - optimisation, determination that the point is contained with a subtree (mother and daughters), and determination of the actual containing daughter. The latter two can be thought of as scanning first 'up' the hierarchy until a volume that is guaranteed to contain the point is found, and then scanning 'down' until the actual volume that contains the point is found.
In `ComputeStep()` three types of computation are treated depending on the current containing volume:

- The volume contains normal (placement) daughters (or none)
- The volume contains a single parameterised volume object, representing many volumes
- The volume is a replica and contains normal (placement) daughters

---

4.1.9 A simple geometry editor

GGE is the Geant4 Graphical Geometry Editor. It is implemented in JAVA and is part of the Momo environment. GGE aims to serve physicists who have a little knowledge of C++ and the Geant4 toolkit to construct his or her own detector geometry in a graphical manner.

GGE provides methods to:

1. construct a detector geometry including *G4Element*, *G4Material*, *G4Solids*, *G4LogicalVolume*, *G4PVPlacement*, etc.
2. view the detector geometry using existing visualization system like DAWN
3. keep the detector object in a persistent way
4. produce corresponding C++ codes after the norm of Geant4 toolkit
5. make a Geant4 executable under adequate environment

GGE is implemented with Java, using Java Foundation Class, Swing-1.0.2. In essence, GGE is made a set of tables which contain all relevant parameters to construct a simple detector geometry.
The software, installation instructions and notes for GGE and other JAVA-based UI tools can be freely downloaded from the Geant4 GUI and Environments web site of Naruto University of Education in Japan.

Materials: elements and mixtures

GGE provides the database of elements in a form of the periodic table, which users can use to construct new materials. GGE provides a pre-constructed database of materials taken from the PDG book. They can be loaded, used, edited and saved as persistent objects.

Users can also create new materials either from scratch or by combining other materials.

- creating a material from scratch:

Use	Name	A	Z	Density	Unit	State	Temperature	Unit	Pressure	Unit

  Only the elements and materials used in the logical volumes are kept in the detector object and are used to generate C++ constructors. **Use** marks the used materials.

- Constructor to create a material from a combination of elements, subsequently added via `AddElement`

Use	Name	Elements	Density	Unit	State	Temperature	Unit	Pressure	Unit

  By clicking the column **Elements**, a new window is open to select one of two methods:

  - Add an element, giving fraction by weight
  - Add an element, giving number of atoms.

Solids

The most popular CSG solids (*G4Box*, *G4Tubs*, *G4Cons*, *G4Trd*) and specific BREPs solids (Pcons, Pgons) are supported at present. All related parameters of such a solid can be specified in a parameter widget.

Users will be able to view each solid using DAWN.

Logical Volume

GGE can specify the following items:

Name	Solid	Material	VisAttribute

The construction and assignment of appropriate entities for *G4FieldManager* and *G4VSensitiveDetector* are left to the user.

Physical Volume

A single copy of a physical volume can be created. Also repeated copies can be created in several manners. First, a user can translate the logical volume linearly.

Name	LogicalVolume	MotherVolume	Many	X0, Y0, Z0	Direction	StepSize	Unit	CopyNum

Combined translation and rotation are also possible, placing an object repeatedly on a ‘‘cylindrical’’ pattern. Simple models of replicas and parametrised volume are also implemented. In the replicas, a volume is slices to create new sub-volumes. In parametrised volumes, several patterns of volumes can be created.

Generation of C++ code: `MyDetectorConstruction.cc`

By simply pushing a button, source code in the form of an include file and a source file are created. They are called `MyDetectorConstruction.cc` and `.hh` files. They reflect all current user modifications in real-time.

Visualization

Examples of individual solids can be viewed with the help of DAWN. The visualization of the whole geometry is be done after the compilation of the source code `MyDetectorConstruction.cc` with appropriate parts of Geant4. (In particular only the geometry and visualization, together with the small other parts they depend on, are needed.)

4.1.10 Importing Solid Models from CAD systems

What can we import from a CAD-System?

Geant4 can import solid models described in STEP compliant CAD systems. These models can describe the solid geometry of detectors made by large number of elements with the greatest accuracy and detail. A solid model contains the purely geometrical data representing the solids and their position in a given reference frame.

It does not contain the material or the hierarchical information associated to the volumes, which are specific to the simulation application. These extra information can be easily associated to the solids imported from the CAD model, allowing to do physics simulation directly in the engineering detector description.

How do we import a Solid Model ?

All what Geant4 needs from a CAD system is a STEP AP203 file. Some CAD systems (for ex. Pro/Engineer) can write STEP compliant output files. Others (for ex. Euclid) exploit third parties product to perform this function. `G4AssemblyCreator` and `G4Assembly` classes from the `STEPinterface` module should be used to read a STEP file generated by a CAD system and create the assembled geometry in Geant4. The following step is to create and/or associate the information on the logical volumes, the physical volumes, the materials, etc. to the solids created by the Geant4 STEP reader. Here is a simple example showing how to instantiate all valid entities as read from a STEP file *tracker.stp*:

```
G4AssemblyCreator MyAC("tracker.stp");
  // Associate a creator to a given STEP file.
MyAC.ReadStepFile();
  // Reads the STEP file.
STEPentity* ent=0;
  // No predefined STEP entity in this example. A dummy pointer is used.
MyAC.CreateG4Geometry(*ent);
  // Generates GEANT4 geometry objects.

void *pl =  MyAC.GetCreatedObject();
  // Retrieve vector of placed entities.
G4Assembly* assembly = new G4Assembly();
  // An assembly is an aggregation of placed entities.
assembly->SetPlacedVector(*(G4PlacedVector*)pl);
  // Initialise the assembly.

G4int solids = assembly->GetNumberOfSolids();
  // Get the total number of solids among all entities.
for(G4int c=0; c<solids; c++)
  // Generate logical volumes and placements for each defined solid.
  {
    ps = assembly->GetPlacedSolid(c);
    G4LogicalVolume* lv = new G4LogicalVolume(ps->GetSolid(), Lead, "STEPlog");
    G4RotationMatrix* hr = ps->GetRotation();
    G4ThreeVector* tr = ps->GetTranslation();
    G4VPhysicalVolume* pv = new G4PVPlacement(hr, *tr, ps->GetSolid()->GetName(),
                                              experimentalHall_phys, false, c);
  }
```

Creating the logical and physical volumes

The two recommended options to create the logical and physical volumes from the STEP geometry description are the following:

- adopt a modular C++ implementation following the template showed above, where each detector component geometry is represented in separate STEP files logically structured;
- use the JAVA based Geant4 Geometrical Editor (GGE).

Exporting a Solid Model to a CAD System

This functionality is not yet available and is planned to be provided in future releases of Geant4.

4.1.11 Converting Geometries from GEANT 3.21

Approach

G3toG4 is the Geant4 facility to convert GEANT 3.21 geometries into Geant4. This is done in two stages:

1. The user supplies a GEANT 3.21 RZ-file (.rz) containing the initialization data structures. An executable `rztog4` reads this file and produces an ASCII *call list* file containing instructions on how to build the geometry. The source code of `rztog4` is FORTRAN.
2. A call list interpreter (`G4BuildGeom.cc`) reads these instructions and builds the geometry in the user's client code for Geant4.

Importing converted geometries into Geant4

Two examples of how to use the call list interpreter are supplied in the directory `examples/extended/g3tog4`:

1. `cltog4` is a simple example which simply invokes the call list interpreter method `G4BuildGeom` from the `G3toG4DetectorConstruction` class, builds the geometry and exits.
2. `clGeometry`, is more complete and is patterned as for the novice Geant4 examples. It also invokes the call list interpreter, but in addition, allows the geometry to be visualized and particles to be tracked.

To build these examples, especially the one involving visualization, the user must have one or more of the following environment variables set:

```
setenv G4VIS_BUILD_<driver>_DRIVER
setenv G4VIS_USE_<driver>
```

where the Geant4 supported drivers are listed in Section 8.6 of this manual.

To compile and build the G3toG4 libraries, simply type

```
gmake
```

from the top-level `source/g3tog4` directory.

To build the converter executable `rztog4`, simply type

```
gmake bin
```

To make everything, simply type:

```
gmake global
```

To remove all `G3toG4` libraries, executables and .d files, simply type

```
gmake clean
```

Current Status

The package has been tested with the geometries of experiments like: BaBar, CMS, Atlas, Zeus, L3, and Opal.
Here is a comprehensive list of features supported and not supported or implemented in the current version of the package:

- Supported shapes: all GEANT 3.21 shapes except for `GTRA`, `CTUB`.
- `PGON`, `PCON` are built using the *specific* solids `G4Polycone` and `G4Polyhedra`.
- GEANT 3.21 `MANY` feature is only partially supported.
  `MANY` positions are resolved in the `G3toG4MANY()` function, which has to be processed before `G3toG4BuildTree()` (it is not called by default).
  In order to resolve `MANY`, the user code has to provide additional info using `G4gsbool(G4String volName, G4String manyVolName)` function for all the overlapping volumes. Daughters of overlapping volumes are then resolved automatically and should not be specified via `Gsbool`.
  Limitation: a volume with a `MANY` position can have only this one position; if more than one position is needed a new volume has to be defined (`gsvolu()`) for each position.
- `GSDV*` routines for dividing volumes are implemented, using `G4PVReplicas`, for shapes:
  - `BOX`, `TUBE`, `TUBS`, `PARA` - all axes;
  - `CONE`, `CONS` - axes 2, 3;
  - `TRD1`, `TRD2`, `TRAP` - axis 3;
  - `PGON`, `PCON` - axis 2;
  - `PARA` -axis 1; axis 2,3 for a special case
- `GSPOSP` is implemented via individual logical volumes for each instantiation.
- `GSROTM` is implemented. Reflections of hierachies based on plain CSG solids are implemented through the `G3Division` class.
- Hits are not implemented.
- Usage of magnetic field class has to be turned on.

4.1.12 Detecting Overlapping Volumes

The problem of overlapping volumes

Volumes are often positioned in other volumes with the intent of been made fully contained in them. When a contained volume actually protrudes from its mother-volume it is defined as overlapping. Volumes are also often positioned in a same volume with the intent of not provoking intersections between themselves. When volumes in a common mother actually intersect themselves are defined as overlapping.

The problem of detecting overlaps between volumes is bounded by the complexity of the solid models description. Hence it requires the same mathematical sophistication which is needed to describe the most complex solids topology, in general. However, a tunable accuracy can be obtained by approximating the solids via first and/or second order surfaces and checking their intersection.

Detecting overlaps: built-in kernel commands

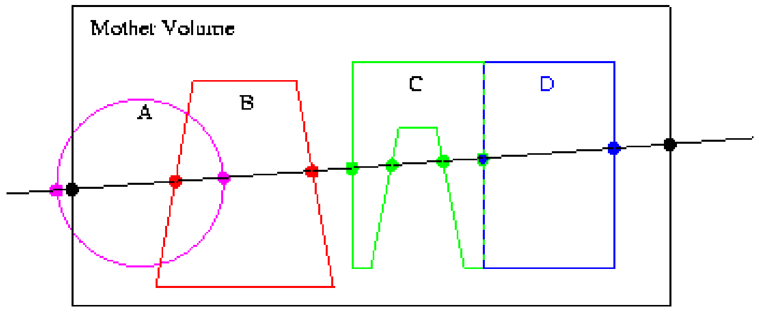
In general, the most powerful clash detection algorithms are provided by CAD systems, treating the intersection between the solids in their topological form.

Geant4 provides some built-in run-time commands to activate verification tests for the user-defined geometry:

```
    geometry/test/run
```

```
--> to start verification of geometry for overlapping
    regions based on standard grid setup.
geometry/test/line_test
--> to activate test along a specified direction and position
    defined by the user.
geometry/test/position
--> to specify position for the line_test.
geometry/test/direction
--> to specify direction for the line_test.
```

To detect overlapping volumes, the built-in test uses the intersection of solids with linear trajectories. For example, consider the following:



Here we have a line intersecting some physical volume (large, black rectangle). Belonging to the volume are four daughters: A, B, C, and D. Indicated by the dots are the intersections of the line with the mother volume and the four daughters.

This example has two geometry errors. First, volume A sticks outside its mother volume (this practice, sometimes used in geant3, is not supported in geant4). This can be noticed because the intersection point (leftmost magenta dot) lies outside the mother volume, as defined by the space between the two black dots.

The second error is that daughter volumes A and B overlap. This is noticeable because one of the intersections with A (rightmost magenta dot) is inside the volume B, as defined as the space between the red dots. Alternatively, one of the intersections with B (leftmost red dot) is inside the volume A, as defined as the space between the magenta dots.

Each of these two types of errors is represented by a line segment, which has a start point, an end point, and, a length. Depending on the type of error, the points are most clearly recognized in either the coordinate system of the volume, the global coordinate system, or the coordinate system of the daughters involved.

Also notice that certain errors will be missed unless a line is supplied in precisely the correct path. Unfortunately, it is hard to predict which lines are best at uncovering potential geometry errors. Instead, the geometry testing code uses a grid of lines, in the hope of at least uncovering gross geometry errors. More subtle errors could easily be missed.

Another difficult issue is roundoff error. For example, daughters C and D lie precisely next to each other. It is possible, due to roundoff, that one of the intersections points will lie just slightly inside the space of the other. In addition, a volume that lies tightly up against the outside of its mother may have an intersection point that just slightly lies outside the mother.

To avoid spurious errors caused by roundoff, a rather generous tolerance of 0.1 micron is used by default. This tolerance can be adjusted as needed by the application through the run-time command:

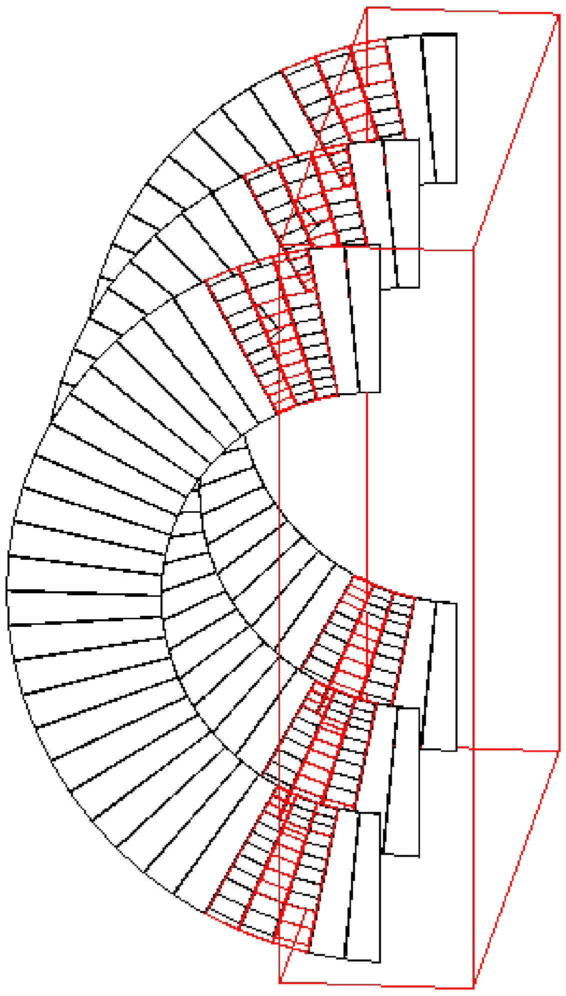
```
   geometry/test/tolerance <new-value>
```

Finally, notice that no mention is made of the possible daughter volumes of A, B, C, and D. To keep the code simple, only the immediate daughters of a volume are checked at one pass. To test these "granddaughter" volumes, the daughters A, B, C, and D each have to be tested themselves in turn. To make this more automatic, an optional recursive algorithm is included; it first tests a target volume, then it loops over all daughter volumes and calls itself.

Pay attention! For a complex geometry, checking the entire volume hierarchy can be extremely time consuming.

Using the visualization driver: DAVID.

The Geant4 visualization offers a powerful debugging tool for detecting potential intersections of physical volumes. The Geant4 DAVID visualization tool can infact automatically detect the overlaps between the volumes defined in Geant4 and converted to a graphical representation for visualization purposes. The accuracy of the graphical representation can be tuned onto the exact geometrical description. In the debugging, physical-volume surfaces are automatically decomposed into 3D polygons, and intersections of the generated polygons are investigated. If a polygon intersects with another one, physical volumes which these polygons belong to are visualized in color (red is the default). The figure below is a sample visualization of a detector geometry with intersecting physical volumes highlighted:



At present physical volumes made of the following solids are able to be debugged: G4Box, G4Cons, G4Para, G4Sphere, G4Trd, G4Trap, G4Tubs. (Existence of other solids is harmless.)

Visual debugging of physical-volume surfaces is performed with the DAWNFILE driver defined in the visualization category and with the two application packages, i.e. Fukui Renderer "DAWN" and a visual intersection debugger "DAVID". You can obtain DAWN and DAVID at the following WWW sites:

- http://arkoop2.kek.jp/~tanaka/DAWN/About_DAWN.html
- http://arkoop2.kek.jp/~tanaka/DAWN/About_DAVID.html
- ftp://i1nws2.fuis.fukui-u.ac.jp/pub/graphics/fukui_graphics_system/

How to compile Geant4 with the DAWNFILE driver incorporated is described in Section 8.6.

If the DAWNFILE driver, DAWN and DAVID are all working well in your host machine, the visual intersection debugging of physical-volume surfaces can be performed as follows:

Set an environmental variable G4DAWNFILE_VIEWER to "david":

```
     % setenv G4DAWNFILE_VIEWER   david
```

This setting makes the DAWNFILE driver invoke DAVID instead of the default viewer, DAWN.

Run your Geant4 executable, invoke the DAWNFILE driver, and execute visualization commands to visualize your detector geometry:

```
     Idle> /vis/open DAWNFILE
     .....(setting camera etc)...
     Idle> /vis/drawVolume
     Idle> /vis/viewer/update
```

Then a file "g4.prim", which describes the detector geometry, is generated in the current directory and DAVID is invoked to read it. (The format of the file g4.prim is described in the following WWW page:
http://geant4.kek.jp/~tanaka/DAWN/G4PRIM_FORMAT_24/)

If DAVID detects intersection of physical-volume surfaces, it automatically invokes DAWN to visualize the detector geometry with the intersected physical volumes highlighted (See the above sample visualization).

If no intersection is detected, visualization is skipped and the following message is displayed on the console:

```
     ------------------------------------------------------
     !!! Number of intersected volumes : 0 !!!
     !!! Congratulations ! \(^o^)/         !!!
     ------------------------------------------------------
```

If you always want to skip visualization, set an environmental variable as follows beforehand:

```
     %  setenv DAVID_NO_VIEW  1
```

Read detailed information of the intersection described in a file named "g4david.log" generated in the current directory. The following is an example of g4david.log:

```
    .....
    !!! INTERSECTED VOLUMES !!!
    caloPhys.0: Tubs: line 17
    caloPhys.1: Tubs: line 25
    .....
```

In this example, the first column tells that a physical volume with name "caloPhys" and with copy number "0" is intersected with another physical volume with the same name but with copy number "1". The second column shows that shapes of these physical volumes are defined with class G4Tubs. The third column indicates the line numbers of the intersecting physical volumes in the file `g4.prim` generated by DAVID.

If necessary, re-visualize the detector geometry with intersected parts highlighted. The data are saved in a file "g4david.prim" in the current directory. This file can be re-visualized with DAWN as follows:

```
     % dawn g4david.prim
```

It is also helpful to convert the generated file g4david.prim into a VRML-formatted file and perform interactive visualization of it with your WWW browser. The file conversion tool is obtainable at the following place:
http://geant4.kek.jp/~tanaka/DAWN/About_prim2vrml1.html

For more details, see the document of DAVID mentioned above.

About the authors

4.2 Material

4.2.1 General considerations

In nature, general materials (chemical compounds, mixtures) are made of elements, and elements are made of isotopes, therefore these are the three main classes designed in Geant4. Each of these classes has a table as a static data member, used for book-keeping the instances created of the respective classes.

G4Isotope
This class describes the properties of atoms: atomic number, number of nucleons, mass per mole, etc.

G4Element
This class describes the properties of atoms: effective atomic number, effective number of nucleons, effective mass per mole, number of isotopes, shell energy, and quantities like cross section per atom, etc.

G4Material
This class describes the macroscopic properties of matter: density, state, temperature, pressure, and macroscopic quantities like radiation length, mean free path, dE/dx, etc.

The *G4Material* class is the one which is visible to the rest of the toolkit and is used by the tracking, the geometry and the physics. It contains all the information relative to the eventual elements and isotopes of which it is made, hiding at the same time their implementation details.

4.2.2 Introduction to the classes

G4Isotope

A *G4Isotope* object has a name, atomic number, number of nucleons, mass per mole, and an index in the table. The constructor automatically stores "this" isotope in the isotopes table, which will assign it an index number.

G4Element

A *G4Element* object has a name, symbol, effective atomic number, effective number of nucleons, effective mass of a mole, an index in the elements table, the number of isotopes, a vector of pointers to such isotopes, a vector of relative abundances referring to such isotopes (where relative abundance means the number of atoms per volume). In addition, the class has methods to add, one by one, the isotopes which are to form the element.

A *G4Element* object can be constructed by directly providing the effective atomic number, effective number of nucleons, and effective mass of a mole, if the user explicitly wants to do so. Alternatively, a *G4Element* object can be constructed by declaring the number of isotopes of which it will be composed. The constructor will "new" a vector of pointers to *G4Isotopes* and a vector of doubles to store their relative abundances. Finally, the method to add an isotope has to be invoked for each of the desired (pre-existing) isotope objects, providing their addresses and relative abundances. At the last isotope entry, the system will automatically compute the effective atomic number, effective number of nucleons and effective mass of a mole, and will store "this" element in the elements table.

A few quantities, with physical meaning or not, which are constant in a given element, are computed and stored here as "derived data members".

G4Material

A *G4Material* object has a name, density, physical state, temperature and pressure (by default the standard conditions), the number of elements and a vector of pointers to such elements, a vector of the fraction of mass for each element, a vector of the atoms (or molecules) numbers of each element, and an index in the materials table. In addition, the class has methods to add, one by one, the elements going to form the material.

A *G4Material* object can be constructed by directly providing the resulting effective numbers, if the user explicitly wants to do so (an underlying element will be created with these numbers). Alternatively, a *G4Material* object can be constructed by declaring the number of elements of which it will be composed. The constructor will "new" a vector of pointers to *G4Element* and a vector of doubles to store their fraction of mass. Finally, the method to add an element has to be invoked for each of the desired (pre-existing) element objects, providing their addresses and fraction of mass. At the last element entry, the system will automatically compute the vector of the number of atoms of each element per volume, the total number of electrons per volume, and will store "this" material in the materials table. In the same way, a material can be constructed as a mixture of others materials and elements.

It should be noted that if the user provides the number of atoms (or molecules) for each element forming the chemical compound, the system automatically computes the fraction of mass. A few quantities, with physical meaning or not, which are constant in a given material, are computed and stored here as "derived data members".

Final considerations The classes will automatically decide if the total of the fractions of mass is correct, and perform the necessary checks. The main reason why a fixed index is kept as a data member is that many cross section tables and energy tables will be built in the physics "by rows of materials (or elements, or even isotopes)". The tracking gives to the physics the address of a material object (the material of the current volume). If the material has an index according to which the cross section table has been built, we have direct access when we want to access a number in such a table. We get directly to the correct row, and the energy of the particle will tell us which column. Without such an index, every access to the cross section or energy tables would imply a search to get to the correct material’s row. More details will be given in the processes Section.

4.2.3 All the ways to build a material

Source listing 4.2.1 illustrates the different ways to define materials.

```
#include <iostream.h>
#include "G4Isotope.hh"
#include "G4Element.hh"
#include "G4Material.hh"
#include "G4UnitsTable.hh"

int main() {

G4String name, symbol;             // a=mass of a mole;
G4double a, z, density;            // z=mean number of protons;
G4int iz, n;                       //iz=nb of protons  in an isotope;
                                   // n=nb of nucleons in an isotope;

G4int ncomponents, natoms;
G4double abundance, fractionmass;
G4double temperature, pressure;

G4UnitDefinition::BuildUnitsTable();

//
// define Elements
//

a = 1.01*g/mole;
G4Element* elH  = new G4Element(name="Hydrogen",symbol="H" , z= 1., a);

a = 12.01*g/mole;
G4Element* elC  = new G4Element(name="Carbon"  ,symbol="C" , z= 6., a);
```

```
a = 14.01*g/mole;
G4Element* elN  = new G4Element(name="Nitrogen",symbol="N" , z= 7., a);

a = 16.00*g/mole;
G4Element* elO  = new G4Element(name="Oxygen"  ,symbol="O" , z= 8., a);

a = 28.09*g/mole;
G4Element* elSi = new G4Element(name="Silicon", symbol="Si", z=14., a);

a = 55.85*g/mole;
G4Element* elFe = new G4Element(name="Iron"    ,symbol="Fe", z=26., a);

a = 183.84*g/mole;
G4Element* elW = new G4Element(name="Tungsten" ,symbol="W",  z=74., a);

a = 207.20*g/mole;
G4Element* elPb = new G4Element(name="Lead"    ,symbol="Pb", z=82., a);

//
// define an Element from isotopes, by relative abundance
//

G4Isotope* U5 = new G4Isotope(name="U235", iz=92, n=235, a=235.01*g/mole);
G4Isotope* U8 = new G4Isotope(name="U238", iz=92, n=238, a=238.03*g/mole);

G4Element* elU  = new G4Element(name="enriched Uranium", symbol="U", ncomponents=2
elU->AddIsotope(U5, abundance= 90.*perCent);
elU->AddIsotope(U8, abundance= 10.*perCent);


cout << *(G4Isotope::GetIsotopeTable()) << endl;

cout << *(G4Element::GetElementTable()) << endl;

//
// define simple materials
//

density = 2.700*g/cm3;
a = 26.98*g/mole;
G4Material* Al = new G4Material(name="Aluminum", z=13., a, density);

density = 1.390*g/cm3;
a = 39.95*g/mole;
G4Material* lAr = new G4Material(name="liquidArgon", z=18., a, density);

density = 8.960*g/cm3;
a = 63.55*g/mole;
G4Material* Cu = new G4Material(name="Copper"   , z=29., a, density);

//
// define a material from elements.   case 1: chemical molecule
//

density = 1.000*g/cm3;
G4Material* H2O = new G4Material(name="Water", density, ncomponents=2);
H2O->AddElement(elH, natoms=2);
H2O->AddElement(elO, natoms=1);

density = 1.032*g/cm3;
G4Material* Sci = new G4Material(name="Scintillator", density, ncomponents=2);
```

```
Sci->AddElement(elC, natoms=9);
Sci->AddElement(elH, natoms=10);

density = 2.200*g/cm3;
G4Material* SiO2 = new G4Material(name="quartz", density, ncomponents=2);
SiO2->AddElement(elSi, natoms=1);
SiO2->AddElement(elO , natoms=2);

density = 8.280*g/cm3;
G4Material* PbWO4= new G4Material(name="PbWO4", density, ncomponents=3);
PbWO4->AddElement(elO , natoms=4);
PbWO4->AddElement(elW , natoms=1);
PbWO4->AddElement(elPb, natoms=1);

//
// define a material from elements.   case 2: mixture by fractional mass
//

density = 1.290*mg/cm3;
G4Material* Air = new G4Material(name="Air  "  , density, ncomponents=2);
Air->AddElement(elN, fractionmass=0.7);
Air->AddElement(elO, fractionmass=0.3);

//
// define a material from elements and/or others materials (mixture of mixtures)
//

density = 0.200*g/cm3;
G4Material* Aerog = new G4Material(name="Aerogel", density, ncomponents=3);
Aerog->AddMaterial(SiO2, fractionmass=62.5*perCent);
Aerog->AddMaterial(H2O , fractionmass=37.4*perCent);
Aerog->AddElement (elC , fractionmass= 0.1*perCent);

//
// examples of gas in non STP conditions
//

density     = 27.*mg/cm3;
pressure    = 50.*atmosphere;
temperature = 325.*kelvin;
G4Material* CO2 = new G4Material(name="Carbonic gas", density, ncomponents=2,
                                     kStateGas,temperature,pressure);
CO2->AddElement(elC, natoms=1);
CO2->AddElement(elO, natoms=2);

density     = 0.3*mg/cm3;
pressure    = 2.*atmosphere;
temperature = 500.*kelvin;
G4Material* steam = new G4Material(name="Water steam ", density, ncomponents=1,
                                      kStateGas,temperature,pressure);
steam->AddMaterial(H2O, fractionmass=1.);

//
// What about vacuum ?  Vacuum is an ordinary gas with very low density
//

density     = universe_mean_density;                //from PhysicalConstants.h
pressure    = 1.e-19*pascal;
temperature = 0.1*kelvin;
new G4Material(name="Galactic", z=1., a=1.01*g/mole, density,
                   kStateGas,temperature,pressure);
```

```
density     = 1.e-5*g/cm3;
pressure    = 2.e-2*bar;
temperature = STP_Temperature;                      //from PhysicalConstants.h
G4Material* beam = new G4Material(name="Beam ", density, ncomponents=1,
                                  kStateGas,temperature,pressure);
beam->AddMaterial(Air, fractionmass=1.);

//
// print the table of materials
//

G4cout << *(G4Material::GetMaterialTable()) << endl;

return EXIT_SUCCESS;
}
```

Source listing 4.2.1
A program which illustrates the different ways to define materials.

As can be seen in the later examples, a material has a state: solid (the default), liquid, or gas. The constructor checks the density and automatically sets the state to gas below a given threshold (10 mg/cm3).

In the case of a gas, one may specify the temperature and pressure. The defaults are STP conditions defined in `PhysicalConstants.hh`.

An element must have the number of nucleons >= number of protons >= 1.

A material must have density, temperature, pressure non null.

4.2.4 The tables

Print a constituent

The following shows how to print a constituent.

```
G4cout << elU << endl;
G4cout << Air << endl;
```

Print the table of materials

The following shows how to print the table of materials.

```
G4cout << *(G4Material::GetMaterialTable()) << endl;
```

4.3 Electromagnetic Field

4.3.1 An overview of propagation in a field

Geant4 is capable of describing and propagating in a large variety of fields. Magnetic fields, uniform or non-uniform, can already be described simply, and propagation of tracks inside them can be performed.

In order to propagate inside a field, we integrate the equation of motion of the particle in the field. In general, this must be done using a Runge-Kutta method for the integration of ordinary differential equations. Several Runge-Kutta methods are available, suitable for different situations. In specific cases (like the uniform field where the analytical solution is known) different solvers can also be used.

Once a method is chosen that allows you to calculate the track's motion in a field, we break up this curved path into linear chord segments. We determine these chord segments so that they closely approximate the curved path. We use the chords to interrogate the *Navigator*, whether the track has crossed a volume boundary.

You can set the accuracy of your volume intersection, by setting a parameter which is called the ''miss distance'' or δ_{miss}. We will use attempt to ensure that all volume intersections will be accurate to within the ''miss distance''.

4.3.2 Practical aspects

Creating a magnetic field for your detector

The simplest way to define a field for your detector involves the following steps:

1. To create a field:

```
G4UniformMagField* magField
  = new G4UniformMagField(G4ThreeVector(0.,0.,fieldValue));
```

2. To set it as the default field:

```
G4FieldManager* fieldMgr
  = G4TransportationManager::GetTransportationManager()
    ->GetFieldManager();
fieldMgr->SetDetectorField(magField);
```

3. To create the objects which calculate the trajectory:

```
fieldMgr->CreateChordFinder(magField);
```

To change the accuracy of volume intersection use the `SetDeltaChord` method:

```
fieldMgr->GetChordFinder()->SetDeltaChord( G4double newValue);
```

Creating a non-magnetic field

This is now possible. The design of the *Field* category allows this, and a first implementation has been made.

Source listing 4.3.1 shows how to define a uniform electric field for the whole of your detector.

```
#include "G4EqMagElectricField.hh"
#include "G4UniformElectricField.hh"

...
{
  // Part of detector description code

  G4FieldManager   *pFieldMgr;
  G4MagIntegratorStepper *pStepper;
  G4EqMagElectricField *fEquation = new G4EqMagElectricField(&myElectricField);

  pStepper = new G4ClassicalRK4( fEquation );
  // or    = new G4SimpleHeum(   fEquation );

  // Set this as a global field
  pFieldMgr= G4TransportationManager::GetTransportationManager()->
       GetFieldManager();

  pFieldMgr->SetDetectorField( &myElectricField );
  pChordFinder = new G4ChordFinder( &myElectricField,
                                    1.0e-2 * mm,      // Minimum step size
                                    pStepper);
  pFieldMgr->SetChordFinder( pChordFinder );
}
```

Source listing 4.3.1
How to define a uniform electric field for the whole of your detector.

Choosing your stepper

Runge-Kutta integration is used to compute the motion of a charged track in a general field. There is a large choice of general steppers, of low and high order, and specialised steppers for pure magnetic fields.

The default stepper is the classical fourth order Runge-Kutta stepper. It is a good general purpose stepper, and is robust. When the field is known to have specific properties, lower or high order steppers can be used to obtain the same quality results using fewer computing cycles.

In particular, if the field is calculated from a field map, a lower order stepper is recommended. The less smooth the field is, the lower the order of the stepper that should be used. The choice of lower order steppers includes the third order stepper `G4SimpleHeum`, the second order `G4ImplicitEuler` and `G4SimpleRunge` and the first order `G4ExplicitEuler`. The first order stepper would be useful only for very rough fields. For somewhat smooth fields (intermediate), the choice between second and third order steppers should be made by trial and error. A study of the best type of stepper for a particular field is recommended for maximal efficiency.

Specialised steppers for pure magnetic fields are also available. They take into account that a local trajectory in a smooth field will not vary significantly from a helix. Combining this in a new way with the Runge-Kutta method, they provide high accuracy at low computational cost.

Again, use the higher order steppers, like `G4HelixHeum`, for fields that are relatively smooth, and use the lower order steppers, like `G4HelixImplicitEuler`, for less smooth fields.

To obtain a stepper other than the default for your field, you can specify your stepper of choice at the time you construct your field manager, or change it later. At construction time simply use

```
G4ChordFinder( G4MagneticField* itsMagField,
               G4double         stepMinimum = 1.0e-2 * mm,
               G4MagIntegratorStepper* pItsStepper = 0 );
```

while at a later time use

```
pChordFinder->GetIntegrationDriver()->RenewStepperAndAdjust( newStepper );
```

About the authors

4.4 Hits

4.4.1 Hit

A hit is a snapshot of the physical interaction of a track in the sensitive region of your detector. You can store various information associated with a *G4Step* object. The information can be

- Position and time of the step
- Momentum and energy of the track
- Energy deposition of the step
- Geometrical information

or any combination of the above.

G4VHit

G4VHit is an abstract base class which represents a hit. You have to inherit this base class and derive your own concrete hit class(es). The member data of your concrete hit class can be, and should be, chosen by yourself.

G4VHit has two virtual methods, `Draw()` and `Print()`. To draw or print out your concrete hits, these methods should be implemented. The way of defining the drawing method is described in Section 8.4.

G4THitsCollection

G4VHit is an abstract class and you have to derive your own concrete classes from it. On the other hand, hits should be stored associated with *G4Event* object, which represents the current event. *G4VHitsCollection* is an abstract class which represents a vector collection of one kind of user defined hits. Thus, you have to prepare one *G4VHitsCollection* concrete class per *G4VHit* concrete class.

G4THitsCollection is a template class derived from *G4VHitsCollection*, and the concrete hits collection class of a particular *G4VHit* concrete class can be instantiated from this template class. Each object of a hits collection must have a unique name for each event.

G4Event has a *G4HCofThisEvent* class object, that is a container class of collections of hits. Hits collections are stored by their pointers, of the type of the base class.

An example of a concrete hit class

Source listing 4.4.1 shows an example of a concrete hit class.

```
#ifndef ExN04TrackerHit_h
#define ExN04TrackerHit_h 1

#include "G4VHit.hh"
#include "G4THitsCollection.hh"
#include "G4Allocator.hh"
#include "G4ThreeVector.hh"

class ExN04TrackerHit : public G4VHit
{
  public:

      ExN04TrackerHit();
      ~ExN04TrackerHit();
      ExN04TrackerHit(const ExN04TrackerHit &right);
      const ExN04TrackerHit& operator=(const ExN04TrackerHit &right);
      int operator==(const ExN04TrackerHit &right) const;

      inline void * operator new(size_t);
      inline void operator delete(void *aHit);

      void Draw() const;
      void Print() const;

  private:
      G4double edep;
      G4ThreeVector pos;

  public:
      inline void SetEdep(G4double de)
      { edep = de; }
      inline G4double GetEdep() const
      { return edep; }
      inline void SetPos(G4ThreeVector xyz)
      { pos = xyz; }
      inline G4ThreeVector GetPos() const
      { return pos; }

};

typedef G4THitsCollection<ExN04TrackerHit> ExN04TrackerHitsCollection;

extern G4Allocator<ExN04TrackerHit> ExN04TrackerHitAllocator;

inline void* ExN04TrackerHit::operator new(size_t)
{
  void *aHit;
  aHit = (void *) ExN04TrackerHitAllocator.MallocSingle();
  return aHit;
}

inline void ExN04TrackerHit::operator delete(void *aHit)
{
  ExN04TrackerHitAllocator.FreeSingle((ExN04TrackerHit*) aHit);
}

#endif
```

Source listing 4.4.1
An example of a concrete hit class.

4.4.2 Sensitive detector

G4VSensitiveDetector

G4VSensitiveDetector is an abstract base class which represents a detector. The principal mandate of a sensitive detector is the construction of hit objects using information from steps along a particle track. The `ProcessHits()` method of *G4VSensitiveDetector* performs this task using *G4Step* objects as input. In the case of a "Readout" geometry (see Section 4.4.3), objects of the *G4TouchableHistory* class may be used as an optional input.

Your concrete detector class should be instantiated with the unique name of your detector. The name can be associated with one or more global names with "/" as a delimiter for categorizing your detectors. For example

```
myEMcal = new MyEMcal("/myDet/myCal/myEMcal");
```

where `myEMcal` is the name of your detector. The pointer to your sensitive detector must be set to one or more *G4LogicalVolume* objects to set the sensitivity of these volumes. The pointer should be also registered to *G4SDManager,* as described in Section 4.4.4.

G4VSensitiveDetector has three major virtual methods.

`ProcessHits()`
: This method is invoked by *G4SteppingManager* when a step is composed in the *G4LogicalVolume* which has the pointer to this sensitive detector. The first argument of this method is a *G4Step* object of the current step. The second argument is a *G4TouchableHistory* object for the ‘‘Readout geometry’’ described in the next section. The second argument is `NULL` for the case ‘‘Readout geometry’’ is not assigned to this sensitive detector. In this method, one or more *G4VHit* objects should be constructed if the current step is meaningful for your detector.

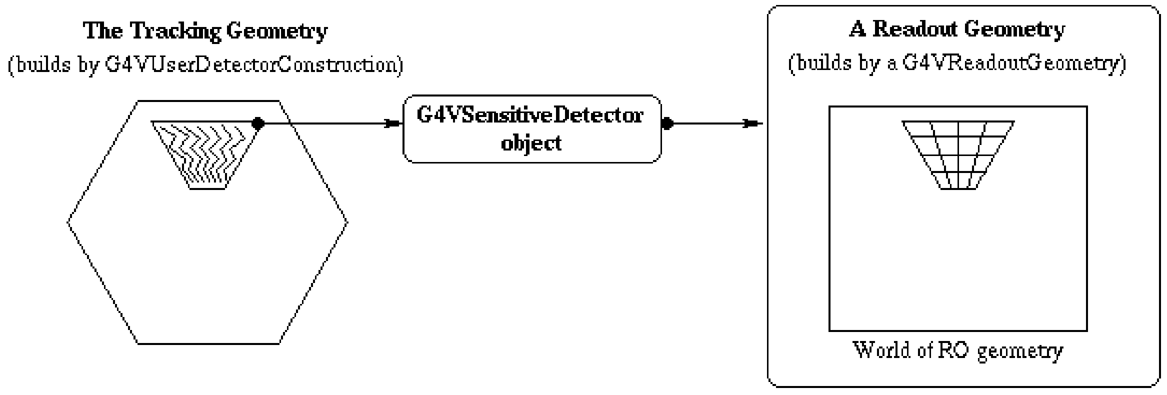
`Initialize()`
: This method is invoked at the beginning of each event. The argument of this method is an object of the *G4HCofThisEvent* class. Hits collections, where hits produced in this particular event are stored, can be associated to the *G4HCofThisEvent* object in this method. The hits collections associated with the *G4HCofThisEvent* object during this method can be used for ‘‘during the event processing’’ digitization.

`EndOfEvent()`
: This method is invoked at the end of each event. The argument of this method is the same object as the previous method. Hits collections occasionally created in your sensitive detector can be associated to the *G4HCofThisEvent* object.

4.4.3 Readout geometry

In the section, we explain how you can define a ‘‘Readout geometry’’. A Readout geometry is a virtual, parallel, geometry for getting the channel number.

As an example, the accordion calorimeter of **ATLAS** has a complicated tracking geometry, however the readout can be done by simple cylindrical sectors divided by theta, phi, and depth. Tracks will be traced in the tracking geometry, the ‘‘real’’ one, and the sensitive detector will have its own readout geometry Geant4 will message to find to which ‘‘readout’’ cell the current hit belongs.


The Tracking Geometry
(builds by G4VUserDetectorConstruction)
G4VSensitiveDetector object
A Readout Geometry
(builds by a G4VReadoutGeometry)
World of RO geometry

The picture shows how this association is done in Geant4. You will have to start by associating a sensitive detector to a volume of the tracking geometry, in the usual way (see Section 4.4.2). Then, you will associate your *G4VReadoutGeometry* object to the sensitive detector.

At tracking time, the base class *G4VReadoutGeometry* will provide to your sensitive detector code the *G4TouchableHistory* in the Readout geometry at the beginning of the step position (position of *PreStepPoint* of *G4Step*) and at this position only.

This *G4TouchableHistory* is given to your sensitive detector code through the *G4VSensitiveDetector* virtual method:

```
        G4bool processHits(G4Step* aStep, G4TouchableHistory* ROhist);
```

by the `ROhist` argument.

You will be able thus, to use both information of the *G4Step* and of the *G4TouchableHistory* coming from your Readout geometry. Note that since the association is done through a sensitive detector object, it is perfectly possible to have several Readout geometries in parallel.

Definition of a virtual geometry setup

The base class for the implementation of a Readout geometry is *G4VReadoutGeometry*. This class has a single pure virtual protected method:

```
        virtual G4VPhysicalVolume* build() = 0;
```

which you will have to override in your concrete class. The *G4VPhysicalVolume* pointer you will have to return is of the physical world of the Readout geometry.

The step by step procedure for constructing a Readout geometry is:

- inherit from *G4VReadoutGeometry* to define a *MyROGeom* class;
- implement the Readout geometry in the `build()` method, returning the physical world of this geometry.

  The world is specified in the same way as for the detector construction: a physical volume with no mother. The axis system of this world is the same as the one of the world for tracking.

  In this geometry you have to declare the sensitive parts in the same way than in the tracking geometry: by setting a non-`NULL` *G4VSensitiveDetector* pointer in -say- the relevant *G4LogicalVolume* objects. This sensitive just needs to be there, but will not be used.

  Actually you will also have to put well defined materials for the volumes you place in this geometry. These materials are irrelevant, since they will not be seen by the tracking. So it is foreseen to be allowed to set a `NULL` pointer in this case of parallel geometry.
- in the `construct()` method of your concrete *G4VUserDetectorConstruction* class:
  - instantiate your Readout geometry:

    ```
    MyROGeom* ROgeom = new MyROGeom("ROName");
    ```
  - build it:

    ```
    ROgeom->buildROGeometry();
    ```

    That will invoke your `build()` method.
  - Instantiate the sensitive detector which will receive the `ROGeom` pointer, `MySensitive`, and add this sensitive to the *G4SDManager*. Associate this sensitive to the volume(s) of the tracking geometry as usual.
  - Associate the sensitive to the Readout geometry:

    ```
    MySensitive->SetROgeometry(ROgeom);
    ```

4.4.4 *G4SDManager*

G4SDManager is the singleton manager class for sensitive detectors.

Activation / inactivation of sensitive detectors

The user interface commands `activate` and `inactivate` are available to control your sensitive detectors. For example:

```
/hits/activate detector_name
/hits/inactivate detector_name
```

where `detector_name` can be the detector name or the category name. For example, if your EM calorimeter is named as `/myDet/myCal/myEMcal`,

```
     /hits/inactivate myCal
```

will inactivate all detectors belonging to `myCal` category.

Access to the hits collections

Hits collections are accessed for various cases.

- Digitization
- Event filtering in *G4VUserStackingAction*
- ‘‘End of event’’ simple analysis
- Drawing / printing hits

The following is an example of how to access a hits collection of a particular concrete type:

```
  G4SDManager* fSDM = G4SDManager::GetSDMpointer();
  G4RunManager* fRM = G4RunManager::GetRunManager();
  G4int collectionID = fSDM->GetCollectionID("collection_name");
  const G4Event* currentEvent = fRM->GetCurrentEvent();
  G4HCofThisEvent* HCofEvent = currentEvent->GetHCofThisEvent();
  MyHitsCollection* myCollection = (MyHitsCollection*)(HC0fEvent->GetHC(collectionID
```

About the authors

4.5 Digitization

4.5.1 Digi

A hit is created by a sensitive detector when a step goes through it. Thus, the sensitive detector is associated to the corresponding *G4LogicalVolume* object(s). On the other hand, a digit is created using information of hits and/or other digits by a digitizer module. The digitizer module is not associated with any volume, and you have to implicitly invoke the `Digitize()` method of your concrete

G4VDigitizerModule class.

Typical usages of digitizer module include:

- simulate ADC and/or TDC
- simulate readout scheme
- generate raw data
- simulate trigger logics
- simulate pile up

G4VDigi

G4VDigi is an abstract base class which represents a digit. You have to inherit this base class and derive your own concrete digit class(es). The member data of your concrete digit class should be defined by yourself. *G4VDigi* has two virtual methods, `Draw()` and `Print()`.

G4TDigiCollection

G4TDigiCollection is a template class for digits collections, which is derived from the abstract base class *G4VDigiCollection*. *G4Event* has a *G4DCofThisEvent* object, which is a container class of collections of digits. The usages of *G4VDigi* and *G4TDigiCollection* are almost the same as *G4VHit* and *G4THitsCollection*, respectively, explained in the previous section.

4.5.2 Digitizer module

G4VDigitizerModule

G4VDigitizerModule is an abstract base class which represents a digitizer module. It has a pure virtual method, `Digitize()`. A concrete digitizer module must have an implementation of this virtual method. The Geant4 kernel classes do not have a ‘‘built-in’’ invocation to the `Digitize()` method. You have to implement your code to invoke this method of your digitizer module.

In the `Digitize()` method, you construct your *G4VDigi* concrete class objects and store them to your *G4TDigiCollection* concrete class object(s). Your collection(s) should be associated with the *G4DCofThisEvent* object.

G4DigiManager

G4DigiManager is the singleton manager class of the digitizer modules. All of your concrete digitizer modules should be registered to *G4DigiManager* with their unique names.

```
G4DigiManager * fDM = G4DigiManager::GetDMpointer();
MyDigitizer * myDM = new MyDigitizer( "/myDet/myCal/myEMdigiMod" );
fDM->AddNewModule(myDM);
```

Your concrete digitizer module can be accessed from your code using the unique module name.

```
      G4DigiManager * fDM = G4DigiManager::GetDMpointer();
      MyDigitizer * myDM = fDM->FindDigitizerModule( "/myDet/myCal/myEMdigiMod" );
      myDM->Digitize();
```

Also, *G4DigiManager* has a *Digitize()* method which takes the unique module name.

```
      G4DigiManager * fDM = G4DigiManager::GetDMpointer();
      MyDigitizer * myDM = fDM->Digitize( "/myDet/myCal/myEMdigiMod" );
```

How to get hitsCollection and/or digiCollection

G4DigiManager has the following methods to access to the hits or digi collections of the currently processing event or of previous events.

First, you have to get the collection ID number of the hits or digits collection.

```
      G4DigiManager * fDM = G4DigiManager::GetDMpointer();
      G4int myHitsCollID = fDM->GetHitsCollectionID( "hits_collection_name" );
      G4int myDigiCollID = fDM->GetDigiCollectionID( "digi_collection_name" );
```

Then, you can get the pointer to your concrete *G4THitsCollection* object or *G4TDigiCollection* object of the currently processing event.

```
      MyHitsCollection * HC = fDM->GetHitsCollection( myHitsCollID );
      MyDigiCollection * DC = fDM->GetDigiCollection( myDigiCollID );
```

In case you want to access to the hits or digits collection of previous events, add the second argument.

```
      MyHitsCollection * HC = fDM->GetHitsCollection( myHitsCollID, n );
      MyDigiCollection * DC = fDM->GetDigiCollection( myDigiCollID, n );
```

where, `n` indicates the hits or digits collection of the `n`th previous event.

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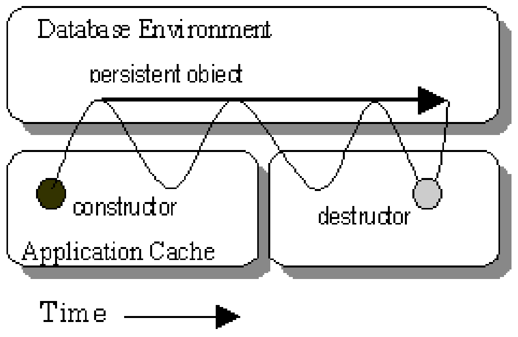
4.6 Object Persistency

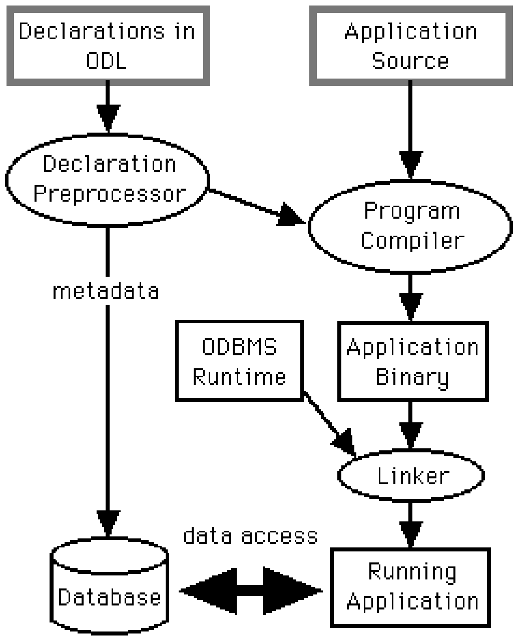
4.6.1 Persistency in Geant4

Object persistency is provided by Geant4 as an optional category, so that the user may run Geant4 with or without a commercial object database management system (ODBMS) package.

When a usual (transient) object is created in C++, the object is placed onto the application heap and it ceases to exist when the application terminates. Persistent objects, on the other hand, live beyond the termination of the application process and may then be accessed by other processes (in some cases, by processes on other machines).



C++ does not have, as an intrinsic part of the language, the ability to store and retrieve persistent objects. However there are many ways to achieve object persistency, one of which is the use of a commercial object database management system. The Object Data Management Group (ODMG) defines an industrial standard for the declaration of persistent-capable objects. Class declarations are described in Object Definition Language (ODL), which has a syntax almost identical to that of C++ class declarations. Once the class declaration is written in ODL, the declaration pre-processor will produce C++ header files, database access wrapper code, and a database schema. Schemas define the format and data types of data members of the persistent-capable class.



4.6.2 ODBMS Packages Required for Geant4 Persistency

In this release of Geant4, **Objectivity/DB** and **HepODBMS** are required by the persistency category.

HepODBMS

HepODBMS provides a standard ODBMS interface for HEP-related applications, which is being developed as a part of CERN RD45 project. HepODBMS handles objects of all kinds including histograms, detector calibrations and geometry, but the emphasis is on the handling of HEP event data, where rates are expected to reach several peta bytes per year in the LHC era. Where ever possible, Geant4 uses HepODBMS and ODMG standards as an interface to commercial ODBMS packages, in order to facilitate the migration of the Geant4 application from one ODBMS package to another.

Objectivity/DB

Objectivity/DB is one of the commercial ODBMS packages selected by HepODBMS. Its storage unit has four logical layers:

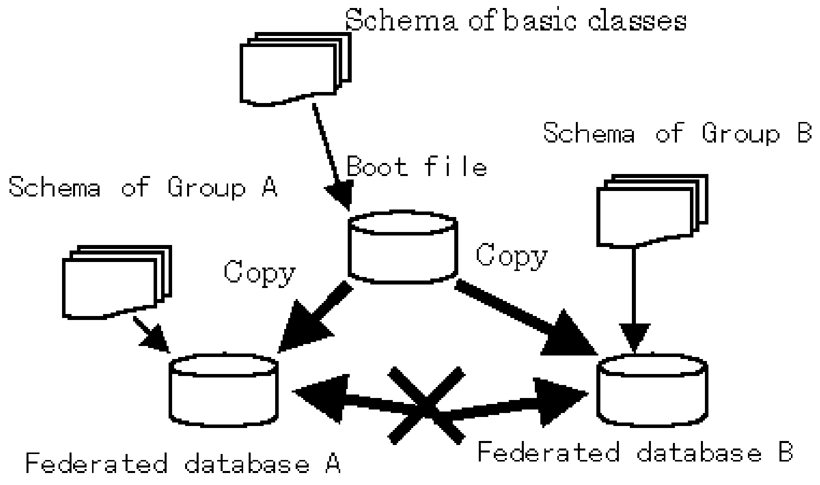
- Federated Database (ooFDObj)
- Database (ooDBObj)
- Container (ooContObj)
- Basic Object (ooObj).

Each layer corresponds to different physical storage layers. A database in Objectivity/DB corresponds to a physical file on the database server. A container is a logical unit of basic objects whose access are treated as a unit of transaction lock. The sser has no direct control over the physical location of each object in the database. However, it is possible to specify a clustering directive for objects which are expected to be accessed simultaneously.

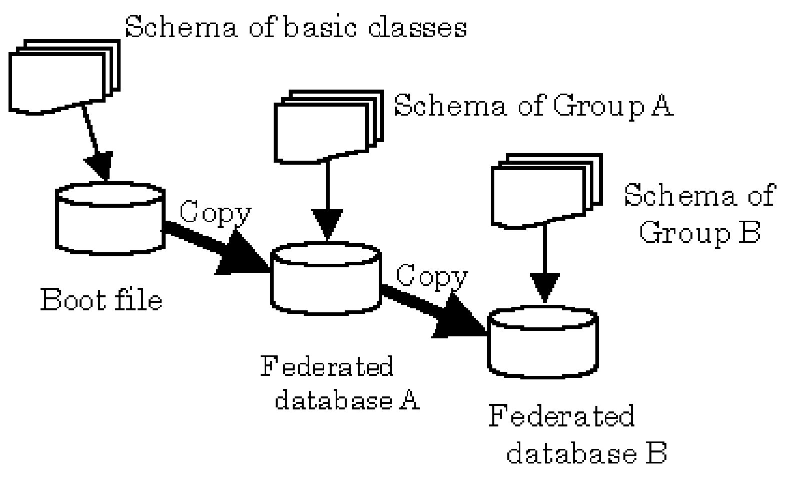
In Objectivity/DB, object declaration language is called DDL (data definition language). The DDL file is then preprocessed with the `ooddlx` compiler to produce schema, `<class>.hh`, `<class>_ref.hh` and `<class>_ddl.cc` files.

A federated database defines the configuration of the associated database files. It also contains the schema information. When a code developer changes the data types or format of the data member in one of the persistent-capable classes, it causes a schema evolution, and the `ooddlx` compiler will report an error. To recover, the code developer should delete the federated database and process all DDL files from scratch. (If the database is already in use, and the user wants to preserve the contents of the database, the developer should provide a new class declaration with schema versioning, and decide whether to update the schema automatically upon the data access.)

In some cases, it is reasonable to divide the class declaration into several code development groups. In the current Objectivity/DB, there is no convenient way to exchange schema information from one federated database to another. Therefore the entire schema information should be copied from one basic federated database, and it should be copied to the next group of the code development chain.



- Group A and B cannot exchange schema if their schema is compiled independently



- Group B can use schema of Group A

The basic schema of HepODBMS is called HEP_BASE, and the Geant4 basic schema G4SCHEMA is constructed on top of HEP_BASE. Users of Geant4 should copy their base schema from G4SCHEMA.

A single database application program can access only one federated database at a run time.

4.6.3 Persistency example

An example of Geant4 persistency is given as `PersistentEx01` under the `geant4/examples/extended/persistency` directory. This example can be built and run by following the step-by-step instructions given below.

Environment for Objectivity/DB and HepODBMS

First, ACL access to the Objectivity/DB directory must be obtained. See "Registration for Access to LHC++" for the license policy. On CERN AFS, the environment variables and path for **Objectivity/DB** and **HepODBMS** may be set up by using a csh script:

```
   source ...geant4/examples/extended/persistency/PersistentEx01/g4odbms_setup.csh
```

In `PersistentEx01`, your persistent objects will be stored into a federated database called `G4EXAMPLE`. Select a directory to which you have write-access, for example:

```
  cd $HOME
  mkdir G4EXAMPLE
  setenv G4EXAMPLE_BOOT_DIR $HOME/G4EXAMPLE
  setenv G4EXAMPLE_BOOT $HOME/G4EXAMPLE/G4EXAMPLE
```

For each federated database, you must specify a unique federated database ID (FDID). Contact your local system manager who is running the Objectivity ‘‘Lock Server’’ for a unique FDID.

```
   setenv G4EXAMPLE_FDID <nnnnn>
```

where <nnnnn> is a unique number assigned to your `G4EXAMPLE` federated database. On CERN AFS, you must start your own "Lock Server" to register your federated database, due to a technical limitation of Objectivity/DB:

```
     oocheckls -notitle ‘hostname‘ || \
       oolockserver -notitle -noauto ‘hostname‘::$G4EXAMPLE_BOOT
```

Do not forget to kill your lock server when you finished running the example applications. To kill the lock server, simply type,

```
     ookillls
```

or,

```
     ps -ef | grep ools
     kill -9 <pid_of_ools>
```

Creating `libG4persistency.a` and `G4SCHEMA`

Now you are ready to create a Geant4 persistency library and related base schema file (`G4SCHEMA`). The schema file contains information on data types and formats for each data member of the persistent-capable object.

```
   cd ...geant4/source/persistency
   gmake           # for granular library setup
   gmake global    # for grobal library setup
```

Note that **HepODBMS**- and **Objectivity**-specific compiler rules are defined in GNUmake include files (`*.gmk`) in the `geant4/config` directory. The persistency library will be created as `libG4persistency.a` in `$(G4WORKDIR)/lib`, and `G4SCHEMA` will be created in `$(G4WORKDIR)/schema`.

Creating federated database and the `PersistentEx01` executable

To create your local `G4EXAMPLE` federated database and `PersistentEx01` executable, change directory to `geant4/examples/extended/persistency/PersistentEx01`, or copy the directory to your working directory, then type gmake.

```
   cd (..to your working directory..)
   cp -r ..geant4/examples/extended/persistency/PersistentEx01 ./
   cd PersistentEx01
   gmake cleandb     # to create G4EXAMPLE
   gmake             # to create PersistentEx01 executable
```

Running `PersistentEx01` and checking the persistent object

Add `geant4/bin` to your path, change directory to `G4EXAMPLE_BOOT_DIR`, then run the executable from there:

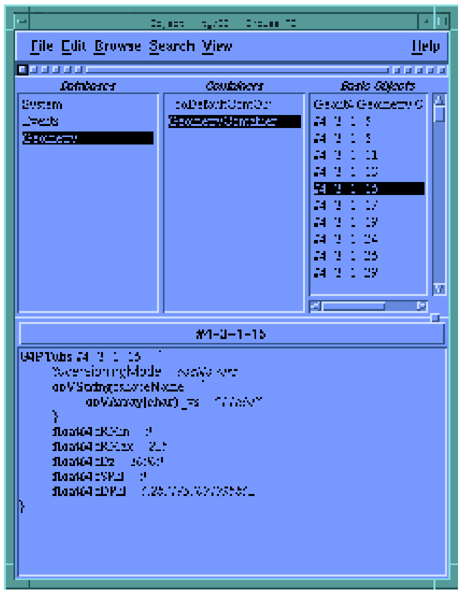
```
set path = ($path ../geant4/bin)
cd $G4EXAMPLE_BOOT_DIR
PersistentEx01 < geant4/examples/extended/persistency/PersistentEx01/PersistentEx
```

The macro `PersistentEx01.in` will process 10 events and store the events and geometry objects into the database.

To check the contents of the database, use `ootoolmgr`.

```
setenv DISPLAY <...to your local display...>
cd $G4EXAMPLE_BOOT_DIR
ootoolmgr -notitle G4EXAMPLE &
```

Then choose ‘‘Browse FD’’ from the ‘‘Tools’’ menu. Following is an example of browsing through the geometry database.



```
[illegible]
```

4.6.4 Making your own persistent object

In the current release of Geant4, *G4PersistencyManager* can store two kinds of objects, namely "events" and "geometry". To make "hits" persistent, the user should derive from *G4VHit* and provide his own persistent-capable class.

To store an event object, the user should construct *G4PersistencyManager* before constructing *G4RunManager*. This is usually done in `main()`.

```
#include "G4RunManager.hh"
#include "G4PersistencyManager.hh"
 int main()
 {
   G4PersistencyManager * persistencyManager = new G4PersistencyManager;
   G4RunManager * runManager = new G4RunManager;
   ...
 }
```

Source listing 4.6.1
How to store a persistent event object.

G4RunManager will call `G4PersistencyManager::Store( theEvent )` at the end of the event action, if it exists. In the current implementation of *G4PersistencyManager*, only the event ID is set in *G4PEvent*.

To store a geometry object, the user should call `Store( theWorld )` in the user run action class, after constructing the detector.

```
void MyRunAction::BeginOfRunAction(G4Run* aRun)
{
  aRun->SetRunID(runIDcounter++);
  if(runIDcounter==1)
  {
    G4VPersistencyManager* persM
     = G4VPersistencyManager::GetPersistencyManager();
    if( persM )
    {
      G4VPhysicalVolume* theWorld
       = G4TransportationManager::GetTransportationManager()
         ->GetNavigatorForTracking()->GetWorldVolume();
      persM->Store(theWorld);
    }
  }
}
```

Source listing 4.6.2
How to store a persistent geometry object.

To store a hits object, the user should provide a persistent-capable hit and hit collection objects by inheriting *G4VHits* and *G4VHitsCollection*. Details on creating persistent-capable hit class will be provided in the next release of Geant4.

Here are brief instructions on how to make a persistent-capable class.

- Rename `.hh` file to `.ddl`
- Inherit from *HepPersObj* (d_Object)
- Change C++ pointer(s) to smart pointer(s)

```
classname* aPtr  --> HepRef(classname) aPtr // in implementation
                 --> ooRef(classname) aRef  // in data member
```

- Use persistent types in data member

```
G4String aString; --> G4PString aString;
```

- Implement database access in the `.cc` file(s).

Example calorimeter hit and hits collection classes are given in Source listing 4.6.3.

```
#include "G4VHit.hh"
#include "G4ThreeVector.hh"
#include "HepODBMS/odbms/HepODBMS.h"
#include "HepODBMS/clustering/HepClusteringHint.h"

 class MyCalorimeterHit : public HepPersObj, public G4VHit
 {
 public:
   MyCalorimeterHit();
  ~MyCalorimeterHit();
   MyCalorimeterHit(const MyCalorimeterHit& right);
   const MyCalorimeterHit& operator=(const MyCalorimeterHit &right);
   int operator==(const MyCalorimeterHit &right) const;
   ...
   static HepClusteringHint clustering;
   ...
 private:
   G4double edep;
   G4ThreeVector pos;
public:
   ...
};

#include "HepODBMS/odbms/HepODBMS.h"
#include "HepODBMS/clustering/HepClusteringHint.h"
#include "HepODBMS/odbms/HepRefVArray.h"

#include "G4VHitsCollection.hh"
#include "MyCalorimeterHit.hh"

class G4VSensitiveDetector;

declare(HepRefVArray,MyCalorimeterHit)
typedef HepRefVArray(MyCalorimeterHit) CaloHitsCollection;

class MyCalorimeterHitsCollection : public d_Object, public G4VHitsCollection
{
public:
  MyCalorimeterHitsCollection();
  MyCalorimeterHitsCollection(G4String aName,G4VSensitiveDetector *theSD);
 ~MyCalorimeterHitsCollection();
  static HepClusteringHint clustering;
  ...
private:
  CaloHitsCollection theCollection;
  ...
};
```

Then in `MyEventAction::endOfEventAction()`,

```
void MyEventAction::endOfEventAction()
{
  ...
  G4VPersistencyManager* persM
   = G4VPersistencyManager::GetPersistencyManager();
  if( persM )
  {
    persM->GetDBApp()->startUpdate();
    persM->GetDBApp()->db("Hits");
  }

  const G4Event* evt = fpEventManager->get_const_currentEvent();

  G4HCofThisEvent * HCE = evt->get_HCofThisEvent();

  MyCalorimeterHitsCollection * pTHC1
   = (MyCalorimeterHitsCollection*)(HCE->get_HC(colID1));
  MyCalorimeterHitsCollection * pTHC2
   = (MyCalorimeterHitsCollection*)(HCE->get_HC(colID2));
  ...
  if( persM )
   persM->GetDBApp()->commit();
  ...
}
```

Source listing 4.6.3
Example calorimeter hit and hits collection classes.

About the authors

5. Tracking and Physics

5.1 Tracking

5.1.1 Basic concepts

Philosophy of tracking

All Geant4 processes, including the transportation of particles, are treated generically. In spite of the name "*tracking*", particles are not *transported* in the tracking category. *G4TrackingManager* is an interface class which brokers transactions between the event, track and tracking categories. A singleton instance of this class handles the message passing between the upper hierarchical object, which is the event manager, and lower hierarchical objects in the tracking category. The event manager is a singleton instance of the *G4EventManager* class.

The tracking manager receives a track from the event manager and takes the actions required to finish tracking it. *G4TrackingManager* aggregates the pointers to *G4SteppingManager*, *G4Trajectory* and *G4UserTrackingAction*. Also there is a "use" relation to *G4Track* and *G4Step.*

G4SteppingManager is the class which plays an essential role in tracking the particle. It takes care of all message passing between objects in the different categories which are relevant to transporting a particle (for example, geometry, interactions in matter, etc.). Its public method `Stepping()` steers the stepping of the particle. The algorithm to handle one step is given below.

1. The particle’s velocity at the beginning of the step is calculated.
2. Each active discrete or continuous process must propose a step length based on the interaction it describes. The smallest of these step lengths is taken.
3. The geometry navigator calculates "newSafety", the distance to the next volume boundary. If the minimum physical-step-length from the processes is shorter than "newSafety", the physical-step-length is selected as the next step length. In this case, no further geometrical calculations will be performed.
4. If the minimum physical-step-length from the processes is longer than "newSafety", the following actions are taken:
   - if the previous step was NOT limited by geometry, the current point is "backed up" to the beginning of the previous step and
   - the distance to the next boundary is re-calculated.

5. The smaller of the minimum physical-step-length and the geometric step length is taken.
6. All active continuous processes are invoked. Note that the particle’s kinetic energy will be updated only after all invoked processes have completed. The change in kinetic energy will be the sum of the contributions from these processes.
7. The track is checked to see whether or not it has been terminated by a continuous process.
8. The current track properties are updated before discrete processes are invoked. This includes:
    - updating the kinetic energy of the current track particle (note that ’sumEnergyChange’ is the sum of the new kinetic energy after each continuos process was invoked, and NOT the sum of the energy difference before and after the process invocation) and
    - updating position and time.
9. The discrete process is invoked. After the invocation,
    - the energy of the current track particle is updated and
    - the secondaries from ParticleChange are stored in SecondaryList. This includes constructing "G4Track" objects, and setting their member data. Note that the stepping manager is responsible for deleting secodaries from ParticleChange.
10. The track is checked to see whether or not it has been terminated by the discrete process.
11. "newSafety" is updated.
12. If the step was limited by the volume boundary, push the particle into the next volume.
13. Invoke the user intervention *G4UserSteppingAction*.
14. Handle hit information.
15. Save data to Trajectory.
16. Update discrete processes Mean-Free Path.
17. Reset maximum interaction length of the occurred discrete process if the parent particle is still alive.
18. One step completed.

What is a step?

G4Step stores the transient information in a step. This includes the two endpoints of the step, `PreStepPoint` and `PostStepPoint`, which contain the points’ coordinates and the volumes containing the points. *G4Step* also stores the change in track properties between the two points. These properties, such as energy and momentum, are updated as the various active processes are invoked.

What is a track?

G4Track keeps information on the final status of the particle after the completion of one step. This means it has information on the previous step during the `AlongStepDoIt` invocations. Only after finishing all `AlongStepDoIt`’s, will *G4Track* have the final information (e.g., the final position). Also take note that, as already mentioned above, *G4Track* will be updated each time after the invocation of a `PostStepDoIt`.

5.1.2 Access to track and step information

How to get track information

Track information may be accessed by invoking various `Get` methods provided in the *G4Track* class.

For details, see the **Software Reference Manual**. Typical information available includes:

- (x,y,z)
- Global time (time since the event is created)
- Local time (time since the track is created)
- Proper time
- Momentum direction (unit vector)
- Kinetic energy
- Accumulated geometrical track length
- Accumulated true track length
- Pointer to dynamic particle
- Pointer to physical volume
- Track ID number
- Track ID number of the parent
- Current step number
- Track status
- (x,y,z) at the start point (vertex position) of the track
- Momentum direction at the start point (vertex position) of the track
- Kinetic energy at the start point (vertex position) of the track
- Pointer to the process which created the current track

How to get step information

Step and step-point information can be retrieved by invoking various `Get` methods provided in the *G4Step*/*G4StepPoint* classes. For details, see the **Software Reference Manual**. Information in *G4Step* includes:

- Pointers to `PreStep` and `PostStepPoint`
- Geometrical step length (step length before the correction of multiple scattering)
- True step length (step length after the correction of multiple scattering)
- Delta of position/time between `Pre` and `PostStepPoint`
- Delta of momentum/energy between `Pre` and `PostStepPoint`. (Note: to get the energy deposited in the step, you cannot use this ’Delta energy’. You have to use ’Total energy deposit’ as below.)
- Pointer to `G4Track`
- Total energy deposited during the step - this is the sum of
    - energy deposited by the energy loss process,
    - the energy lost by secondaries which have NOT been generated because each of their energies was below the cut threshold

Information in *G4StepPoint* (`Pre` and `PostStepPoint`) includes:

- (x, y, z, t)
- (px, py, pz, Ek)
- Momentum direction (init vector)
- Pointers to physical volumes
- Safety
- Beta, gamma
- Polarization

- Step status
- Pointer to the physics process which defined the current step and its `DoIt` type
- Pointer to the physics process which defined the previous step and its `DoIt` type
- Total track length
- Global time (time since the current event is started)
- Local time (time since the current track is started)
- Proper time

How to get "particle change"

You can access the information kept in particle change by invoking various `Get` methods provided in the *G4ParticleChange* class. Typical information available includes (for details, see the **Software Reference Manual**):

- final momentum direction of the parent particle
- final kinetic energy of the parent particle
- final position of the parent particle
- final global time of the parent particle
- final proper time of the parent particle
- final polarization of the parent particle
- status of the parent particle (*G4TrackStatus*)
- true step length (this is used by multiple scattering to put the result of transformation from the geometrical step length to the true step length)
- local energy deposited - this consists of either
    - energy deposited by the energy loss process, or
    - the energy lost by secondaries which have NOT been generated because each of their energies was below the cut threshold.
- number of secondaries particles
- list of secondary particles (list of *G4Track*)

5.1.3 Handling of secondary particles

Secondary particles are passed as *G4Track*'s from a physics process to tracking. *G4ParticleChange* provides the following four methods for a physics process:

- `AddSecondary( G4Track* aSecondary )`
- `AddSecondary( G4DynamicParticle* aSecondary )`
- `AddSecondary( G4DynamicParticle* aSecondary, G4ThreeVector position )`
- `AddSecondary( G4DynamicParticle* aSecondary, G4double time )`

In all but the first, the construction of *G4Track* is done in the methods using informaton given by the arguments.

5.1.4 User actions

There are two kinds to actions the user can do to the Geant4 kernel during the tracking. These are:

- User tracking action, and
- User stepping action. The user can put his/her own codes of interactions into the kernel in these action methods. For details, see the **Software Reference Manual**.

5.1.5 Verbose outputs

You can turn the verbose information output flag on or off. By setting the control level of the verbose flag, you can get from brief to very detailed information on the track/step. *e.g.*

```
G4UImanager* UI = G4UImanager::GetUIpointer();
UI->ApplyCommand("/tracking/verbose 1");
```

5.1.6 Trajectory and trajectory point

G4Trajectory and G4TrajectoryPoint

G4Trajectory and *G4TrajectoryPoint* are the default concrete classes provided by Geant4, which are derived from *G4VTrajectory* and *G4VTrajectoryPoint* base classes, respectively. A *G4Trajectory* class object is created by *G4TrackingManager* when a *G4Track* is passed from *G4EventManager*. *G4Trajectory* has the following data members:

- ID numbers of the track and the track's parent
- Particle name, charge, and its PDG code
- A collection of *G4TrajectoryPoint* pointers

G4TrajectoryPoint corresponds to a step point along the path followed by the track. Its position is given by a *G4ThreeVector*. A *G4TrajectoryPoint* class object is created in the *AppendStep()* method of *G4Trajectory* and this method is invoked by *G4TrackingManager* at the end of each step. The first point is created when the *G4Trajectory* is created, thus the first point is the original vertex.

The creation of a trajectory can be controlled by invoking *G4TrackingManager::SetStoreTrajectory(G4bool)*. A UI command */tracking/storeTrajectory _bool_* does the same. The user can set this flag for each individual track from his/her own *G4UserTrackingAction::PreUserTrackingAction()* method.

> **The user should not create trajectories for secondaries in a shower due to the large amount of memory consumed.**

All the created trajectories in an event are stored in *G4TrajectoryContainer* class object and this object will be kept by *G4Event*. To draw or print trajectories generated in an event, the user can invoke *DrawTrajectory()* or *ShowTrajectory()* of *G4VTrajectory*, respectively, from his/her *G4UserEventAction::EndOfEventAction()*. The geometry must be drawn previously to the trajectory drawing. The color of a drawn trajectory is the following.

- Red : negatively charged particle
- Green : neutral particle
- Blue : positively charged particle

> **Due to improvements in *G4Navigator*, a track can execute more than one turn of its spiral trajectory without breaking steps as long as the trajectory does not cross a geometrical boundary. Thus a trajectory drawn may not be circular.**

Customize trajectory and trajectory point

G4Track and *G4Step* are transient classes. They are not available at the end of the event. Thus, the concrete classes *G4VTrajectory* and *G4VTrajectoryPoint* are the only ones a user may employ for end-of-event analysis or for persistency. As mentioned above, the default classes which Geant4 provides, i.e. *G4Trajectory* and *G4TrajectoryPoint*, have only the very primitive quantities. The user can customize his/her own trajectory and trajectory point classes directly derived from the respective base classes.

To use the customized trajectory, the user has to construct his/her concrete trajectory class object in his/her own *G4UserTrackingAction::PreUserTrackingAction()* and set the pointer to *G4TrackingManager* via *SetTrajectory()* method. In the user's *AppendStep()* method implementation in his/her own trajectory class, the customized trajectry point class object must be constructed. This *AppendStep()* method will be invoked by *G4TrackingManager*.

To customize trajectory drawing, the user can override *DrawTrajectory()* method in his/her own trajectory class.

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5.2 Physics Processes

Physics processes describe how particles interact with a material. Seven major categories of processes are provided by Geant4:

1. electromagnetic,
2. hadronic,

3. decay,
4. photolepton-hadron,
5. optical,
6. parameterization and
7. transportation.

The generalization and abstraction of physics processes is a key issue in the design of Geant4. All physics processes are treated in the same manner from the tracking point of view. The Geant4 approach enables anyone to create a process and assign it to a particle type. This openness should allow the creation of processes for novel, domain-specific or customised purposes by individuals or groups of users.

Each process has two groups of methods which play an important role in tracking, `GetPhysicalInteractionLength` (GPIL) and `DoIt`. The GPIL method gives the step length from the current space-time point to the next space-time point. It does this by calculating the probability of interaction based on the process's cross section information. At the end of this step the `DoIt` method should be invoked. The `DoIt` method implements the details of the interaction, changing the particle's energy, momentum, direction and position, and producing secondary tracks if required. These changes are recorded as *G4VParticleChange* objects(see Particle Change).

G4VProcess

G4VProcess is the base class for all physics processes. Each physics process must implement virtual methods of *G4VProcess* which describe the interaction (DoIt) and determine when an interaction should occur (GPIL). In order to accommodate various types of interactions *G4VProcess* provides three `DoIt` methods:

- `G4VParticleChange* AlongStepDoIt( const G4Track& track, const G4Step& stepData )`

  This method is invoked while *G4SteppingManager* is transporting a particle through one step. The corresponding `AlongStepDoIt` for each defined process is applied for every step regardless of which process produces the minimum step length. Each resulting change to the track information is recorded and accumulated in *G4Step*. After all processes have been invoked, changes due to `AlongStepDoIt` are applied to *G4Track*, including the particle relocation and the safety update. Note that after the invocation of `AlongStepDoIt`, the endpoint of the *G4Track* object is in a new volume if the step was limited by a geometric boundary. In order to obtain information about the old volume, *G4Step* must be accessed, since it contains information about both endpoints of a step.

- `G4VParticleChange* PostStepDoIt( const G4Track& track, const G4Step& stepData )`

  This method is invoked at the end point of a step, only if its process has produced the minimum step length, or if the process is forced to occur. *G4Track* will be updated after each invocation of `PostStepDoIt`, in contrast to the `AlongStepDoIt` method.

- `G4VParticleChange* AtRestDoIt( const G4Track& track, const G4Step& stepData )`

  This method is invoked only for stopped particles, and only if its process produced the minimum step length or the process is forced to occur.

For each of the above `DoIt` methods *G4VProcess* provides a corresponding pure virtual GPIL method:

- `G4double PostStepGetPhysicalInteractionLength( const G4Track& track, G4double previousStepSize, G4ForceCondition* condition )`

  This method generates the step length allowed by its process. It also provides a flag to force the interaction to occur regardless of its step length.

- `G4double AlongStepGetPhysicalInteractionLength( const G4Track& track, G4double previousStepSize, G4double currentMinimumStep, G4double& proposedSafety, G4GPILSelection* selection )`

  This method generates the step length allowed by its process.

- `G4double AtRestGetPhysicalInteractionLength( const G4Track& track, G4ForceCondition* condition )`

  This method generates the step length in time allowed by its process. It also provides a flag to force the interaction to occur regardless of its step length.

Other pure virtual methods in *G4Vprocess* follow:

- `virtual G4bool IsApplicable(const G4ParticleDefinition&)`

  returns true if this process object is applicable to the particle type.

- `virtual void BuildPhysicsTable(const G4ParticleDefinition&)`

  is messaged by the process manager, whenever cross section tables should be rebuilt due to changing cut-off values. It is not mandatory if the process is not affected by cut-off values.

- `virtual void StartTracking()` and

- `virtual void EndTracking()`

  are messaged by the tracking manager at the beginning and end of tracking the current track.

Other base classes for processes

Specialized processes may be derived from seven additional virtual base classes which are themselves derived from *G4VProcess*. Three of these classes are used for simple processes:

G4VRestProcess	processes using only the `AtRestDoIt` method
	example: neutron capture
G4VContinuousProcess	processes using only the `AlongStepDoIt` method

	example: cerenkov
G4VDiscreteProcess	processes using only the `PostStepDoIt` method
	example: compton scattering, hadron inelastic interaction

The other four classes are provided for rather complex processes:

G4VContinuousDiscreteProcess	processes using both `AlongStepDoIt` and `PostStepDoIt` methods
	example: transportation, ionisation(energy loss and delta ray)
G4VRestDiscreteProcess	processes using both `AtRestDoIt` and `PostStepDoIt` methods
	example: positron annihilation, decay (both in flight and at rest)
G4VRestContinuousProcess	processes using both `AtRestDoIt` and `AlongStepDoIt` methods
G4VRestContinuousDiscreteProcess	processes using `AtRestDoIt`, `AlongStepDoIt and PostStepDoIt methods`

Particle change

G4VParticleChange and its descendants are used to store the final state information of the track, including secondary tracks, which has been generated by the `DoIt` methods. The instance of *G4VParticleChange* is the only object whose information is updated by the physics processes, hence it is responsible for updating the step. The stepping manager collects secondary tracks and only sends requests via particle change to update *G4Step*.

G4VParticleChange is introduced as an abstract class. It has a minimal set of methods for updating *G4Step* and handling secondaries. A physics process can therefore define its own particle change derived from *G4VParticleChange*. Three pure virtual methods are provided,

- `virtual G4Step* UpdateStepForAtRest( G4Step* step ),`
- `virtual G4Step* UpdateStepForAlongStep( G4Step* step )` and
- `virtual G4Step* UpdateStepForPostStep( G4Step* step ),`

which correspond to the three `DoIt` methods of *G4VProcess*. Each derived class should implement these methods.

5.2.1 Electromagnetic interactions

This section summarizes the electromagnetic physics processes which are installed in Geant4. For details on the implementation of these processes please refer to the **Physics Reference Manual**.

5.2.1.1 "Standard" e.m. processes

The following is a summary of the standard electromagnetic processes available in Geant4.

- Photon processes
  - Compton scattering (class name *G4ComptonScattering*)
  - Gamma conversion (also called pair production, class name *G4GammaConversion*)
  - Photo-electric effect (class name *G4PhotoElectricEffect*)
- Electron/positron processes
  - Bremsstrahlung (class name *G4eBremsstrahlung*)
  - Ionisation and delta ray production (class name *G4eIonisation*)
  - Positron annihilation (class name *G4eplusAnnihilation*)
  - The energy loss process (class name *G4eEnergyLoss*) handles the continuous energy loss of particles. These continuous energy losses come from the ionisation and bremsstrahlung processes.
  - Synchrotron radiation (class name *G4SynchrotronRadiation*)
- Hadron (e.m.) processes
  - Ionisation (class name *G4hIonisation*)
  - Energy loss (class name *G4hEnergyLoss*)
- The multiple scattering process
  The class name *G4MultipleScattering* is a general process in the sense that the same process/class is used to simulate the multiple scattering of all the charged particles (i.e. it is used for e+/e-,muons/charged hadrons).

  The ionisation/energy loss of the hadrons can be simulated optionally using the *G4PAIonisation*/*G4PAIenergyLoss* classes.

  The (e)ionisation, bremsstrahlung, positron annihilation, energy loss, and multiple scattering processes have been implemented in the so called ‘‘integral approach’’ as well, the corresponding class names are:
  - *G4IeBremsstrahlung*
  - *G4IeIonisation*
  - *G4IeplusAnnihilation*
  - *G4IeEnergyLoss*
  - *G4IMultipleScattering*

5.2.1.2 Low Energy Electromagnetic processes

The following is a summary of the Low Energy Electromagnetic processes available in Geant4. Further information is available in the homepage of the Geant4 Low Energy Electromagnetic Physics Working Group. The physics content of these processes is documented in Geant4 Physics Reference Manual and in other papers.

- **Photon processes**
  - Compton scattering (class *G4LowEnergyCompton*)
  - Polarized Compton scattering (class *G4LowEnergyPolarizedCompton*)
  - Rayleigh scattering (class *G4LowEnergyRayleigh*)
  - Gamma conversion (also called pair production, class *G4LowEnergyGammaConversion*)
  - Photo-electric effect (class*G4LowEnergyPhotoElectric*)
- **Electron processes**
  - Bremsstrahlung (class *G4LowEnergyBremsstrahlung*)
  - Ionisation and delta ray production (class *G4LowEnergyIonisation*)

- **Hadron and ion processes**
  - Ionisation and delta ray production (class *G4hLowEnergyIonisation*)

An example of the registration of these processes in a Physics List is given in souce listing 5.2.1.

```
void LowEnPhysicsList::ConstructEM()
{
  theParticleIterator->reset();

  while( (*theParticleIterator)() ){

    G4ParticleDefinition* particle = theParticleIterator->value();
    G4ProcessManager* pmanager = particle->GetProcessManager();
    G4String particleName = particle->GetParticleName();

    if (particleName == "gamma") {

      theLEPhotoElectric   = new G4LowEnergyPhotoElectric();
      theLECompton         = new G4LowEnergyCompton();
      theLEGammaConversion = new G4LowEnergyGammaConversion();
      theLERayleigh        = new G4LowEnergyRayleigh();

      pmanager->AddDiscreteProcess(theLEPhotoElectric);
      pmanager->AddDiscreteProcess(theLECompton);
      pmanager->AddDiscreteProcess(theLERayleigh);
      pmanager->AddDiscreteProcess(theLEGammaConversion);

    }
    else if (particleName == "e-") {

      theLEIonisation = new G4LowEnergyIonisation();
      theLEBremsstrahlung = new G4LowEnergyBremsstrahlung();
      theeminusMultipleScattering = new G4MultipleScattering();

      pmanager->AddProcess(theeminusMultipleScattering,-1,1,1);
      ///pmanager->AddProcess(theLEIonisation,-1,2,2);
      pmanager->AddProcess(theLEIonisation,-1,-1,2);
      pmanager->AddProcess(theLEBremsstrahlung,-1,-1,3);

    }
    else if (particleName == "e+") {

      theeplusMultipleScattering = new G4MultipleScattering();
      theeplusIonisation = new G4eIonisation();
      theeplusBremsstrahlung = new G4eBremsstrahlung();
      theeplusAnnihilation = new G4eplusAnnihilation();

      pmanager->AddProcess(theeplusMultipleScattering,-1,1,1);
      pmanager->AddProcess(theeplusIonisation,-1,2,2);
      pmanager->AddProcess(theeplusBremsstrahlung,-1,-1,3);
      pmanager->AddProcess(theeplusAnnihilation,0,-1,4);
    }
  }
}
```

Source listing 5.2.1
`Registration of electromagnetic low energy electron/photon processes`

Advanced **examples** illustrating the use of Low Energy Electromagnetic processes are available as part of the Geant4 release and are further documented here.

To run the Low Energy code for photon and electron electromagnetic processes, **data files** need to be copied by the user to his/her code repository. These files are distributed together with Geant4 release. The user should set the environment variable **G4LEDATA** to the directory where he/she has copied the files.

Options are available for low energy electromagnetic processes for hadrons and ions in terms of public member functions of the G4hLowEnergyIonisation class:
- SetHighEnergyForProtonParametrisation(G4double)
- SetLowEnergyForProtonParametrisation(G4double)
- SetHighEnergyForAntiProtonParametrisation(G4double)
- SetLowEnergyForAntiProtonParametrisation(G4double)
- SetElectronicStoppingPowerModel(const G4ParticleDefinition*,const G4String&)
- SetNuclearStoppingPowerModel(const G4String&)
- SetNuclearStoppingOn()
- SetNuclearStoppingOff()
- SetBarkasOn()
- SetBarkasOff()
- SetFluorescence(const G4bool)

The available models for ElectronicStoppingPower and NuclearStoppingPower are documented in the class diagrams.

5.2.1.3 Interactions of muons

The following is a summary of the muon interaction processes available in Geant4.

- Bremsstrahlung (class name *G4MuBremsstrahlung*)
- Ionisation and delta ray/knock on electron production (class name *G4MuIonisation*)
- Nuclear interaction (class name *G4MuNuclearInteraction*)
- Direct pair production (class name *G4MuPairProduction*)
- Energy loss process (class name *G4MuEnergyLoss*),
  where the total continuous energy loss is treated. In the case of muons, the bremsstrahlung, ionisation and pair production processes give contributions to the total continuous energy loss.

5.2.1.4 ‘‘X-ray production’’ processes

The following is a summary of the X-ray production processes available in Geant4.

- Cerenkov process (class name *G4Cerenkov*)
- Transition radiation (class names *G4TransitionRadiation* and *G4ForwardXrayTR*).

The Low Energy electromagnetic processes listed in section 5.2.1.2 also produce X-rays through fluorescence.

5.2.2 Hadronic interactions

This section briefly introduces hadronic physics processes installed in Geant4. For details of the implementation of hadronic interactions available in Geant4, please refer to the **Physics Reference Manual**.

5.2.2.1 Treatment of cross-sections

Cross section data sets

Each hadronic process object (derived from *G4HadronicProcess*) may have one or more "cross section data sets" associated with it. The term "data set" is meant, in a broad sense, to be an object that encapsulates methods and data for calculating total cross sections for a given process. The methods and data may take many forms, from a simple equation using a few hard-wired numbers to a sophisticated parameterisation using large data tables. Cross section data sets are derived from the abstract class *G4VCrossSectionDataSet*, and are required to implement the following methods:

```
    G4bool IsApplicable( const G4DynamicParticle*, const G4Element* )
```

This method must return `True` if the data set is able to calculate a total cross section for the given particle and material, and `False` otherwise.

```
    G4double GetCrossSection( const G4DynamicParticle*, const G4Element* )
```

This method, which will be invoked only if `True` was returned by `IsApplicable`, must return a cross section, in Geant4 default units, for the given particle and material.

```
    void BuildPhysicsTable( const G4ParticleDefinition& )
```

This method may be invoked to request the data set to recalculate its internal database or otherwise reset its state after a change in the cuts or other parameters of the given particle type.

```
    void DumpPhysicsTable( const G4ParticleDefinition& ) = 0
```

This method may be invoked to request the data set to print its internal database and/or other state information, for the given particle type, to the standard output stream.

Cross section data store

Cross-section data-sets are used by the process for the calculation of Physical Interaction Length. A given cross section data set may only apply to a certain energy range, or may only be able to calculate cross sections for a particular type of particle. The class *G4CrossSectionDataStore* has been provided to allow the user to specify, if desired, a series of data sets for a process, and to arrange the priority of data sets so that the appropriate one is used for a given energy range, particle, and material. It implements the following public methods:

```
 G4CrossSectionDataStore()
~G4CrossSectionDataStore()
```

The constructor and destructor, and

```
G4double GetCrossSection( const G4DynamicParticle*, const G4Element* )
```

For the given particle and material, this method returns a cross section value provided by one of the collection of cross section data sets listed in the data store object. If there are no known data sets, a `G4Exception` is thrown and `DBL_MIN` is returned. Otherwise, each data set in the list is queried, in reverse list order, by invoking its `IsApplicable` method for the given particle and material. The first data set object that responds positively will then be asked to return a cross section value via its `GetCrossSection` method. If no data set responds positively, a `G4Exception` is thrown and `DBL_MIN` is returned.

```
void AddDataSet( G4VCrossSectionDataSet* aDataSet )
```

This method adds the given cross section data set to the end of the list of data sets in the data store. For the evaluation of cross sections, the list has a LIFO (Last In First Out) priority, meaning that data sets added later to the list will have priority over those added earlier to the list. Another way of saying this, is that the data store, when given a `GetCrossSection` request, does the `IsApplicable` queries in reverse list order, starting with the last data set in the list and proceeding to the first, and the first data set that responds positively is used to calculate the cross section.

```
void BuildPhysicsTable( const G4ParticleDefinition& aParticleType )
```

This method may be invoked to indicate to the data store that there has been a change in the cuts or other parameters of the given particle type. In response, the data store will invoke the `BuildPhysicsTable` of each of its data sets.

```
void DumpPhysicsTable( const G4ParticleDefinition& )
```

This method may be used to request the data store to invoke the `DumpPhysicsTable` method of each of its data sets.

Default cross sections

The defaults for total cross section data and calculations have been encapsulated in the singleton class *G4HadronCrossSections*. Each hadronic process: *G4HadronInelasticProcess*, *G4HadronElasticProcess*, *G4HadronFissionProcess*, and *G4HadronCaptureProcess*, comes already equipped with a cross section data store and a default cross section data set. The data set objects are really just shells that invoke the singleton *G4HadronCrossSections* to do the real work of calculating cross sections.

The default cross sections can be overridden in whole or in part by the user. To this end, the base class *G4HadronicProcess* has a ‘‘get’’ method:

```
    G4CrossSectionDataStore* GetCrossSectionDataStore()
```

which gives public access to the data store for each process. The user’s cross section data sets can be added to the data store according to the following framework:

```
    G4Hadron...Process aProcess(...)

    MyCrossSectionDataSet myDataSet(...)

    aProcess.GetCrossSectionDataStore()->AddDataSet( &MyDataSet )
```

The added data set will override the default cross section data whenever so indicated by its `IsApplicable` method.

In addition to the ‘‘get’’ method, *G4HadronicProcess* also has the method

```
    void SetCrossSectionDataStore( G4CrossSectionDataStore* )
```

which allows the user to completely replace the default data store with a new data store.

It should be noted that a process does not send any information about itself to its associated data store (and hence data set) objects. Thus, each data set is assumed to be formulated to calculate cross sections for one and only one type of process. Of course, this does not prevent different data sets from sharing common data and/or calculation methods, as in the case of the *G4HadronCrossSections* class mentioned above. Indeed, *G4VCrossSectionDataSet* specifies only the abstract interface between physics processes and their data sets, and leaves the user free to implement whatever sort of underlying structure is appropriate.

The current implementation of the data set *G4HadronCrossSections* reuses the total cross-sections for inelastic and elastic scattering, radiative capture and fission as used with **GHEISHA** to provide cross-sections for calculation of the respective mean free paths of a given particle in a given material.

Cross-sections for low energy neutron transport

The cross section data for low energy neutron transport are organised in a set of files, that are read in by the corresponding data set classes at 0 time. Hereby the file system is used, in order to allow highly granular access to the data. The ‘‘root’’ directory of the cross-section directory structure is accessed through an environment variable, `NeutronHPCrossSections`, which is to be set by the user. The classes accessing the total cross-sections of the individual processes, i.e., the cross-section data set classes for low energy neutron transport, are *G4NeutronHPElasticData*, *G4NeutronHPCaptureData*, *G4NeutronHPFissionData*, and *G4NeutronHPInelasticData*. For detailed descriptions of the low energy neutron total cross-sections, they may be registered by the user as described above with the data stores of the corresponding processes for neutron interactions.

It should be noted, that using these total cross-section classes does not imply that also the models from neutron_hp have to be used. It is up to the user to decide, whether this is desirable or not for his particular problem.

5.2.2.2 Hadrons at rest

List of implemented "Hadron at Rest" processes

The following process classes have been implemented:

- pi- absorption (class name *G4PionMinusAbsorptionAtRest* or *G4PiMinusAbsorptionAtRest*)
- kaon- absorption (class name *G4KaonMinusAbsorptionAtRest* or *G4KaonMinusAbsorption*)
- neutron capture (class name *G4NeutronCaptureAtRest*)
- anti-proton annihilation (class name *G4AntiProtonAnnihilationAtRest*)
- anti-neutron annihilation (class name *G4AntiNeutronAnnihilationAtRest*)
- mu- capture (class name *G4MuonMinusCaptureAtRest*)

Note that the last process is not, strictly speaking, a ‘‘hadron at rest’’ process, since the mu- is not a hadron. It does, nonetheless, share common features with the others in the above list because of the implementation model chosen. The differences betweeen the alternative implementation for kaon and pion absorption concern the fast part of the emitted particle spectrum. G4PiMinusAbsorptionAtRest, and G4KaonMinusAbsorptionAtRest focus especially on a good description of this part of the spectrum.

Implementation Interface to Geant4

All of these classes are derived from the abstract class *G4VRestProcess*. In addition to the constructor and destructor methods, the following public methods of the abstract class have been implemented for each of the above six processes:

- `AtRestGetPhysicalInteractionLength( const G4Track&, G4ForceCondition* )`
  This method returns the time taken before the interaction actually occurs. In all processes listed above, except for muon capture, a value of zero is returned. For the muon capture process the muon capture lifetime is returned.

- `AtRestDoIt( const G4Track&, const G4Step& )`
  This method generates the secondary particles produced by the process.

- `IsApplicable( const G4ParticleDefinition& )`
  This method returns the result of a check to see if the process is possible for a given particle.

Example of how to use a hadron at rest process

Including a ‘‘hadron at rest’’ process for a particle, a pi- for example, into the Geant4 system is straightforward and can be done in the following way:

- create a process:

```
        theProcess = new G4PionMinusAbsorptionAtRest();
```

- register the process with the particle’s process manager:

```
        theParticleDef = G4PionMinus::PionMinus();
        G4ProcessManager* pman = theParticleDef->GetProcessManager();
        pman->AddRestProcess( theProcess );
```

5.2.2.3 Hadrons in flight

What processes do you need?

For hadrons in motion, there are four physics process classes. Table 5.2.2.3 shows each process and the particles for which it is relevant.

G4HadronElasticProcess	pi+, pi-, K^+, K^0_S, K^0_L, K^-, p, p-bar, n, n-bar, lambda, lambda-bar, Sigma^+, Sigma^-, Sigma^+-bar, Sigma^--bar, Xi^0, Xi^-, Xi^0-bar, Xi^--bar
G4HadronInelasticProcess	pi+, pi-, K^+, K^0_S, K^0_L, K^-, p, p-bar, n, n-bar, lambda, lambda-bar, Sigma^+, Sigma^-, Sigma^+-bar, Sigma^--bar, Xi^0, Xi^-, Xi^0-bar, Xi^--bar
G4HadronFissionProcess	all
G4CaptureProcess	n, n-bar

Table 5.2.2.3
Hadronic processes and relevant particles.

How to register Models

To register an inelastic process model for a particle, a proton for example, first get the pointer to the particle’s process manager:

```
   G4ParticleDefinition *theProton = G4Proton::ProtonDefinition();
   G4ProcessManager *theProtonProcMan = theProton->GetProcessManager();
```

Create an instance of the particle’s inelastic process:

```
   G4ProtonInelasticProcess *theProtonIEProc = new G4ProtonInelasticProcess();
```

Create an instance of the model which determines the secondaries produced in the interaction, and calculates the momenta of the particles:

```
   G4LEProtonInelastic *theProtonIE = new G4LEProtonInelastic();
```

Register the model with the particle's inelastic process:

```
   theProtonIEProc->RegisterMe( theProtonIE );
```

Finally, add the particle's inelastic process to the list of discrete processes:

```
   theProtonProcMan->AddDiscreteProcess( theProtonIEProc );
```

The particle's inelastic process class, *G4ProtonInelasticProcess* in the example above, derives from the *G4HadronicInelasticProcess* class, and simply defines the process name and calls the *G4HadronicInelasticProcess* constructor. All of the specific particle inelastic processes derive from the *G4HadronicInelasticProcess* class, which calls the `PostStepDoIt` function, which returns the particle change object from the *G4HadronicProcess* function `GeneralPostStepDoIt`. This class also gets the mean free path, builds the physics table, and gets the microscopic cross section. The *G4HadronicInelasticProcess* class derives from the *G4HadronicProcess* class, which is the top level hadronic process class. The *G4HadronicProcess* class derives from the *G4VDiscreteProcess* class. The inelastic, elastic, capture, and fission processes derive from the *G4HadronicProcess* class. This pure virtual class also provides the energy range manager object and the `RegisterMe` access function.

A sample case for the proton's inelastic interaction model class is shown in source listing 5.2.2, where `G4LEProtonInelastic.hh` is the name of the include file:

```
 ---------------------------- include file -------------------------------------

#include "G4InelasticInteraction.hh"
 class G4LEProtonInelastic : public G4InelasticInteraction
 {
 public:
    G4LEProtonInelastic() : G4InelasticInteraction()
    {
      SetMinEnergy( 0.0 );
      SetMaxEnergy( 25.*GeV );
    }
    ~G4LEProtonInelastic() { }
    G4ParticleChange *ApplyYourself( const G4Track &aTrack,
                                     G4Nucleus &targetNucleus );
 private:
    void CascadeAndCalculateMomenta( required arguments );
 };

 ---------------------------- source file --------------------------------------

 #include "G4LEProtonInelastic.hh"
 G4ParticleChange *
  G4LEProton Inelastic::ApplyYourself( const G4Track &aTrack,
                                       G4Nucleus &targetNucleus )
  {
    theParticleChange.Initialize( aTrack );
    const G4DynamicParticle *incidentParticle = aTrack.GetDynamicParticle();
    // create the target particle
    G4DynamicParticle *targetParticle = targetNucleus.ReturnTargetParticle();
    CascadeAndCalculateMomenta( required arguments )
    { ... }
    return &theParticleChange;
  }
```

Source listing 5.2.2
An example of a proton inelastic interaction model class.

The `CascadeAndCalculateMomenta` function is the bulk of the model and is to be provided by the model's creator. It should determine what secondary particles are produced in the interaction, calculate the momenta for all the particles, and put this information into the *ParticleChange* object which is returned.

The *G4LEProtonInelastic* class derives from the *G4InelasticInteraction* class, which is an abstract base class since the pure virtual function `ApplyYourself` is not defined there. *G4InelasticInteraction* itself derives from the *G4HadronicInteraction* abstract base class. This class is the base class for all the model classes. It sorts out the energy range for the models and provides class utilities. The *G4HadronicInteraction* class provides the `Set/GetMinEnergy` and the `Set/GetMaxEnergy` functions which determine the minimum and maximum energy range for the model. An energy range can be set for a specific element, a specific material, or for general applicability:

```
 void SetMinEnergy( G4double anEnergy, G4Element *anElement )
 void SetMinEnergy( G4double anEnergy, G4Material *aMaterial )
 void SetMinEnergy( const G4double anEnergy )
 void SetMaxEnergy( G4double anEnergy, G4Element *anElement )
 void SetMaxEnergy( G4double anEnergy, G4Material *aMaterial )
 void SetMaxEnergy( const G4double anEnergy )
```

Which models are there, and what are the defaults

In Geant4, any model can be run together with any other model without the need for the implementation of a special interface, or batch suite, and the ranges of applicability for the different models can be steered at initialisation time. This way, highly specialised models (valid only for one material and particle, and applicable only in a very restricted energy range) can be used in the same application, together with more general code, in a coherent fashion.

Each model has its intrinsic range of applicability, and which of the models is the right choice for the simulation depends very much on the use-case. Consequently, there are no ‘‘defaults’’. Physics lists, though, specifying sets of models for various purposes will be provided in due course.

We have been implementing three types of hadronic shower models, parametrisation driven models, data driven models, and theory driven models.

- Parametrisation driven models are used for all processes pertaining to particles coming to rest, and interacting with the nucleus. For particles in flight, two sets of models exist for inelastic scattering; low energy, and high energy models. Both sets are based originally on the **GHEISHA** package of Geant3.21, and the original approaches to primary interaction, nuclear excitation, intra-nuclear cascade and evaporation is kept. The models are located in the sub-directories `hadronics/models/low_energy` and `hadronics/models/high_energy`. The low energy models are targeted towards energies below 20 GeV; the high energy models cover the energy range from 20 GeV to O(TeV). Fission, capture and coherent elastic scattering are also modeled through parametrised models.
- Data driven models are available for the transport of low energy neutrons in matter in sub-directory `hadronics/models/neutron_hp`. The modeling is based on the data formats of **ENDF/B-VI**, and all distributions of this standard data format are implemented. The data sets used are selected from data libraries that conform to these standard formats. The file system is used in order to allow granular access to, and flexibility in, the use of the cross-sections for different isotopes, and channels. The energy coverage of these models is from thermal energies to 20 MeV.
- Theory driven models are available for inelastic scattering in a first implementation, covering the full energy range of LHC experiments. They are located in sub-directory `hadronics/models/generator`. The current philosophy implies the usage of parton string models at high energies, of intra-nuclear transport models at intermediate energies, and of statistical break-up models for de-excitation.

5.2.3 Particle decay process

This section briefly introduces decay processes installed in Geant4. For details of the implementation of particle decays, please refer to the **Physics Reference Manual**.

5.2.3.1 Particle decay class

Geant4 provides a *G4Decay* class for both ‘‘At Rest’’ and ‘‘In Flight’’ particle decays. *G4Decay* can be applied to all particles except:

massless particles, i.e.,	`G4ParticleDefinition::thePDGMass <= 0`
particles with ‘‘negative’’ life time, i.e.,	`G4ParticleDefinition::thePDGLifeTime < 0`
shortlived particles, i.e.,	`G4ParticleDefinition::fShortLivedFlag = True`

You can switch on/off the particle decay for some particle by using `G4ParticleDefinition::SetPDGStable()` as well as `ActivateProcess()` and `InActivateProcess()` methods of *G4ProcessManager*.

The *G4Decay* proposes the step length (or step time for `AtRest`) according to the life time of the particle except `PreAssignedDecayProperTime` is defined in *G4DynamicParticle*.

The *G4Decay* class does not define decay modes of the particle. Geant4 provides two ways of determining decay modes:

- using *G4DecayChannel* in *G4DecayTable*
- using `thePreAssignedDecayProducts` of *G4DynamicParticle*

The *G4Decay* class only calculates the `PhysicalInteractionLength` and boosts decay products created by *G4VDecayChannel* or event generators. See below for information on determination of the decay modes.

An object of *G4Decay* can be shared by particles. Registration of the decay process to particles in the `ConstructPhysics` method of *PhysicsList* (see Section 2.5.3) is shown in Source listing 5.2.3.

```
#include "G4Decay.hh"
void ExN02PhysicsList::ConstructGeneral()
{
  // Add Decay Process
  G4Decay* theDecayProcess = new G4Decay();
  theParticleIterator->reset();
  while( (*theParticleIterator)() ){
    G4ParticleDefinition* particle = theParticleIterator->value();
    G4ProcessManager* pmanager = particle->GetProcessManager();
    if (theDecayProcess->IsApplicable(*particle)) {
      pmanager ->AddProcess(theDecayProcess);
      // set ordering for PostStepDoIt and AtRestDoIt
      pmanager ->SetProcessOrdering(theDecayProcess, idxPostStep);
      pmanager ->SetProcessOrdering(theDecayProcess, idxAtRest);
    }
  }
}
```

Source listing 5.2.3
Registration of the decay process to particles in the `ConstructPhysics` method of *PhysicsList*.

5.2.3.2 Decay table

Each particle has its *G4DecayTable*, which stores information on the decay modes of the particle. Each decay mode, with its branching ratio, corresponds to an object of various ‘‘decay channel’’ classes derived from *G4VDecayChannel*. Default decay modes are created in the constructors of particle classes. For example, the decay table of the neutral pion has *G4PhaseSpaceDecayChannel* and *G4DalitzDecayChannel* as follows:

```
  // create a decay channel
  G4VDecayChannel* mode;
  // pi0 -> gamma + gamma
  mode = new G4PhaseSpaceDecayChannel("pi0",0.988,2,"gamma","gamma");
  table->Insert(mode);
  // pi0 -> gamma + e+ + e-
  mode = new G4DalitzDecayChannel("pi0",0.012,"e-","e+");
  table->Insert(mode);
```

Decay modes and branching ratios defined in Geant4 are listed in Section 5.3.2.

5.2.3.3 Pre-assigned decay modes by event generators

Decays of heavy flavor particles, such as B mesons and W/Z bosons, are very complex, with many varieties of decay modes and decay mechanisms. It is impossible to define all decay modes of heavy particles by using *G4VDecayChannel*.

Many models for heavy particle decays are given by various event generators. In other words, decays of heavy particles should be defined by event generators, and not by the Geant4 decay process.

In Geant4, *G4VPrimaryGenerator* automatically sets `*thePreAssignedDecayProducts` of *G4DynamicParticle* if primary events created by the event generators have information on the decay products of heavy particles.

5.2.4 Photolepton-hadron processes

To be delivered.

5.2.5 Optical Photon Processes

All GEANT3.21 physics processes involving optical photons have been ported to GEANT4. The level of complexity in the physics implementation is equivalent to the one in GEANT3.21 for the Cerenkov effect and light absorption, while one new interaction model at medium boundaries is considerably more sophisticated. Moreover, the GEANT4 tracking of optical photons now includes Rayleigh scattering at optical wavelengths.

The optical properties needed by these processes are stored as entries in the *G4MaterialPropertiesTable* class. This table is a private data member of the *G4Material* class. Each instance of *G4Material* has a pointer to a *G4MaterialPropertiesTable* which contains properties of the material that are expressible as a function of another variable, such as photon momentum, for example. *G4MaterialPropertiesTable* is implemented as a hash directory. Each entry in a hash directory has a *value* and a *key*. The *key* is used to quickly and efficiently retrieve the corresponding value. All *values* in the dictionary are instantiations of class *G4MaterialPropertyVector*, and all *keys* are of type *G4String*.

A *G4MaterialPropertyVector* is composed of instantiations of the class *G4MPVEntry*. In the case of optical properties of a material, the *G4MPVEntry* is composed of a photon momentum and a corresponding property value. The *G4MaterialPropertyVector* is implemented as a `G4std::vector`, with the sorting operation defined as $\mathrm{MPVEntry}_1 < \mathrm{MPVEntry}_2 == \mathrm{photon\_momentum}_1 < \mathrm{photon\_momentum}_2$. This results in all `G4MaterialPropertyVectors` being sorted in ascending order of photon momenta. It is possible for the user to add as many material (optical) properties to the material as he wishes using the methods supplied by the *G4MaterialPropertiesTable* class.

5.2.5.1 Generation of photons in `processes/electromagnetic/xrays` - Cerenkov Effect

When a charged particle is travelling in a dispersive medium faster than the speed of light in that same medium, optical photons are emitted on the surface of a cone, opening at an increasingly acute angle with respect to the particle's instantaneous direction, as the particle slows down. As well, the frequency of the photons emitted increases, and the number produced decreases.

The flux, spectrum, polarization and emission of Cerenkov radiation in G4Cerenkov's `AlongStepDoIt` follow well known formulas, albeit with the inherent computational limitation which firstly arises from step wise simulation, and secondly from a numerical integration required to calculate the average number of Cerenkov photons per step. The process makes use of a *G4PhysicsTable* which contains incremental integrals to expedite this calculation.

At present, the user may limit the step size by specifying a maximum (average) number of Cerenkov photons created during the step, via the `SetMaxNumPhotonsPerStep(const G4int NumPhotons)` method. The actual number generated will necessarily be different due to the Poissonian nature of the production. Presently, the production density of photons is distributed evenly along the particle's (rectilinear) track segment.

The frequently very large number of secondaries produced in a single step (about 300/cm in water), compelled the idea in GEANT3.21 of suspending the primary particle until all the progeny have been tracked. Notwithstanding that GEANT4 employs dynamic memory allocation inherent in C^{++} and thus does not suffer from the limitations of GEANT3.21 via a fixed large initial ZEBRA store, GEANT4 nevertheless provides for an analogous flexibility by way of the public method `SetTrackSecondariesFirst`. An example of the registration of the Cerenkov process is given in source listing 5.2.4.

```
#include "G4Cerenkov.hh"

void ExptPhysicsList::ConstructOp(){

  G4Cerenkov*   theCerenkovProcess = new G4Cerenkov("Cerenkov");

  G4int MaxNumPhotons = 300;

  theCerenkovProcess->SetTrackSecondariesFirst(true);
  theCerenkovProcess->SetMaxNumPhotonsPerStep(MaxNumPhotons);

  theParticleIterator->reset();
  while( (*theParticleIterator)() ){
    G4ParticleDefinition* particle = theParticleIterator->value();
    G4ProcessManager* pmanager = particle->GetProcessManager();
    G4String particleName = particle->GetParticleName();
    if (theCerenkovProcess->IsApplicable(*particle)) {
      pmanager->AddContinuousProcess(theCerenkovProcess);
    }
  }
}
```

Source listing 5.2.4
Registration of the Cerenkov process in *PhysicsList*.

5.2.5.2 Generation of Photons in `processes/electromagnetic/xrays` - Scintillation

Every scintillating material has a characteristic light yield and an intrinsic resolution which generally broadens the statistical distribution due to impurities. A scintillator is also characterized by its photon emission spectrum and by the exponential decay of its time spectrum. Scintillation may be simulated by specifying these empirical parameters for a material. It is sufficient to specify in the user's

DetectorConstruction class a relative spectral distribution as a function of photon energy for the scintillating material. An example of this is shown in source listing 5.2.5.

```
const G4int NUMENTRIES = 9;
G4double Scnt_PP[NUMENTRIES] = { 6.6*eV, 6.7*eV, 6.8*eV, 6.9*eV,
                                 7.0*eV, 7.1*eV, 7.2*eV, 7.3*eV, 7.4*eV };

G4double Scnt_SCINT[NUMENTRIES] = { 0.000134, 0.004432, 0.053991, 0.241971,
                                    0.398942, 0.000134, 0.004432, 0.053991,
                                    0.241971 };

G4Material* Scnt;
G4MaterialPropertiesTable* Scnt_MPT = new G4MaterialPropertiesTable();

Scnt_MPT->AddProperty("SCINTILLATION", Scnt_PP, Scnt_SCINT, NUMENTRIES);

Scnt->SetMaterialPropertiesTable(Scnt_MPT);
```

Source listing 5.2.5
Specification of scintillation properties in *DetectorConstruction*.

The process, yield, decay time and resolution scale are implemented and defined in the user's *PhysicsList* as shown in source listing 5.2.6.

```
G4Scintillation* theScintProcess = new G4Scintillation("Scintillation");

theScintProcess->SetTrackSecondariesFirst(true);
theScintProcess->SetScintillationYield(50000./MeV);
theScintProcess->SetResolutionScale(1.0);
theScintProcess->SetScintillationTime(45.*ns);
```

Source listing 5.2.6
Implementation of scintillation process in *PhysicsList*.

This means that at present, Geant4 can only accommodate one scintillation material in any given application. A Poisson-distributed number of photons is generated according to the energy lost during the step. A resolution scale of 1.0 produces a statistical fluctuation around the average yield set with SetScintillationYield, while values >1 broaden the fluctuation and a value of zero produces no fluctuation. Each photon's frequency is sampled from the empirical spectrum. The photons originate evenly along the track segment and are emitted uniformly into 4pi with a random linear polarization.

5.2.5.3 Tracking of Photons in `processes/optical`

Absorption

The implementation of optical photon absorption, G4OpAbsorption, is trivial in that the process merely kills the particle. The procedure requires a *G4MaterialPropertiesTable* to be filled by the user with absorption length data, using `ABSLENGTH` as the property *key* in the public method `AddProperty`.

Rayleigh Scattering

The differential cross section in Rayleigh scattering, ?/?, is proportional to $\cos^2$(?), where ? is the polar angle of the new polarization (vector) with respect to the old polarization. The *G4OpRayleigh* scattering process samples this angle accordingly and then calculates the scattered photon's new direction by requiring that it be perpendicular to the photon's new polarization. This process thus depends on the particle's polarization (spin). A photon which is not conferred a polarization at production, either via the `SetPolarization` method of the *G4PrimaryParticle* class, or indirectly with the `SetParticlePolarization` method of the *G4ParticleGun* class, may not be Rayleigh scattered. Optical photons produced by the `G4Cerenkov` process have inherently a polarization perpendicular to the cone's surface at production. The photon's polarization is a data member of the *G4DynamicParticle* class.

The *G4OpRayleigh* class provides a `RayleighAttenuationLengthGenerator` method, which calculates the attenuation coefficient of a medium following the Einstein-Smoluchowski formula whose derivation requires the use of statistical mechanics, includes temperature, and depends on the isothermal compressibility of the medium. This generator is convenient when the Rayleigh attenuation length is not known from measurement but may be calculated from first principle using the above material constants. The procedure requires a *G4MaterialPropertiesTable* to be filled by the user with Rayleigh scattering length data, unless the `RayleighAttenuationLengthGenerator` method is employed.

Boundary Process

As in GEANT3.21, the medium boundary may be specified as between two dielectric materials, one dielectric and a metal, or one dielectric and a 'black' medium. In the case of two dielectric materials the photon can be total internal reflected, refracted or reflected; depending on the photon's wavelength, angle of incidence, polarization and the refractive indices on both sides of the boundary. The latter may be specified as a function of wavelength and hence constitutes a material constant (property) which has not only one constant value but requires a vector of paired numbers. To provide for this notion, the *G4Material* class contains a pointer to a *G4MaterialPropertiesTable* where several material properties of this kind may be listed as *G4MaterialPropertyVectors*, each belonging to a different *key* (string) via a `G4std::map`. The *G4MaterialPropertyVectors* are themselves generated from an assembly of *G4MPVEntry*(ies). This functionality is added to the materials directory of the material category.

Inasmuch as Fresnel reflection and refraction are intertwined through their relative probabilities of occurrence, as expressed in Maxwell's equations, neither process, nor total internal reflection, are viewed as individual processes deserving separate class implementation. Nonetheless, we tried to adhere to the abstraction of having independent processes by splitting the code into different methods where practicable.

One implementation of the *G4OpBoundaryProcess* class employs the UNIFIED model [reference] of the DETECT [reference] program. This model is thoroughly described in [references], and we refer the reader to the GEANT4 Physics Reference Manual for details. The UNIFIED model tries to provide a realistic simulation, which deals with all aspects of surface finish and reflector coating. The original GEANT3.21 implementation of this process is also available via the GLISUR methods flag.

In the UNIFIED model, the surface may be assumed as smooth and covered with a metallized coating representing a specular reflector with given reflection coefficient, or painted with a diffuse reflecting material where Lambertian reflection occurs. The surfaces may or may not be in optical contact with another component and most importantly, one may consider a surface to be made up of micro-facets with normal vectors that follow given distributions around the nominal normal for the volume at the impact point. The latter is retrieved via the *GetLocalExitNormal* method of the *G4Navigator* class.

5.2.6 Parameterization

In this section we describe how to use the parameterization or "fast simulation" facilities of GEANT4. Examples are provided in the **examples/novice/N05 directory**.

5.2.6.1 Generalities:

The Geant4 parameterization facilities allow you to shortcut the detailed tracking in a given volume and for given particle types in order for you to provide your own implementation of the physics and of the detector response.

The volume to which you will bind parameterisations is called an ***envelope***. An envelope can have a geometrical sub-structure but all points in its daughter or sub-daughter (etc...) volumes are said to be also in the envelope.

Envelopes correspond often to the volumes of sub-detectors: electromagnetic calorimeter, tracking chamber etc. With GEANT4 it is also possible to define envelopes by overlaying a parallel or "ghost" geometry as we will see in section 5.2.6.8.

In GEANT4 parameterisations have three main features. You will have to specify:

- For which particle types your parameterisation is available;
- What are the dynamics conditions for which your parameterisation is available and must be triggered;
- The parameterisation properly said: where you will kill the primary or move it or create secondaries (etc...) and where you will compute the detector response.

GEANT4 will message your parameterisations code for each step starting in the volume of the envelope. It will proceed by first asking to the parameterisations available for the current particle type if one of them (and only one) wants to issue a trigger and if so it will invoke its parameterisation code properly said. In this case, the tracking ***will not apply physics*** to particle in the step. However, the UserSteppingAction will be invoked.

Parameterisations look like a "user stepping action" but are more advanced because:

- Your parameterisation code is messaged only in the envelope you bind it;
- Your parameterisation code is messaged anywhere in the envelope, even it the track is located in a daughter volume of the hierarchy;

- You can bind parameterisations to envelopes in a very flexible way.
- GEANT4 will provide informations on the envelope to your parameterisation code;

5.2.6.2 Overview of parameterisation components:

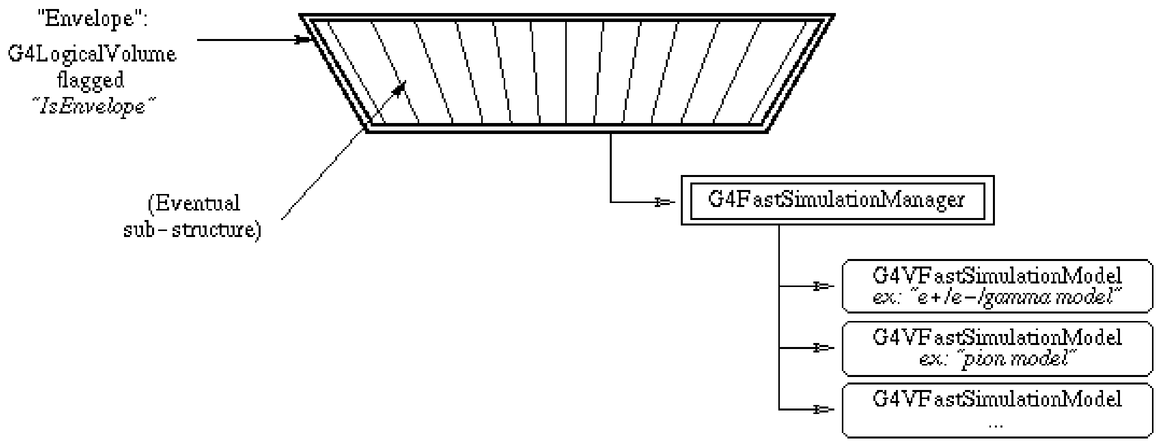
The GEANT4 components allowing you to implement and control parameterisations are:

- **`G4VFastSimulationModel`**This is the abstract class for the implementation of parameterisations. You have to inherit from it to implement you concrete parameterisation model.

- **`G4FastSimulationManager`**The G4VFastSimulationModel objects are attached to the envelope through a G4FastSimulationManager. This object will manage the list of models and will message them at tracking time.

- **`Envelope`** An envelope in GEANT4 is a **`G4LogicalVolume`** object which is simply flagged as being an envelope. The parameterisation is bound to the envelope by setting a G4FastSimulationManager pointer to it.

  The figure below shows how the G4VFastSimulationModel and G4FastSimulationManager objects are bound to the envelope:



- **`G4FastSimulationManagerProcess`**This is a G4VProcess. It provides the interface between the tracking and the parameterisation. It has to be set in the process list of the particles you want to parameterise. (An automated way of setting this process to the appropriate particles is foreseen.)

- **`G4GlobalFastSimulationManager`**This a singleton class which provides the management of the G4FastSimulationManager objects and some ghost facilities.

5.2.6.3 The `G4VFastSimulationModel` abstract class:

- **Constructors:**

  The G4VFastSimulationModel class has two constructors. The second one allows you to get a quick "getting started".

- **`G4VFastSimulationModel(`*`const G4String& aName`*`)`:** Where aName identifies the parameterisation model.

- **`G4VFastSimulationModel(`*`const G4String& aName, G4LogicalVolume*, G4bool IsUnique=false`*`)`:** In addition to the model name, this constructor accepts a G4LogicalVolume pointer. This volume will automatically becomes the envelope, and the needed G4FastSimulationManager object is constructed if necessary giving it the G4LogicalVolume pointer and the boolean value. If it already exists, the model is simply added to this manager. However the *G4VFastSimulationModel object will not keep track of the envelope given in the constructor*.
  The boolean argument is there for optimization purpose: if you know that the G4LogicalVolume envelope is placed only once you can turn this boolean value to "true" (an automated mechanism is foreseen here.)

- **Virtual methods:**

  The G4VFastSimulationModel has three pure virtual methods you have thus to override in your concrete class:

  - **`G4bool IsApplicable(`*`const G4ParticleDefinition&`*`)`:** In your implementation, you have to return "true" when your model is applicable to the G4ParticleDefinition passed to this method. The G4ParticleDefinition provides all intrisic particle informations (mass, charge, spin, name ...).

    In the case you want to implement a model valid for precise particle types, it is recommended for efficiency that you use the static pointer of the corresponding particle classes.
    As an example, in a model valid for *gamma*s only, the IsApplicable() method should take the form:

    ```
    #include "G4Gamma.hh"
    G4bool MyGammaModel::IsApplicable(const G4ParticleDefinition& partDef)
    {
      return &partDef == G4Gamma::GammaDefinition();
    }
    ```

  - **`G4bool ModelTrigger(`*`const G4FastTrack&`*`)`:** You have to return "true" when the dynamics conditions to trigger your parameterisation are fulfiled.
    The G4FastTrack provides you access to the current G4Track, gives simple access to envelope related features (G4LogicalVolume, G4VSolid, G4AffineTransform references between the global and the envelope local coordinates systems) and simple access to the position, momentum expressed in the envelope coordinate system. Using those quantities and the G4VSolid methods, you can for example easily check how far you are from the envelope boundary.

  - **`void DoIt(`*`const G4FastTrack&, G4FastStep&`*`)`:** Your parameterisation properly said. The G4FastTrack reference provides input informations. The final state of the particles after parameterisation has to be returned through the G4FastStep reference. This final state is described has "requests" the tracking will apply after your parameterisation has been invoked.

5.2.6.4 The `G4FastSimulationManager` class:

(We explain in section 5.2.6.8 the G4FastSimulationManager functionnalities regarding the use of ghost volumes.)

- **Constructor:**
  - **`G4FastSimulationManager(`*`G4LogicalVolume *anEnvelope, G4bool IsUnique=false`*`):`** This is the only constructor. In this constructor you specify the envelope by giving the G4LogicalVolume pointer. The G4FastSimulationManager object will bind itself to this envelope and will notify this G4LogicalVolume to become an envelope. If you know that this volume is placed only once, you can turn the IsUnique boolean to "true" to allow some optimization. (however an automated mechanism is foreseen.)
    Note that if you choose to use the G4VFastSimulationModel(const G4String&, G4LogicalVolume*, G4bool) constructor for you model, the G4FastSimulationManager will be constructed using the given G4LogicalVolume* and G4bool values of the model constructor.

- **G4VFastSimulationModel objects management:**
  - **`void AddFastSimulationModel(G4VFastSimulationModel*)`**
  - **`RemoveFastSimulationModel(G4VFastSimulationModel*)`**
    Those two methods provide the usual management functionnalities.

- **Interface with the G4FastSimulationManagerProcess:**

  This is described in the User's Guide for Toolkit Developers (section 3.9.6)

5.2.6.5 The "Envelope":

The **`G4LogicalVolume`** class is described in Section 4.1.3. Here we focus on the envelope aspect.

- **Turn on to envelope mode:**

  The setup of a G4LogicalVolume to become an envelope is done transparently: when a G4FastSimulationManager object is created, it uses the G4LogicalVolume pointer given in its constructor to invoke the G4LogicalVolume method:

  `void BecomeEnvelopeForFastSimulation(G4FastSimulationManager*)`

- **Turn off envelope mode:**

  If you need to turn off the envelope mode of a G4LogicalVolume, you have to invoke:

  `void ClearEnvelopeForFastSimulation()`.

- **Existing limitation:**

  It exists a small limitation in the present implementation with envelope definition:

  a G4LogicalVolume placed in the hierarchy tree of an envelope must not be placed elsewhere than in this envelope.

  The reason why of this limitation is that, for efficiency reasons, the G4FastSimulationManager pointer of an envelope is recursively propagated into the G4logicalVolume of its daughters, in order to allow a quick check at tracking time (actually no warnings are issued in this situation !.)

- **Ghost Envelopes:**

  Ghost envelopes are envelopes defined in a parallel geometry. Like envelopes of the tracking geometry, you will have to set to them a G4FastSimulationManager object and G4VFastSimulationModel objects.

  We explain in more detail how you can build and use ghost envelopes in section 5.2.6.8.

5.2.6.6 The `G4FastSimulationManagerProcess`:

This G4VProcess serves as an interface between the tracking and the parameterisation. At tracking time, it collaborates with the G4FastSimulationManager of the current volume if any to allow the models to trigger. If no manager exists or if no model issues a trigger, the tracking goes on normally.

In the existing implementation, you have to set this process in the G4ProcessManager of the particles you parameterise to enable your parameterisation.

(An automated way of putting this process in the G4ProcessManager of the concerned particles is foreseen, since GEANT4 has all the necessary information.)

The processes ordering is:

```
          [n-3] ...
          [n-2] Multiple Scattering
          [n-1] G4FastSimulationManagerProcess
          [ n ] G4Transportation
```

This ordering is important in the case you use ghost geometries, since the G4FastSimulationManagerProcess will provide navigation in the ghost world to limit the step on ghost boundaries.

The G4FastSimulationManager must be added to the process list of a particle as a continuous and discrete process if you use ghost geometries for this particle. You can add it as a discrete process if you don’t use ghosts.
The following code sets the G4FastSimulationManagerProcess to all the particles as a discrete and continuous process:

```
void MyPhysicsList::addParameterisation()
{
  G4FastSimulationManagerProcess*
    theFastSimulationManagerProcess = new G4FastSimulationManagerProcess();
  theParticleIterator->reset();
  while( (*theParticleIterator)() )
    {
      G4ParticleDefinition* particle = theParticleIterator->value();
      G4ProcessManager* pmanager = particle->GetProcessManager();
      pmanager->AddProcess(theFastSimulationManagerProcess, -1, 0, 0);
    }
}
```

5.2.6.7 The `G4GlobalFastSimulationManager` singleton class:

This class is a singleton. You can get access to it by:

```
#include "G4GlobalFastSimulationManager.hh"
...
...
G4GlobalFastSimulationManager* globalFSM;
globalFSM = G4GlobalFastSimulationManager::getGlobalFastSimulationManager();
...
...
```

Presently, you will mainly need to use the GlobalFastSimulationManager if you use ghost geometries.

5.2.6.8 Parameterisation using ghost geometries:

In some cases, volumes of the tracking geometry do not allow to define envelopes. This can be the case with a geometry coming out of a CAD system. Since such a geometry is flat, you need to use a parallel geometry to define the envelopes.
It can be also interesting in the case you want to make the parameterisation of charged pions to define the envelope by the volume grouping together the electromagnetic and hadronic calorimeters of the detector. A strong requirement coming out here is that you will probably not want the electrons to see this envelope, which means that ghost geometries have to be organized by particle flavours.

Using ghost geometries implies some more overhead in the parameterisation mechanism for the particles sensitive to ghosts, since a navigation is provided in the ghost geometry by the G4FastSimulationManagerProcess. But note, since you will place only a few volumes in this ghost world, that the geometry computations will stay rather cheap.

In the existing implementation, you don’t need to build explicitely the ghost geometries, the G4GlobalFastSimulationManager provides this construction. It starts by making an empty "clone" of the world for tracking provided by the construct() method of your G4VUserDetectorConstruction concrete class. You will provide the placements of the envelopes compared to the ghost world coordinates in the G4FastSimulationManager objects. A ghost envelope is recognized by the fact its associated G4FastSimulationManager retains a non-empty list of placements.
The G4GlobalFastSimulationManager will then use both those placements and the IsApplicable()

methods of the models attached to the G4FastSimulationManager objects to build the flavour-dependant ghost geometries.
Then at the beginning of the tracking of a particle, the appropriate ghost world -if any- will be selected.

The steps you have to provide to build one ghost envelope are:

1. Build the envelope (ie a G4LogicalVolume): myGhostEnvelope;
2. Build a G4FastSimulationManager object, myGhostFSManager, giving myGhostEnvelope as argument of the constructor;
3. Give to the G4FastSimulationManager all placements of the myGhostEnvelope, by invoking for each of them the G4FastSimulationManager methods:

   ```
   AddGhostPlacement(G4RotationMatrix*, const G4ThreeVector&);
   ```

   or:

   ```
   AddGhostPlacement(G4Transform3D*);
   ```

   Where the rotation matrix, translatation vector of 3D transformation describe the placement relative to the ghost world coordinates.
4. Build your G4VFastSimulationModel objects, and add them to the myGhostFSManager.
   The IsApplicable() methods of your models will be used by the G4GlobalFastSimulationManager to build the ghost geometries corresponding to a given particle type.
5. Invoke the G4GlobalFastSimulationManager method:

   ```
   G4GlobalFastSimulationManager::getGlobalFastSimulationManager()->
        CloseFastSimulation();
   ```

This last call will provoke the G4GlobalFastSimulationManager to build the flavour-dependant ghost geometries. This call must be done before the RunManager closes the geometry. (It is foreseen that the run manager in the future will invoke the CloseFastSimulation() to synchronize properly with the closing of the geometry).

Visualization facilities are provided for ghosts geometries. After the CloseFastSimulation() invokation, it is possible to ask for the drawing of ghosts in an interactive sessions. The basic commands are:

- /vis/draw/Ghosts particle_name
  Which makes the drawing of the ghost geometry associated to the particle specified by name in the command line.
- /vis/draw/Ghosts
  Which draws all the ghost geometries.

5.2.7 Transportation process

To be delivered by J. Apostolakis (John.Apostolakis@cern.ch)

About the authors

5.3 Particles

5.3.1 Basic concepts

There are three levels of classes to describe particles in Geant4.

G4ParticleDefinition	defines a particle
G4DynamicParticle	describes a particle interacting with materials
G4Track	describes a particle traveling in space and time

G4ParticleDefinition aggregates information to characterize a particle's properties, such as name, mass, spin, life time, and decay modes. *G4DynamicParticle* aggregates information to describe the dynamics of particles, such as energy, momentum, polarization, and proper time, as well as ''particle definition'' information. *G4Track* includes all information necessary for tracking in a detector simulation, such as time, position, and step, as well as ''dynamic particle'' information.

G4Track has all the information necessary for tracking in Geant4. It includes position, time, and step, as well as kinematics. Details of *G4Track* will be described in Section 5.1.

Besides above three classes, *G4ParticleWithCuts* class plays an important role. It provides the functionality to convert the cut value in range into energy thresholds for all materials.

5.3.2 Definition of a particle

There are a large number of elementary particles and nuclei. Geant4 provides the *G4ParticleDefinition* class to represent particles, and various particles, such as the electron, proton, and gamma have their own classes derived from *G4ParticleDefinition*.

We do not need to make a class in Geant4 for every kind of particle in the world. There are more than 100 types of particles defined in Geant4 by default. Which particles should be included, and how to implement them, is determined according to the following criteria. (Of course, the user can define any particles he wants. Please see the **User's Guide: For ToolKit Developers**)

5.3.2.1 Particle List in Geant4

This list includes all particles in Geant4 and you can see properties of particles such as

- PDG encoding
- mass and width
- spin, isospin and parity
- life time and decay modes
- quark contents

Here is a list of particles in Geant4. This list is generated automatically by using Geant4 functionality, so listed values are same as those in your Geant4 application. (as far as you do not change source codes)

Categories

- gluon / quarks / di-quarks
- leptons
- mesons
- baryons
- ions
- others

5.3.2.2 Classification of particles

a. elementary particles which should be tracked in Geant4
   All particles that can fly a finite length and interact with materials in detectors are included in this category. In addition, some particles with a very short lifetime are included.
   1. stable particles
      Stable means that the particle can not decay, or has a very small possibility to decay in detectors, e.g., gamma, electron, proton, and neutron.
   2. long life ($>10^{-14}$sec) particles
      Particles which may travel a finite length, e.g., muon, charged pions.
   3. short life particles that need to decay in Geant4
      For example, p^0,h
   4. K^0 system
      K^0 "decays" immediately into K^0_S or K^0_L, and then K^0_S/K^0_L decays according to its life time and decay modes.
   5. optical photons
      Gammas and optical photons are distinguished in the simulation view, though both are the same particle (photons with different energies). For example, optical photons are used for Cerenkov light and scintillation light.
   6. geantinos/charged geantinos
      Geantinos and charged geantinos are virtual particles for simulation which do not interact with materials and undertake transportation processes only.

b. nuclei
   Any kinds of nucleus can be used in Geant4, such as alpha(He-4), uranium-238 and excited states of carbon-14. Nuclei in Geant4 are divided into two groups from the viewpoint of implementation.
   1. light nuclei
      Light nuclei frequently used in simulation, e.g., alpha, deuteron, He3, triton.
   2. heavy nuclei
      Nuclei other than those defined in the previous category.

   Note that G4ParticleDefinition represents nucleus state and G4DynamicParticle represents atomic state with some nucleus. Both alpha particle with charge of +2 and helium atom with no charge aggregates the same "particle definition" of G4Alpha, but different G4DynamicParticle objects should be assigned to them. (Details can be found below)
c. short-lived particles
   Particles with very short life time decay immediately and are never tracked in the detector geometry. These particles are usually used only inside physics processes to implement some models of interactions. *G4VShortLivedParticle* is provided as the base class for these particles. All classes related to particles in this category can be found in `shortlived` sub-directory under the `particles` directory.
   1. quarks/di-quarks
      For example, all 6 quarks.
   2. gluons
   3. baryon excited states with very short life
      For example, spin 3/2 baryons and anti-baryons
   4. meson excited states with very short life
      For example, spin 1 vector bosons

5.3.2.3 Implementation of particles

Singleton:	Categories a, b-1

These particles are frequently used for tracking in Geant4. An individual class is defined for each particle in these categories. The object in each class is unique and defined as a static object (so-called singleton). The user can get pointers to these objects by using static methods in their own classes.

On-the-fly creation:	Category b-2

Ions will travel in a detector geometry and should be tracked, however, the number of ions which may be used for hadronic processes is so huge that ions are dynamic rather than static. Each ion corresponds to one object of the *G4Ions* class, and it will be created on the fly in the `G4ParticleTable::GetIon()` method.

Dynamic creation by processes:	Category c

Particle types in this category are are not created by default, but will only be created by request from processes or directly by users. Each shortlived particle corresponds to one object of a class derived from *G4VshortLivedParticle,* and it will be created dynamically during the ‘‘initialization phase’’.

5.3.2.4 *G4ParticleDefinition*

The *G4ParticleDefinition* class has ‘‘read-only’’ properties to characterize individual particles, such as name, mass, charge, spin, and so on. These properties are set during initialization of each particle.

Methods to get these properties are listed in Table 5.3.1.

`G4String GetParticleName()`	particle name
`G4double GetPDGMass()`	mass
`G4double GetPDGWidth()`	decay width
`G4double GetPDGCharge()`	electric charge
`G4double GetPDGSpin()`	spin
`G4int GetPDGiParity()`	parity (0:not defined)
`G4int GetPDGiConjugation()`	charge conjugation (0:not defined)
`G4double GetPDGIsospin()`	iso-spin
`G4double GetPDGIsospin3()`	3rd-component of iso-spin
`G4int GetPDGiGParity()`	G-parity (0:not defined)
`G4String GetParticleType()`	particle type
`G4String GetParticleSubType()`	particle sub-type
`G4int GetLeptonNumber()`	lepton number
`G4int GetBaryonNumber()`	baryon number
`G4int GetPDGEncoding()`	particle encoding number by PDG
`G4int GetAntiPDGEncoding()`	encoding for anti-particle of this particle

Table 5.3.1
Methods to get particle properties.

Table 5.3.2 shows the methods of *G4ParticleDefinition* for getting information about decay modes and the life time of the particle.

`G4bool GetPDGStable()`	stable flag
`G4double GetPDGLifeTime()`	life time
`G4DecayTable* GetDecayTable()`	decay table

Table 5.3.2
Methods to get particle decay modes and life time.

Users can modify these properties, though the other properties listed above can not be change without rebuilding the libraries.

G4ParticleDefinition provides methods for setting and/or getting cut off values, as shown in Table 5.3.3.

However, these methods only provide the functionality to set and get values. Calculation of energy cut-off values from a cut-off value in range is implemented in the *G4ParticleWithCuts* class, as described below.

In addition, each particle has its own *G4ProcessManger* object that manages a list of processes applicable to the particle.

5.3.2.5 *G4ParticleWithCuts*

G4ParticleWithCuts class provides the functionality to convert the cut value in range into energy thresholds for all materials as well as inherits *G4ParticleDefintion* functionality. Each particle has its cut-off value in range (for each material) and should be derived from *G4ParticleWithCuts* if the cut-off value is relevant for physics processes. Please see **Section 5.4** for the detail explanation of cut values in Geant4.

G4ParticleWithCuts class inherits *G4ParticleDefintion* and provides the functionality to convert the cut value in range into energy thresholds for all materials.

```
virtual void          SetCuts(G4double );
virtul  void          SetRangeCut(G4double aCut, const G4Material*):
virtual G4double*     GetLengthCuts() const;
virtual G4double      GetRangeThreshold(const G4Material* ) const;
virtual G4double*     GetEnergyCuts() const;
virtual G4double      GetEnergyThreshold(const G4Material* ) const;
G4bool                GetApplyCutsFlag() const;
void                  SetApplyCutsFlag(G4bool flag);
```

Table 5.3.3
Methods to set/get cut values.

`SetCuts()` method is provided to set a cut value in range to the praticle type (for all materials). Another method of `SetRangeCut()` is used only if you want to set different cut value in range for a material.

GetRangeThreshold() and `GetEnergyThreshold()` methods are provided to get cut value for a particular material in range and energy respectively. `GetLengthCuts()` (`GetEnergyCuts()`) method gives an array of cut values in range (energy) for all materials.

When `SetCuts()` method is invoked, the given cut value in range is converted to cut values in energy for all materials. At first, tables of energy loss for all materials, as a function of kinetic energy, are calculated by using formula given by the `ComputeLoss()`. Then, cut-off energies corresponding to the cut-off in range are calculated by using the `CalcEnergyCuts` method.

G4ParticleWithCuts also provides a static method of `SetEnergyRange()` in order to define energy range where physics process can be applied to this particle type. This energy range is set from 0.99 keV to 100TeV in default.

5.3.3 Dynamic particle

The *G4DynamicParticle* class has kinematics information for the particle and is used for describing the dynamics of physics processes. The properties in *G4DynamicParticle* are listed in Table 5.3.4.

`G4double theDynamicalMass`	dynamical mass
`G4ThreeVector theMomentumDirection`	normalized momentum vector
`G4ParticleDefinition* theParticleDefinition`	definition of particle
`G4ThreeVector thePolarization`	polarization vector
`G4double theKineticEnergy`	kinetic energy
`G4double theProperTime`	proper time
`G4ElectronOccupancy* theElectronOccupancy`	electron orbits for ions

Table 5.3.4
Methods to set/get cut off values.

Here, the dynamical mass is defined as the mass for the dynamic particle. For most cases, it is same as the mass defined in *G4ParticleDefinition* class (i.e. mass value given by `GetPDGMass()` method). However, there are two exceptions.

- resonace particle
- ions

Resonace particles have large mass width and the total energy of decay products at the center of mass system can be different event by event.

As for ions, *G4ParticleDefintion* defines a nucleus and *G4DynamicParticle* defines an atom. *G4ElectronOccupancy* describes state of orbital electrons. So, the dynaimc mass can be different from the PDG mass by the mass of electrons (and their binding energy).

Decay products of heavy flavor particles are given in many event generators. In such cases, *G4VPrimaryGenerator* sets this information in `*thePreAssignedDecayProducts`. In addition, decay time of the particle can be set arbitrarily time by using `PreAssignedDecayProperTime`.

About the authors

5.4 Production Threshold versus Tracking Cut

5.4.1 General considerations

We have to fulfill two contradictory requirements. It is the responsibility of each individual **process** to produce secondary particles according to its own capabilities. On the other hand, it is only the Geant4 kernel (i.e., tracking) which can ensure an overall coherence of the simulation.

The general principles in Geant4 are the following:

1. Each **process** has its intrinsic limit(s) to produce secondary particles.
2. All particles produced (and accepted) will be tracked up to **zero range**.
3. Each **particle** has a suggested cut in range (which is converted to energy for all materials), and defined via a `SetCut()` method (see Section 2.4.2).

Points 1 and 2 imply that the cut associated with the **particle** is a (recommended) **production** threshold of secondary particles.

5.4.2 Set production threshold (`SetCut` methods)

As already mentioned, each kind of particle has a suggested production threshold. Some of the processes will not use this threshold (e.g., decay), while other processes will use it as a default value for their intrinsic limits (e.g., ionisation and bremsstrahlung).

See Section 2.4.2 to see how to set the production threshold.

5.4.3 Apply cut

The `DoIt` methods of each process can produce secondary particles. Two cases can happen:

- a process sets its intrinsic limit greater than or equal to the recommended production threshold. OK. Nothing has to be done (nothing can be done !).
- a process sets its intrinsic limit smaller than the production threshold (for instance 0).

  The list of secondaries is sent to the *SteppingManager* via a *ParticleChange* object.

BEFORE being recopied to the temporary stack for later tracking, the particles below the production threshold will be kept or deleted according to the safe mechanism explained hereafter.

- The *ParticleDefinition* (or *ParticleWithCuts*) has a boolean data member: `ApplyCut`.
- `ApplyCut` is OFF: do nothing. All the secondaries are stacked (and then tracked later on), regardless of their initial energy. The Geant4 kernel respects the best that the physics can do, but neglects the overall coherence and the efficiency. Energy conservation is respected as far as the processes know how to handle correctly the particles they produced!
- `ApplyCut` in ON: the *TrackingManager* checks the range of each secondary against the production threshold and against the safety. The particle is stacked if `range > min(cut,safety)`.
  - If not, check if the process has nevertheless set the flag ‘‘good for tracking’’ and then stack it (see Section 5.4.4 below for the explanation of the `GoodForTracking` flag).
  - If not, recuperate its kinetic energy in the `localEnergyDeposit`, and set `tkin=0`.
  - Then check in the *ProcessManager* if the vector of *ProcessAtRest* is not empty. If yes, stack the particle for performing the ‘‘Action At Rest’’ later. If not, and only in this case, abandon this secondary.

  With this sophisticated mechanism we have the global cut that we wanted, but with energy conservation, and we respect boundary constraint (safety) and the wishes of the processes (via ‘‘good for tracking’’).

5.4.4 Why produce secondaries below threshold?

A process may have good reasons to produce particles below the recommended threshold:

- checking the range of the secondary versus geometrical quantities like safety may allow one to realize the possibility that the produced particle, even below threshold, will reach a sensitive part of the detector;
- another example is the gamma conversion: the positron is always produced, even at zero energy, for further annihilation.

These secondary particles are sent to the ‘‘Stepping Manager’’ with a flag `GoodForTracking` to pass the filter explained in the previous section (even when `ApplyCut` is ON).

5.4.5 Cuts in stopping range or in energy?

The cuts in stopping range allow one to say that the energy has been released at the correct space position, limiting the approximation within a given distance. On the contrary, cuts in energy imply accuracies of the energy depositions which depend on the material.

5.4.6 Summary

In summary, we do not have tracking cuts; we only have production thresholds in range. All particles produced and accepted are tracked up to zero range.

It must be clear that the overall coherency that we provide cannot go beyond the capability of processes to produce particles down to the recommended threshold.

In other words a process can produce the secondaries down to the recommended threshold, and by interrogating the geometry, or by realizing when mass-to-energy conversion can occur, recognize when particles below the threshold have to be produced.

5.4.7 Special tracking cuts

One may need to cut given particle types in given volumes for optimisation reasons. This decision is under user control, and can happen for particles during tracking as well.

The user must be able to apply these special cuts only for the desired particles and in the desired volumes, without introducing an overhead for all the rest.

The approach is as follows:

- special user cuts are registered in the *UserLimits* class (or its descendant), which is associated with the logical volume class.

  The current default list is:

- max allowed step size
- max total track length
- max total time of flight
- min kinetic energy
- min remaining range

The user can instantiate a *UserLimits* object only for the desired logical volumes and do the association.

The first item (max step size) is automatically taken into account by the G4 kernel while the others items must be managed by the user, as explained below.

Example(see novice/N02): in the Tracker region, in order to force the step size not to exceed 1/10 of the Tracker thickness, it is enough to put the following code in `DetectorConstruction::Construct()`:

```
        G4double maxStep = 0.1*TrackerLength;
        logicTracker->SetUserLimits(new G4UserLimits(maxStep));
```

The *G4UserLimits* class is in `source/global/management`.

- Concerning the others cuts, the user must define dedicaced process(es). He registers this process (or its descendant) only for the desired particles in their process manager. He can apply his cuts in the `DoIt` of this process, since, via *G4Track*, he can access the logical volume and *UserLimits*.

  An example of such process (called *UserSpecialCuts*) is provided in the repository, but not inserted in any process manager of any particle.

  Example: neutrons. One may need to abandon the tracking of neutrons after a given time of flight (or a charged particle in a magnetic field after a given total track length ... etc ...).

  Example(see novice/N02): in the Tracker region, in order to force the total time of flight of the neutrons not to exceed 10 milliseconds, put the following code in `DetectorConstruction::Construct()`:

```
        G4double maxTime = 10*ms;
        logicTracker->SetUserLimits(new G4UserLimits(DBL_MAX,DBL_MAX,maxTime));
```

  and put the following code in `N02PhysicsList`:

```
        G4ProcessManager* pmanager = G4Neutron::Neutron->GetProcessManager();
        pmanager->AddProcess(new G4UserSpecialCuts(),-1,-1,1);
```

  (The default *G4UserSpecialCuts* class is in `source/processes/transportation`.)

About the authors

6. User Actions

6.1 Mandatory User Actions and Initializations

Geant4 has three virtual classes whose methods the user must override in order to implement a simulation. They require the user to define the detector, specify the physics to be used, and describe how initial particles are to be generated.

`G4VUserDetectorConstruction`

```
     class G4VUserDetectorConstruction
     {
       public:
         G4VUserDetectorConstruction();
         virtual ~G4VUserDetectorConstruction();

       public:
         virtual G4VPhysicalVolume* Construct() = 0;
     };
```

Source listing 6.1.1
`G4VUserDetectorConstruction`

`G4VUserPhysicsList`

This is an abstract class for constructing particles and processes. The user must derive a concrete class from it and implement three virtual methods:

- `ConstructParticle()` to instantiate each requested particle type,
- `ConstructPhysics()` to instantiate the desired physics processes and register each of them with the process managers of the appropriate particles, and
- `SetCuts(G4double aValue)` to set a cut value in range for all particles in the particle table, which invokes the rebuilding of the physics table.

When called, the `Construct()` method of *G4VUserPhysicsList* first invokes `ConstructParticle()`

and then `ConstructProcess()`. The `ConstructProcess()` method must always invoke the `AddTransportation()` method in order to insure particle transportation. `AddTransportation()` must never be overridden.

G4VUserPhysicsList provides several utility methods for the implementation of the above virtual methods. They are presented with comments in the class declaration in source listing 6.1.2.

```
      class G4VUserPhysicsList
      {
        public:
          G4VUserPhysicsList();
          virtual ~G4VUserPhysicsList();

        public:

          void Construct();

        protected:

          virtual void ConstructParticle() = 0;
          virtual void ConstructProcess() = 0;

        protected:
         //  !! Caution: this class must not be overriden !!
          void AddTransportation();

        public:
          virtual void SetCuts(G4double aCut) = 0;

         //  "SetCutsWithDefault" method sets a cut value with the default
         //   cut values for all particle types in the particle table
          void SetCutsWithDefault();

        protected:
          //
          void BuildPhysicsTable(G4ParticleDefinition* );

        protected:
          // Following are utility methods for SetCuts/reCalcCuts

          // Reset cut values in energy for all particle types
          // By calling this methods, the run manager will invoke
          // SetCuts() just before event loop
          void ResetCuts();

          // SetCutValue sets a cut value for a particle type
          void SetCutValue(G4double aCut, const G4String& name);
          void ReCalcCutValue(const G4String& name);

          //  "setCutsForOthers" method sets a cut value to all particle types
          //  which have not be called SetCuts() methods yet.
          //  (i.e. particles which have no definite cut values)
          void SetCutValueForOthers(G4double cutValue);

          // "setCutsForOtherThan"  sets a cut value to all particle types
          // other than particle types specified in arguments
          void SetCutValueForOtherThan(G4double cutValue,
                                  G4ParticleDefinition* first,
                                  G4ParticleDefinition* second  = NULL,
                                  G4ParticleDefinition* third   = NULL,
                                  G4ParticleDefinition* fourth  = NULL,
                                  G4ParticleDefinition* fifth   = NULL,
                                  G4ParticleDefinition* sixth   = NULL,
                                  G4ParticleDefinition* seventh = NULL,
                                  G4ParticleDefinition* eighth  = NULL,
                                  G4ParticleDefinition* ninth  = NULL,
                                  G4ParticleDefinition* tenth   = NULL  );

          //  "reCalcCutsForOthers" method re-calculates a cut value
          //  to all particle types which have not be called SetCuts() methods yet.
          void ReCalcCutValueForOthers();

        public:
          //  set/get the default cut value
          //  Calling SetDefaultCutValue causes re-calculation of cut values
          //  and physics tables just before the next event loop
          void     SetDefaultCutValue(G4double newCutValue);
          G4double GetDefaultCutValue() const;

        protected:
          // this is the default cut value for all particles
          G4double defaultCutValue;

        public:
          // Print out the List of registered particles types
          void DumpList() const;

        public:
        // Print out information of cut values
          void DumpCutValuesTable() const;
          void DumpCutValues(const G4String &particle_name = "ALL") const;
          void DumpCutValues(G4ParticleDefinition* ) const;

        protected:
          // adds new ProcessManager to all particles in the Particle Table
          //   this routine is used in Construct()
          void InitializeProcessManager();

        public:
          // add process manager for particles created on-the-fly
          void AddProcessManager(G4ParticleDefinition* newParticle,
                            G4ProcessManager*    newManager = NULL );

        protected:
          // the particle table has the complete List of existing particle types
          G4ParticleTable* theParticleTable;
          G4ParticleTable::G4PTblDicIterator* theParticleIterator;

        protected:
        // pointer to G4UserPhysicsListMessenger
          G4UserPhysicsListMessenger* theMessenger;

       public:
         void  SetVerboseLevel(G4int value);
         G4int GetVerboseLevel() const;

       protected:
         G4int verboseLevel;
```

```
        // control flag for output message
        //  0: Silent
        //  1: Warning message
        //  2: More

    };
```

Source listing 6.1.2
`G4VUserPhysicsList`

`G4VUserPrimaryGeneratorAction`

```
class G4VUserPrimaryGeneratorAction
{
  public:
    G4VUserPrimaryGeneratorAction();
    virtual ~G4VUserPrimaryGeneratorAction();

  public:
    virtual void GeneratePrimaries(G4Event* anEvent) = 0;
};
```

Source listing 6.1.3
`G4VUserPrimaryGeneratorAction`

About the authors

6.2 Optional User Actions

There are five virtual classes whose methods the user may override in order to gain control of the simulation at various stages.

`G4UserRunAction`

```
class G4UserRunAction
{
  public:
    G4UserRunAction();
    virtual ~G4UserRunAction();

  public:
    virtual void BeginOfRunAction(const G4Run*);
    virtual void EndOfRunAction(const G4Run*);
};
```

Source listing 6.2.1
`G4UserRunAction`

`G4UserEventAction`

This class has two virtual methods which are invoked by *G4EventManager* for each event:

`beginOfEventAction()`
: This method is invoked before converting the primary particles to *G4Track* objects. A typical use of this method is initializing and/or booking histograms for a particular event.

`endOfEventAction()`
: This method is invoked at the very end of event processing. It is typically used for a simple analysis of the processed event.

```
class G4UserEventAction
{
  public:
      G4UserEventAction() {;}
      virtual ~G4UserEventAction() {;}
      virtual void BeginOfEventAction(const G4Event*);
      virtual void EndOfEventAction(const G4Event*);
  protected:
      G4EventManager* fpEventManager;
};
```

Source listing 6.2.2
`G4UserEventAction`

`G4UserStackingAction`

This class has three virtual methods, `ClassifyNewTrack`, `NewStage` and `PrepareNewEvent` which the user may override in order to control the various track stacking mechanisms.

`ClassifyNewTrack()` is invoked by *G4StackManager* whenever a new *G4Track* object is "pushed" onto a stack by *G4EventManager*. `ClassifyNewTrack()` returns an enumerator, *G4ClassificationOfNewTrack*, whose value indicates to which stack, if any, the track will be sent. This value should be determined by the user. *G4ClassificationOfNewTrack* has four possible values:

`fUrgent` - track is placed in the *urgent* stack

`fWaiting` - track is placed in the *waiting* stack, and will not be simulated until the *urgent* stack is empty

`fPostpone` - track is postponed to the next event

`fKill` - the track is deleted immediately and not stored in any stack.

These assignments may be made based on the origin of the track which is obtained as follows:

```
G4int parent_ID = aTrack->get_parentID();
```

where

`parent_ID = 0` indicates a primary particle

`parent_ID > 0` indicates a secondary particle

`parent_ID < 0` indicates postponed particle from previous event.

`NewStage()` is invoked when the *urgent* stack is empty and the *waiting* stack contains at least one *G4Track* object. Here the user may kill or re-assign to different stacks all the tracks in the *waiting* stack by calling the `stackManager->ReClassify()` method which, in turn, calls the `ClassifyNewTrack()` method. If no user action is taken, all tracks in the *waiting* stack are transferred to the *urgent* stack. The user may also decide to abort the current event even though some tracks may remain in the *waiting* stack by calling `stackManager->clear()`. This method is valid and safe only if it is called from the *G4UserStackingAction* class. A global method of event abortion is

```
G4UImanager * UImanager = G4UImanager::GetUIpointer();
UImanager->ApplyCommand("/event/abort");
```

`PrepareNewEvent()` is invoked at the beginning of each event. At this point no primary particles have been converted to tracks, so the *urgent* and *waiting* stacks are empty. However, there may be tracks in the *postponed-to-next-event* stack; for each of these the `ClassifyNewTrack()` method is called and the track is assigned to the appropriate stack.

```
#include "G4ClassificationOfNewTrack.hh"

class G4UserStackingAction
{
  public:
      G4UserStackingAction();
      virtual ~G4UserStackingAction();
  protected:
      G4StackManager * stackManager;

  public:
//---------------------------------------------------------------
// virtual methods to be implemented by user
//---------------------------------------------------------------
//
      virtual G4ClassificationOfNewTrack
        ClassifyNewTrack(const G4Track*);
//
//---------------------------------------------------------------
//
      virtual void NewStage();
//
//---------------------------------------------------------------
//
      virtual void PrepareNewEvent();
//
//---------------------------------------------------------------

};
```

Source listing 6.2.3
`G4UserStackingAction`

G4UserTrackingAction

```
//---------------------------------------------------------------
//
// G4UserTrackingAction.hh
//
// Description:
//   This class represents actions taken place by the user at each
//   end of stepping.
//
//---------------------------------------------------------------

///////////////////////////
class G4UserTrackingAction
///////////////////////////
{

//--------
   public:
//--------

// Constructor & Destructor
   G4UserTrackingAction(){};
   virtual ~G4UserTrackingAction(){}

// Member functions
   virtual void PreUserTrackingAction(const G4Track*){}
   virtual void PostUserTrackingAction(const G4Track*){}

//-----------
   protected:
//-----------

// Member data
   G4TrackingManager* fpTrackingManager;

};
```

Source listing 6.2.4
`G4UserTrackingAction`

G4UserSteppingAction

```
//-----------------------------------------------------------------
//
//  G4UserSteppingAction.hh
//
//  Description:
//    This class represents actions taken place by the user at each
//    end of stepping.
//
//-----------------------------------------------------------------

///////////////////////////
class G4UserSteppingAction
///////////////////////////
{

//--------
   public:
//--------

// Constructor and destructor
   G4UserSteppingAction(){}
   virtual ~G4UserSteppingAction(){}

// Member functions
   virtual void UserSteppingAction(const G4Step*){}

//-----------
   protected:
//-----------

// Member data
   G4SteppingManager* fpSteppingManager;

};
```

Source listing 6.2.5
`G4UserSteppingAction`

7. Communication and Control

7.1 Built-in Commands

Geant4 has various built-in user interface commands, each of which corresponds roughly to a Geant4 category. These commands can be used

- interactively via a (Graphical) User Interface - (G)UI,
- in a macro file via /control/execute <command>,
- within C++ code with the ApplyCommand method of G4UImanager.

Note
The availability of individual commands, the ranges of parameters, the available candidates on individual command parameters **vary** according to the implementation of your application and may even **vary** dynamically during the execution of your job.

List of built-in commands

About the authors

7.2 User Interface - Defining New Commands

7.2.1 *G4UImessenger*

G4UImessenger is a base class which represents a messenger that delivers command(s) to the destination class object. Your concrete messenger should have the following functionalities.

- Construct your command(s) in the constructor of your messenger.
- Destruct your command(s) in the destructor of your messenger.

These requirements mean that your messenger should keep all pointers to your command objects as its data members.

You can use *G4UIcommand* derived classes for the most frequent types of command. These derived classes have their own conversion methods according to their types, and they make implementation of the `SetNewValue()` and `GetCurrentValue()` methods of your messenger much easier and simpler.

For complicated commands which take various parameters, you can use the *G4UIcommand* base class, and construct *G4UIparameter* objects by yourself. You don't need to delete *G4UIparameter* object(s).

In the `SetNewValue()` and `GetCurrentValue()` methods of your messenger, you can compare the *G4UIcommand* pointer given in the argument of these methods with the pointer of your command, because your messenger keeps the pointers to the commands. Thus, you don't need to compare by command name. Please remember, in the cases where you use *G4UIcommand* derived classes, you should store the pointers with the types of these derived classes so that you can use methods defined in the derived classes according to their types without casting.

G4UImanager/G4UIcommand/G4UIparameter have very powerful type and range checking routines. You are strongly recommended to set the range of your parameters. For the case of a numerical value (`int` or `double`), the range can be given by a *G4String* using C++ notation, e.g., `"X > 0 && X < 10"`. For the case of a string type parameter, you can set a candidate list. Please refer to the detailed descriptions below.

`GetCurrentValue()` will be invoked after the user's application of the corresponding command, and before the `SetNewValue()` invocation. This `GetCurrentValue()` method will be invoked only if

- at least one parameter of the command has a range
- at least one parameter of the command has a candidate list
- at least the value of one parameter is omitted and this parameter is defined as omittable and `currentValueAsDefault`

For the first two cases, you can re-set the range or the candidate list if you need to do so, but these ‘‘re-set’’ parameters are needed only for the case where the range or the candidate list varies dynamically.

A command can be ‘‘state sensitive’’, i.e., the command can be accepted only for a certain *G4ApplicationState*(s). For example, the `/run/beamOn` command should not be accepted when Geant4 is processing another event (‘‘EventProc’’ state). You can set the states available for the command with the `AvailableForStates()` method.

7.2.2 *G4UIcommand* and its derived classes

Methods available for all derived classes

These are methods defined in the *G4UIcommand* base class which should be used from the derived classes.

- `void SetGuidance(char*)`

  Define a guidance line. You can invoke this method as many times as you need to give enough amount of guidance. Please note that the first line will be used as a title head of the command guidance.

- `void availableForStates(G4ApplicationState s1,...)`

  If your command is valid only for certain states of the Geant4 kernel, specify these states by this method. Currently available states are `PreInit, Init, Idle, GeomClosed,` and `EventProc`. Please note that the `Pause` state will be removed from *G4ApplicationState*.

- `void SetRange(char* range)`

  Define a range of the parameter(s). Use C++ notation, e.g., `"x > 0 && x < 10"`, with variable name(s) defined by the `SetParameterName()` method. For the case of a *G4ThreeVector*, you can set the relation between parameters, e.g., `"x > y"`.

G4UIdirectory

This is a *G4UIcommand* derived class for defining a directory.

- `G4UIdirectory(char* directoryPath)`

  Constructor. Argument is the (full-path) directory, which must begin and terminate with ‘`/`’.

G4UIcmdWithoutParameter

This is a *G4UIcommand* derived class for a command which takes no parameter.

- `G4UIcmdWithoutParameter(char* commandPath,G4UImessenger* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

G4UIcmdWithABool

This is a *G4UIcommand* derived class which takes one boolean type parameter.

- `G4UIcmdWithABool(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

- `void SetParameterName(char* paramName,G4bool omittable)`

  Define the name of the boolean parameter and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(G4bool defVal)`

Define the default value of the boolean parameter.

- `G4bool GetNewBoolValue(G4String paramString)`

  Convert *G4String* parameter value given by the `SetNewValue()` method of your messenger into boolean.

- `G4String convertToString(G4bool currVal)`

  Convert the current boolean value to *G4String* which should be returned by the `GetCurrentValue()` method of your messenger.

G4UIcmdWithAnInteger

This is a *G4UIcommand* derived class which takes one integer type parameter.

- `G4UIcmdWithAnInteger(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

- `void SetParameterName(char* paramName,G4bool omittable)`

  Define the name of the integer parameter and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(G4int defVal)`

  Define the default value of the integer parameter.

- `G4int GetNewIntValue(G4String paramString)`

  Convert *G4String* parameter value given by the `SetNewValue()` method of your messenger into integer.

- `G4String convertToString(G4int currVal)`

  Convert the current integer value to *G4String*, which should be returned by the `GetCurrentValue()` method of your messenger.

G4UIcmdWithADouble

This is a *G4UIcommand* derived class which takes one double type parameter.

- `G4UIcmdWithADouble(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

- `void SetParameterName(char* paramName,G4bool omittable)`

Define the name of the double parameter and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(G4double defVal)`

  Define the default value of the double parameter.

- `G4double GetNewDoubleValue(G4String paramString)`

  Convert *G4String* parameter value given by the `SetNewValue()` method of your messenger into double.

- `G4String convertToString(G4double currVal)`

  Convert the current double value to *G4String* which should be returned by the `GetCurrentValue()` method of your messenger.

G4UIcmdWithAString

This is a *G4UIcommand* derived class which takes one string type parameter.

- `G4UIcmdWithAString(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

- `void SetParameterName(char* paramName,G4bool omittable)`

  Define the name of the string parameter and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(char* defVal)`

  Define the default value of the string parameter.

- `void SetCandidates(char* candidateList)`

  Define a candidate list which can be taken by the parameter. Each candidate listed in this list should be separated by a single space. If this candidate list is given, a string given by the user but which is not listed in this list will be rejected.

G4UIcmdWith3Vector

This is a *G4UIcommand* derived class which takes one three vector parameter.

- `G4UIcmdWith3Vector(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

- `void SetParameterName`
  `(char* paramNamX,char* paramNamY,char* paramNamZ,G4bool omittable)`

  Define the names of each component of the three vector and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(G4ThreeVector defVal)`

  Define the default value of the three vector.

- `G4ThreeVector GetNew3VectorValue(G4String paramString)`

  Convert the *G4String* parameter value given by the `SetNewValue()` method of your messenger into a *G4ThreeVector*.

- `G4String convertToString(G4ThreeVector currVal)`

  Convert the current three vector to *G4String*, which should be returned by the `GetCurrentValue()` method of your messenger.

G4UIcmdWithADoubleAndUnit

This is a *G4UIcommand* derived class which takes one double type parameter and its unit.

- `G4UIcmdWithADoubleAndUnit(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

- `void SetParameterName(char* paramName,G4bool omittable)`

  Define the name of the double parameter and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(G4double defVal)`

  Define the default value of the double parameter.

- `void SetUnitCategory(char* unitCategory)`

  Define acceptable unit category.

- `void SetDefaultUnit(char* defUnit)`

  Define the default unit. Please use this method and the `SetUnitCategory()` method alternatively.

- `G4double GetNewDoubleValue(G4String paramString)`

  Convert *G4String* parameter value given by the `SetNewValue()` method of your messenger into double. Please note that the return value has already been multiplied by the value of the given unit.

- `G4double GetNewDoubleRawValue(G4String paramString)`

  Convert *G4String* parameter value given by the `SetNewValue()` method of your messenger into double but without multiplying the value of the given unit.

- `G4double GetNewUnitValue(G4String paramString)`

  Convert *G4String* unit value given by the `SetNewValue()` method of your messenger into double.

- `G4String convertToString(G4bool currVal,char* unitName)`

  Convert the current double value to a *G4String*, which should be returned by the `GetCurrentValue()` method of your messenger. The double value will be divided by the value of the given unit and converted to a string. Given unit will be added to the string.

G4UIcmdWith3VectorAndUnit

This is a *G4UIcommand* derived class which takes one three vector parameter and its unit.

- `G4UIcmdWith3VectorAndUnit(char* commandpath,G4UImanager* theMessenger)`

  Constructor. Arguments are the (full-path) command name and the pointer to your messenger.

-
  ```
  void SetParameterName
   (char* paramNamX,char* paramNamY,char* paramNamZ,G4bool omittable)
  ```

  Define the names of each component of the three vector and set the omittable flag. If omittable is true, you should define the default value using the next method.

- `void SetDefaultValue(G4ThreeVector defVal)`

  Define the default value of the three vector.

- `void SetUnitCategory(char* unitCategory)`

  Define acceptable unit category.

- `void SetDefaultUnit(char* defUnit)`

  Define the default unit. Please use this method and the `SetUnitCategory()` method alternatively.

- `G4ThreeVector GetNew3VectorValue(G4String paramString)`

  Convert a *G4String* parameter value given by the `SetNewValue()` method of your messenger into a *G4ThreeVector*. Please note that the return value has already been multiplied by the value of the given unit.

- `G4ThreeVector GetNew3VectorRawValue(G4String paramString)`

  Convert a *G4String* parameter value given by the `SetNewValue()` method of your messenger into three vector, but without multiplying the value of the given unit.

- `G4double GetNewUnitValue(G4String paramString)`

  Convert a *G4String* unit value given by the `SetNewValue()` method of your messenger into a double.

- `G4String convertToString(G4ThreeVector currVal,char* unitName)`

  Convert the current three vector to a *G4String* which should be returned by the `GetCurrentValue()` method of your messenger. The three vector value will be divided by the value of the given unit and converted to a string. Given unit will be added to the string.

Additional comments on the `SetParameterName()` method

> You can add one additional argument of `G4bool` type for every `SetParameterName()` method mentioned above. This additional argument is named `currentAsDefaultFlag` and the default value of this argument is `false`. If you assign this extra argument as `true`, the default value of the parameter will be overriden by the current value of the target class.

7.2.3 An example messenger

This example is of *G4ParticleGunMessenger*, which is made by inheriting *G4UIcommand*.

```
#ifndef G4ParticleGunMessenger_h
#define G4ParticleGunMessenger_h 1

class G4ParticleGun;
class G4ParticleTable;
class G4UIcommand;
class G4UIdirectory;
class G4UIcmdWithoutParameter;
class G4UIcmdWithAString;
class G4UIcmdWithADoubleAndUnit;
class G4UIcmdWith3Vector;
class G4UIcmdWith3VectorAndUnit;

#include "G4UImessenger.hh"
#include "globals.hh"

class G4ParticleGunMessenger: public G4UImessenger
{
  public:
    G4ParticleGunMessenger(G4ParticleGun * fPtclGun);
    ~G4ParticleGunMessenger();

  public:
    void SetNewValue(G4UIcommand * command,G4String newValues);
    G4String GetCurrentValue(G4UIcommand * command);

  private:
    G4ParticleGun * fParticleGun;
    G4ParticleTable * particleTable;

  private: //commands
    G4UIdirectory *             gunDirectory;
    G4UIcmdWithoutParameter *   listCmd;
    G4UIcmdWithAString *        particleCmd;
    G4UIcmdWith3Vector *        directionCmd;
    G4UIcmdWithADoubleAndUnit * energyCmd;
    G4UIcmdWith3VectorAndUnit * positionCmd;
    G4UIcmdWithADoubleAndUnit * timeCmd;

};

#endif
```

Source listing 7.2.1
An example of `G4ParticleGunMessenger.hh`.

```
#include "G4ParticleGunMessenger.hh"
#include "G4ParticleGun.hh"
#include "G4Geantino.hh"
#include "G4ThreeVector.hh"
#include "G4ParticleTable.hh"
#include "G4UIdirectory.hh"
#include "G4UIcmdWithoutParameter.hh"
#include "G4UIcmdWithAString.hh"
#include "G4UIcmdWithADoubleAndUnit.hh"
#include "G4UIcmdWith3Vector.hh"
```

```
#include "G4UIcmdWith3VectorAndUnit.hh"
#include <iostream.h>

G4ParticleGunMessenger::G4ParticleGunMessenger(G4ParticleGun * fPtclGun)
:fParticleGun(fPtclGun)
{
  particleTable = G4ParticleTable::GetParticleTable();

  gunDirectory = new G4UIdirectory("/gun/");
  gunDirectory->Set_guidance("Particle Gun control commands.");

  listCmd = new G4UIcmdWithoutParameter("/gun/list",this);
  listCmd->Set_guidance("List available particles.");
  listCmd->Set_guidance(" Invoke G4ParticleTable.");

  particleCmd = new G4UIcmdWithAString("/gun/particle",this);
  particleCmd->Set_guidance("Set particle to be generated.");
  particleCmd->Set_guidance(" (geantino is default)");
  particleCmd->SetParameterName("particleName",true);
  particleCmd->SetDefaultValue("geantino");
  G4String candidateList;
  G4int nPtcl = particleTable->entries();
  for(G4int i=0;i<nPtcl;i++)
  {
    candidateList += particleTable->GetParticleName(i);
    candidateList += " ";
  }
  particleCmd->SetCandidates(candidateList);

  directionCmd = new G4UIcmdWith3Vector("/gun/direction",this);
  directionCmd->Set_guidance("Set momentum direction.");
  directionCmd->Set_guidance("Direction needs not to be a unit vector.");
  directionCmd->SetParameterName("Px","Py","Pz",true,true);
  directionCmd->SetRange("Px != 0 || Py != 0 || Pz != 0");

  energyCmd = new G4UIcmdWithADoubleAndUnit("/gun/energy",this);
  energyCmd->Set_guidance("Set kinetic energy.");
  energyCmd->SetParameterName("Energy",true,true);
  energyCmd->SetDefaultUnit("GeV");
  energyCmd->SetUnitCandidates("eV keV MeV GeV TeV");

  positionCmd = new G4UIcmdWith3VectorAndUnit("/gun/position",this);
  positionCmd->Set_guidance("Set starting position of the particle.");
  positionCmd->SetParameterName("X","Y","Z",true,true);
  positionCmd->SetDefaultUnit("cm");
  positionCmd->SetUnitCandidates("micron mm cm m km");

  timeCmd = new G4UIcmdWithADoubleAndUnit("/gun/time",this);
  timeCmd->Set_guidance("Set initial time of the particle.");
  timeCmd->SetParameterName("t0",true,true);
  timeCmd->SetDefaultUnit("ns");
  timeCmd->SetUnitCandidates("ns ms s");

  // Set initial value to G4ParticleGun
  fParticleGun->SetParticleDefinition( G4Geantino::Geantino() );
  fParticleGun->SetParticleMomentumDirection( G4ThreeVector(1.0,0.0,0.0) );
  fParticleGun->SetParticleEnergy( 1.0*GeV );
  fParticleGun->SetParticlePosition(G4ThreeVector(0.0*cm, 0.0*cm, 0.0*cm));
  fParticleGun->SetParticleTime( 0.0*ns );
}
```

```
G4ParticleGunMessenger::~G4ParticleGunMessenger()
{
  delete listCmd;
  delete particleCmd;
  delete directionCmd;
  delete energyCmd;
  delete positionCmd;
  delete timeCmd;
  delete gunDirectory;
}

void G4ParticleGunMessenger::SetNewValue(
  G4UIcommand * command,G4String newValues)
{
  if( command==listCmd )
  { particleTable->dumpTable(); }
  else if( command==particleCmd )
  {
    G4ParticleDefinition* pd = particleTable->findParticle(newValues);
    if(pd != NULL)
    { fParticleGun->SetParticleDefinition( pd ); }
  }
  else if( command==directionCmd )
  { fParticleGun->SetParticleMomentumDirection(directionCmd->
     GetNew3VectorValue(newValues)); }
  else if( command==energyCmd )
  { fParticleGun->SetParticleEnergy(energyCmd->
     GetNewDoubleValue(newValues)); }
  else if( command==positionCmd )
  { fParticleGun->SetParticlePosition(
     directionCmd->GetNew3VectorValue(newValues)); }
  else if( command==timeCmd )
  { fParticleGun->SetParticleTime(timeCmd->
     GetNewDoubleValue(newValues)); }
}

G4String G4ParticleGunMessenger::GetCurrentValue(G4UIcommand * command)
{
  G4String cv;

  if( command==directionCmd )
  { cv = directionCmd->convertToString(
     fParticleGun->GetParticleMomentumDirection()); }
  else if( command==energyCmd )
  { cv = energyCmd->convertToString(
     fParticleGun->GetParticleEnergy(),"GeV"); }
  else if( command==positionCmd )
  { cv = positionCmd->convertToString(
     fParticleGun->GetParticlePosition(),"cm"); }
  else if( command==timeCmd )
  { cv = timeCmd->convertToString(
     fParticleGun->GetParticleTime(),"ns"); }
  else if( command==particleCmd )
  { // update candidate list
    G4String candidateList;
    G4int nPtcl = particleTable->entries();
    for(G4int i=0;i<nPtcl;i++)
    {
      candidateList += particleTable->GetParticleName(i);
      candidateList += " ";
    }
    particleCmd->SetCandidates(candidateList);
  }
  return cv;
}
```

Source listing 7.2.2
An example of `G4ParticleGunMessenger.cc`.

7.2.4 How to control the output of *G4cout/G4cerr*

Instead of *cout* and *cerr*, Geant4 uses *G4cout* and *G4cerr*. Output streams from *G4cout/G4cerr* are handled by *G4UImanager* which allows the application programmer to control the flow of the stream. Output strings may therefore be displayed on another window or stored in a file. This is accomplished as follows:

1. Derive a class from *G4UIsession* and implement the two methods:

   ```
   G4int ReceiveG4cout(G4String coutString);
   G4int ReceiveG4cerr(G4String cerrString);
   ```

   These methods receive the string stream of *G4cout* and *G4cerr*, respectively. The string can be handled to meet specific requirements. The following sample code shows how to make a log file of the output stream:

   ```
   ostream logFile;
   logFile.open("MyLogFile");
   G4int MySession::ReceiveG4cout(G4String coutString)
   {
     logFile << coutString << flush;
     return 0;
   }
   ```

2. Set the destination of *G4cout/G4cerr* using `G4UImanager::SetCoutDestination(session)`.

   Typically this method is invoked from the constructor of *G4UIsession* and its derived classes, such as *G4UIGAG/G4UIteminal*. This method sets the destination of *G4cout/G4cerr* to the session. For example, when the following code appears in the constructor of *G4UIterminal*, the method `SetCoutDestination(this)` tells *UImanager* that this instance of *G4UIterminal* receives the stream generated by *G4cout*.

   ```
   G4UIterminal::G4UIterminal()
   {
     UI = G4UImanager::GetUIpointer();
     UI->SetCoutDestination(this);
     //  ...
   }
   ```

Similarly, `UI->SetCoutDestination(NULL)` must be added to the destructor of the class.

3. Write or modify the main program. To modify `exampleN01` to produce a log file, derive a class as described in step 1 above, and add the following lines to the main program:

```
#include "MySession.hh"
main()
{
  // get the pointer to the User Interface manager
  G4UImanager* UI = G4UImanager::GetUIpointer();
  // construct a session which receives G4cout/G4cerr
  MySession * LoggedSession = new MySession;
  UI->SetCoutDestination(LoggedSession);
  // session->SessionStart(); // not required in this case
  // .... do simulation here ...

  delete LoggedSession;
  return 0;
}
```

Note: *G4cout/G4cerr* should not be used in the constructor of a class if the instance of the class is intended to be used as `static`. This restriction comes from the language specification of C++. See the documents below for details.

M.A.Ellis, B.Stroustrup. ‘‘Annotated C++ Reference Manual’’, Section 3.4
P.J.Plauger, ‘‘The Draft Standard C++ Library’’

About the authors

8. Visualization

8.1 Visualization Introduction

In this section, we describe how to perform Geant4 Visualization, i.e., to visualize detector components, particle trajectories, tracking steps, hits, texts (character strings), etc.

There are many varieties of requirements for Geant4 Visualization. For example,

1. Very quick response to survey successive events
2. High-quality outputs for presentation and documentation
3. Impressive special effects for demonstration
4. Flexible camera control for debugging geometry of detector components and physics
5. Interactive picking of graphical objects for attribute editing or feedback to the associated data
6. Highlighting collisions of physical volumes visually
7. Remote visualization via the Internet
8. Cooperative works with graphical user interfaces

Geant4 Visualization is able to respond to all these requirements, but it is very difficult to responds to all of these requirements with only one built-in visualizer. Therefore, Geant4 supports an abstract interface to be applicable to many kinds of graphics systems. Here a "graphics system" means either an application running as an independent process of Geant4 or a graphics library to be compiled with Geant4. Geant4 Visualization also supports concrete interfaces to varieties of graphics systems by default. These graphics systems are all complementary to each other. A concrete interface to a graphics system is called a "visualization driver".

Visualization procedures are controlled by the "Visualization Manager", described with a user class *MyVisManager* which is a descendent of the class *G4VisManager* defined in the visualization category. The Visualization Manager accepts users' requests for visualization, processes them, and passes the processed requirements to the abstract interface, i.e., to the currently selected visualization driver.

Geant4 application developers should know the following things for visualization.

1. Visualizable objects
2. How to use visualization attributes, e.g., color
3. How to select the visualization drivers in compilation and in execution
4. How to use the built-in visualization commands
5. How to use the drawing methods of the Visualization Manager, etc

These issues are described in succeeding sections. Features and notes of each driver are briefly described in Section 8.6 "**Visualization Drivers**", and details are described in WWW pages referred there. Some advanced and/or driver-dependent topics are also described in Section 8.10 "**More About Visualization**". See also macro files `examples/novice/N03/visTutor/exN03VisX.mac`.

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8.2 What Can Be Visualized?

In Geant4 Visualization, you can visualize simulated data such as:

- Detector components
  - A hierarchical structure of physical volumes
  - A piece of physical volume, logical volume, and solid
- Particle trajectories and tracking steps
- Hits of particles in detector components

and other user defined objects such as:

- A polyline, that is, a set of successive line segments
- A marker which marks an arbitrary 3D position
- texts, i.e., character strings for a description, a comment, or a title
- Eye guides such as coordinate axes

You can visualize all these things either with visualization commands or by calling visualizing functions in your C++ source codes.

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8.3 Visualization Attributes

Visualization attributes are a set of information associated with the visualizable objects. This information is necessary only for visualization, and is not included in geometrical information such as shapes, position, and orientation. A typical example of a visualization attribute is "colour". For example, in visualizing a box, the Visualization Manager must know its colour. If an object to be visualized has not been assigned a set of visualization attributes, then a proper default set is used automatically.

A set of visualization attributes is held by an instance of class *G4VisAttributes* defined in the `graphics_reps` category. In the following, we explain the main fields of the *G4VisAttributes* one by one.

8.3.1 Visibility

Visibility is a boolean flag to control the visibility of objects that are passed to the Visualization Manager for visualization. Visibility is set with the following access function:

```
     void G4VisAttributes::SetVisibility (G4bool visibility);
```

If you give `false` to the argument, and if culling is activated (see below), visualization is skipped for objects for which this set of visualization attributes is assigned. The default value of visibility is `true`.

Note that whether an object is visible or not is also affected by the current culling policy, which can be tuned with visualization commands.

By default the following public constant static data member is defined:

```
     static const G4VisAttributes Invisible;
```

in which visibility is set to `false`. It can be referred to as `G4VisAttributes::Invisible`, e.g.:

```
     experimentalHall_logical -> SetVisAttributes (G4VisAttributes::Invisible);
```

8.3.2 Colour

Class *G4VisAttributes* holds its colour entry as an object of class *G4Colour* (an equivalent class name, *G4Color*, is also available).

Class *G4Colour* has 4 fields, which represent the RGBA (red, green, blue, and alpha) components of colour. Each component takes a value between 0 and 1. If an irrelevant value, i.e., a value less than 0 or greater than 1, is given as an argument of the constructor, such a value is automatically clipped to 0 or 1. Alpha is opacity, which is not used at present. You can use its default value `1`, which means "opaque" in instantiation of *G4Colour*.

A *G4Colour* object is instantiated by giving red, green, and blue components to its constructor, i.e.,

```
     G4Colour::G4Colour ( G4double r = 1.0,
                          G4double g = 1.0,
                          G4double b = 1.0,
                          G4double a = 1.0);
                                  // 0<=red, green, blue <= 1.0
```

The default value of each component is 1.0. That is to say, the default colour is "white" (opaque).

For example, colours which are often used can be instantiated as follows:

```
G4Colour  white   ()              ;  // white
G4Colour  white   (1.0, 1.0, 1.0) ;  // white
G4Colour  gray    (0.5, 0.5, 0.5) ;  // gray
G4Colour  black   (0.0, 0.0, 0.0) ;  // black
G4Colour  red     (1.0, 0.0, 0.0) ;  // red
G4Colour  green   (0.0, 1.0, 0.0) ;  // green
G4Colour  blue    (0.0, 0.0, 1.0) ;  // blue
G4Colour  cyan    (0.0, 1.0, 1.0) ;  // cyan
G4Colour  magenta (1.0, 0.0, 1.0) ;  // magenta
G4Colour  yellow  (1.0, 1.0, 0.0) ;  // yellow
```

After instantiation of a *G4Colour* object, you can access to its components with the following access functions:

```
G4double G4Colour::GetRed   () const ; // Get the red   component.
G4double G4Colour::GetGreen () const ; // Get the green component.
G4double G4Colour::GetBlue  () const ; // Get the blue  component.
```

A *G4Colour* object is passed to a *G4VisAttributes* object with the following access functions:

```
//----- Set functions of G4VisAttributes.
void G4VisAttributes::SetColour (const G4Colour& colour);
void G4VisAttributes::SetColor (const G4Color& color );
```

We can also set RGBA components directly:

```
//----- Set functions of G4VisAttributes
void G4VisAttributes::SetColour ( G4double red   ,
                                  G4double green ,
                                  G4double blue  ,
                                  G4double alpha = 1.0);

void G4VisAttributes::SetColor  ( G4double red   ,
                                  G4double green ,
                                  G4double blue  ,
                                  G4double alpha = 1.);
```

The following constructor with *G4Colour* as its argument is also supported:

```
//----- Constructor of G4VisAttributes
G4VisAttributes::G4VisAttributes (const G4Colour& colour);
```

Note that colour assigned to a *G4VisAttributes* object is not always the real colour which appears in visualization. Because the real colour may be decided, incorporating shading and lighting effects etc. Incorporation of such effects is done by your selected visualization drivers and graphics systems.

8.3.3 Forced wireframe and forced solid styles

As you will see later, you can select a "drawing style" from various options. For example, you can select your detector components to be visualized in "wireframe" or with "surfaces". In the former, only the edges of your detector are drawn and so the detector looks transparent. In the latter, your detector looks opaque with shading effects.

The forced wireframe and forced solid styles make it possible to mix the wireframe and surface visualization (if your selected graphics system supports such visualization). For example, you can make only the outer wall of your detector "wired" (transparent) and can see inside in detail.

Forced wireframe style is set with the following access function:

```
void G4VisAttributes::SetForceWireframe (G4bool force);
```

If you give `true` as the argument, objects for which this set of visualization attributes is assigned are always visualized in wireframe even if in general, the surface drawing style has been requested. The default value of the forced wireframe style is `false`.

Similarly, forced solid style, i.e., to force that objects are always visualized with surfaces, is set with:

```
void G4VisAttributes::SetForceSolid (G4bool force);
```

The default value of the forced solid style is `false`, too.

8.3.4 Constructors of *G4VisAttributes*

The following constructors are supported for class *G4VisAttributes*:

```
//----- Constructors of class G4VisAttributes
G4VisAttributes (void);
G4VisAttributes (G4bool visibility);
G4VisAttributes (const G4Colour& colour);
G4VisAttributes (G4bool visibility, const G4Colour& colour);
```

8.3.5 How to assign *G4VisAttributes* to a logical volume

In constructing your detector components, you may assign a set of visualization attributes to each "logical volume" in order to visualize them later (if you do not do this, the graphics system will use a default set). You cannot make a solid such as *G4Box* hold a set of visualization attributes; this is because a solid should hold only geometrical information. At present, you cannot make a physical volume hold one, but there are plans to design a memory-efficient way to do it; however, you can visualize a transient piece of solid or physical volume with a temporary assigned set of visualization attributes.

Class *G4LogicalVolume* holds a pointer of *G4VisAttributes.* This field is set and referenced with the following access functions:

```
//----- Set functions of G4VisAttributes
void G4VisAttributes::SetVisAttributes (const G4VisAttributes* pVA);
void G4VisAttributes::SetVisAttributes (const G4VisAttributes& VA);

//----- Get functions of G4VisAttributes
const G4VisAttributes* G4VisAttributes::GetVisAttributes () const;
```

The following is sample C++ source codes for assigning a set of visualization attributes with cyan colour and forced wireframe style to a logical volume:

```
//----- C++ source codes: Assigning G4VisAttributes to a logical volume
...
     // Instantiation of a logical volume
myTargetLog = new G4LogicalVolume( myTargetTube,BGO, "TLog", 0, 0, 0);
...
```

```
     // Instantiation of a set of visualization attributes with cyan colour
G4VisAttributes * calTubeVisAtt = new G4VisAttributes(G4Colour(0.,1.,1.));
     // Set the forced wireframe style
calTubeVisAtt->SetForceWireframe(true);
     // Assignment of the visualization attributes to the logical volume
myTargetLog->SetVisAttributes(calTubeVisAtt);

//----- end of C++ source codes
```

Note that the life of the visualization attributes must be at least as long as the objects to which they are assigned; it is the users' responsibility to ensure this, and to delete the visualization attributes when they are no longer needed (or just leave them to die at the end of the job).

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8.4 Polylines, Markers and Text

Polylines, markers and text are defined in the `graphics_reps` category, and are used only for visualization. Here we explain their definitions and usages.

8.4.1 Polylines

A polyline is a set of successive line segments. It is defined with a class *G4Polyline* defined in the `graphics_reps` category. A polyline is used to visualize tracking steps, particle trajectories, coordinate axes, and any other user-defined objects made of line segments.

G4Polyline is defined as a list of *G4Point3D* objects, i.e., vertex positions. The vertex positions are set to a *G4Polyline* object with the `push_back()` method.

For example, an x-axis with length 5 cm and with red color is defined in Source listing 8.4.1.

```
 //----- C++ source codes: An example of defining a line segment
// Instantiate an emply polyline object
G4Polyline  x_axis;

// Set red line colour
G4Colour         red(1.0, 0.0, 0.0);
G4VisAttributes  att(red);
x_axis.SetVisAttributes(&att);

// Set vertex positions
x_axis.push_back( G4Point3D(0., 0., 0.) );
x_axis.push_back( G4Point3D(5.*cm, 0., 0.) );

 //----- end of C++ source codes
```

Source listing 8.4.1
Defining an x-axis with length 5 cm and with colour red.

8.4.2 Markers

Here we explain how to use 3D markers in Geant4 Visualization.

What are Markers?

Markers set marks at arbitrary positions in the 3D space. They are often used to visualize hits of particles at detector components. A marker is a 2-dimensional primitive with shape (square, circle, etc), color, and special properties (a) of always facing the camera and (b) of having the possibility of a size defined in screen units (pixels). Here "size" means "overall size", e.g., diameter of circle and side of square (but diameter and radius access functions are defined to avoid ambiguity).

So the user who constructs a marker should decide whether or not it should be visualized to a given size in world coordinates by setting the world size. Alternatively, the user can set the screen size and the marker is visualized to its screen size. Finally, the user may decide not to set any size; in that case, it is drawn according to the sizes specified in the default marker specified in the class *G4ViewParameters*.

By default, "square" and "circle" are supported in Geant4 Visualization. The former is described with class *G4Square*, and the latter with class *G4Circle*:

Marker Type	**Class Name**
circle	*G4Circle*
right square	*G4Square*

These classes are inherited from class *G4VMarker*. They have constructors as follows:

```
      //----- Constructors of G4Circle and G4Square
      G4Circle::G4Circle (const G4Point3D& pos );
      G4Square::G4Square (const G4Point3D& pos);
```

Access functions of class *G4VMarker* are summarized below.

Access functions of markers

Source listing 8.4.2 shows the access functions inherited from the base class *G4VMarker*.

```
//----- Set functions of G4VMarker
void G4VMarker::SetPosition( const G4Point3D& );
void G4VMarker::SetWorldSize( G4double );
void G4VMarker::SetWorldDiameter( G4double );
void G4VMarker::SetWorldRadius( G4double );
void G4VMarker::SetScreenSize( G4double );
void G4VMarker::SetScreenDiameter( G4double );
void G4VMarker::SetScreenRadius( G4double );
void G4VMarker::SetFillStyle( FillStyle );
// Note: enum G4VMarker::FillStyle {noFill, hashed, filled};

//----- Get functions of G4VMarker
G4Point3D G4VMarker::GetPosition () const;
G4double G4VMarker::GetWorldSize () const;
G4double G4VMarker::GetWorldDiameter () const;
G4double G4VMarker::GetWorldRadius () const;
G4double G4VMarker::GetScreenSize () const;
G4double G4VMarker::GetScreenDiameter () const;
G4double G4VMarker::GetScreenRadius () const;
FillStyle G4VMarker::GetFillStyle () const;
// Note: enum G4VMarker::FillStyle {noFill, hashed, filled};
```

Source listing 8.4.2
The access functions inherited from the base class *G4VMarker*.

Source listing 8.4.3 shows sample C++ source code to define a very small red circle, i.e., a dot with diameter 1.0 pixel. Such a dot is often used to visualize a hit.

```
//----- C++ source codes: An example of defining a red small maker
G4Circle circle(position); // Instantiate a circle with its 3D
                           // position. The argument "position"
                           // is defined as G4Point3D instance
circle.SetScreenDiameter (1.0); // Should be circle.SetScreenDiameter
                                //  (1.0 * pixels) - to be implemented
circle.SetFillStyle (G4Circle::filled); // Make it a filled circle
G4Colour colour(1.,0.,0.);              // Define red color
G4VisAttributes attribs(colour);        // Define a red visualization attribute
circle.SetVisAttributes(attribs);       // Assign the red attribute to the circle
//----- end of C++ source codes
```

Source listing 8.4.3
Sample C++ source code to define a very small red circle.

8.4.3 Text

Text, i.e., a character string, is used to visualize various kinds of description, particle name, energy, coordinate names etc. Text is described by the class *G4Text* . The following constructors are supported:

```
//----- Constructors of G4Text
G4Text (const G4String& text);
G4Text (const G4String& text, const G4Point3D& pos);
```

where the argument `text` is the text (string) to be visualized, and `pos` is the 3D position at which the text is visualized.

Note that class *G4Text* also inherits *G4VMarker*. Size of text is recognized as "font size", i.e., height of the text. All the access functions defined for class *G4VMarker* mentioned above are available. In addition, the following access functions are available, too:

```
//----- Set functions of G4Text
void G4Text::SetText ( const G4String& text ) ;
void G4Text::SetOffset ( double dx, double dy ) ;

//----- Get functions of G4Text
G4String G4Text::GetText () const;
G4double G4Text::GetXOffset () const;
G4double G4Text::GetYOffset () const;
```

Method `SetText()` defines text to be visualized, and `GetText()` returns the defined text. Method `SetOffset()` defines x (horizontal) and y (vertical) offsets in the screen coordinates. By default, both offsets are zero, and the text starts from the 3D position given to the constructor or to the method `G4VMarker:SetPosition()`. Offsets should be given with the same units as the one adopted for the size, i.e., world-size or screen-size units.

Source listing 8.4.4 shows sample C++ source code to define text with the following properties:

- Text: "Welcome to Geant4 Visualization"
- Position: (0.,0.,0.) in the world coordinates
- Horizontal offset: 10 pixels

- Vertical offset: -20 pixels
- Colour: blue (default)

```
//----- C++ source codes: An example of defining a visualizable text

//----- Instantiation
G4Text text ;
text.SetText ( "Welcome to Geant4 Visualization");
text.SetPosition ( G4Point3D(0.,0.,0.) );
// These three lines are equivalent to:
//  G4Text text ( "Welcome to Geant4 Visualization",
//                 G4Point3D(0.,0.,0.) );

//----- Size (font size in units of pixels)
G4double fontsize = 24.; // Should be 24. * pixels - to be implemented.
text.SetScreenSize ( fontsize );

//----- Offsets
G4double x_offset = 10.; // Should be 10. * pixels - to be implemented.
G4double y_offset = -20.; // Should be -20. * pixels - to be implemented.
text.SetOffset( x_offset, y_offset );

//----- Color (Blue is the default setting, and so the codes below are omissible)
G4Colour blue( 0., 0., 1. );
G4VisAttributes att ( blue );
text.SetVisAttributes ( att );

//----- end of C++ source codes
```

Source listing 8.4.4
An example of defining text.

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8.5 Making a Visualization Executable

Here we explain how to write the `main()` function and create an executable for it, realizing your selected visualization drivers. In order to perform visualization with your Geant4 executable, you have to compile it with visualization driver(s) realized. You may be dazzled by so many choices of visualization driver, but you need not use all of them at one time.

8.5.1 Available visualization drivers

Depending on what have been installed on your system, several kinds of visualization driver are available. You can choose one or many drivers to be realized in compilation, depending on your purposes for visualization. Features, and some notes of each driver, are briefly described in Section 8.6 "**Visualization Drivers**", and details are described in the WWW pages referred to there. Some advanced and/or driver-dependent topics are also described in Section 8.10 "**More About visualization**".

Table 8.1 lists all the available drivers in alphabetic order. In order that each visualization driver works, the corresponding graphics system has to be installed beforehand. Table 8.1 summarizes the available visualization drivers with their required graphics systems and available platforms.

Driver	**Required 3D Graphics System**	**Platform**
DAWNFILE	Fukui Renderer DAWN	UNIX, Windows
DAWN-Network	Fukui Renderer DAWN	UNIX
HepRepFile	WIRED event display	UNIX, Windows
OPACS	OPACS, OpenGL	UNIX, Windows with X environments
OpenGL-Xlib	OpenGL	UNIX with Xlib
OpenGL-Motif	OpenGL	UNIX with Motif
OpenGL-Win32	OpenGL	Windows
OpenInventor-X	OpenInventor, OpenGL	UNIX with Xlib or Motif
OpenInventor-Win32	OpenInventor, OpenGL	Windows
RayTracer	(JPEG viewer)	UNIX, Windows
VRMLFILE	(VRML viewer)	UNIX, Windows
VRML-Network	(VRML viewer)	UNIX

Table 8.1
All available visualization drivers, in alphabetic order.

Unless an environment variable `G4VIS_NONE` is set to "1", visualization drivers that do not depend on outer libraries are automatically incorporated into Geant4 libraries in the their installation. (Here "installation of Geant4 libraries" means "generation of Geant4 libraries by compilation.") The automatically incorporated visualization drivers are: DAWNFILE, HepRep-File, RayTracer, and VRMLFILE.

For others, the OPACS drivers, the OpenGL drivers and the OpenInventor drivers are not incorporated by default. The DAWN-Network driver and the VRML-Network driver are not incorporated by default, either, since they require the network setting of the installed machine. In order to incorporate them, environmental variables named "`G4VIS_BUILD_DRIVERNAME_DRIVER`" should be set to "`1`" before installing the Geant4 libraries:

```
setenv G4VIS_BUILD_DAWN_DRIVER         1  # DAWN-Network driver
setenv G4VIS_BUILD_OPACS_DRIVER        1  # OPACS driver
setenv G4VIS_BUILD_OPENGLX_DRIVER      1  # OpenGL-Xlib driver
setenv G4VIS_BUILD_OPENGLXM_DRIVER     1  # OpenGL-Motif driver
setenv G4VIS_BUILD_OIX_DRIVER          1  # OpenInventor-Xlib driver
setenv G4VIS_BUILD_VRML_DRIVER         1  # VRML-Network
```

Unless an environment variable G4VIS_NONE is set to "1", setting any of these sets a C-pre-processor flag of the same name; also C-pre-processor flag G4VIS_BUILD is set (see config/G4VIS_BUILD.gmk), which makes the selected driver incorporated into Geant4 libraries in their installation.

8.5.2 How to realize visualization drivers in an executable

You can realize and use visualization driver(s) you want in your Geant4 executable. These can only be from the set installed into the Geant4 libraries beforehand. You will be warned if the one you request is not available.

In order to realize visualization drivers, you must do the followings before compiling your Geant4 executable:

1. Write your own visualization manager, inheriting the base class *G4VisManager* defined in the `source/visualization/management` and register your selected visualization drivers. You are required to implement one pure virtual function, `void RegisterGraphicsSystems()`.
2. Instantiate and initialize the visualization manager in the `main()` function.
3. Set environmental variables "`G4VIS_USE_DRIVERNAME`" to "1", if your selected visualization drivers depend on outer libraries.

As for 1., for example, the DAWNFILE and the OpenGL-Xlib drivers are registered as follows:

```
...
  RegisterGraphicsSystem (new G4DAWNFILE);
...
#ifdef G4VIS_USE_OPENGLX
  RegisterGraphicsSystem (new G4OpenGLImmediateX);
  RegisterGraphicsSystem (new G4OpenGLStoredX);
#endif
...
```

See `examples/novice/N03/src/ExN03VisManager.cc` for more details.

As for 2., how to write the `main()` function is explained in the next section.

As for 3., by default, you get the DAWNFILE, HepRep, RayTracer, VRMLFILE drivers. Additionally, you can choose from the DAWN-Network, OPACS, OpenGL-Xlib, OpenGL-Motif, OpenInventor, and VRML-Network drivers, each of which can be selected by setting a proper environmental variable:

```
setenv G4VIS_USE_DAWN         1
```

```
     setenv G4VIS_USE_OPACS         1
     setenv G4VIS_USE_OPENGLX       1
     setenv G4VIS_USE_OPENGLXM      1
     setenv G4VIS_USE_OIX           1
     setenv G4VIS_USE_VRML          1
```

(Of course, this has to be chosen from the set incorporated into the Geant4 libraries in their compilation.) Unless an environment variable G4VIS_NONE is set, these sets a C-pre-processor flag of the same name.

Also, unless an environment variable G4VIS_NONE is set, C-pre-processor flag G4VIS_USE is always set by the GNUmakefile `config/G4VIS_USE.gmk` . This flag is available in describing the `main()` function.

You may have to set additional environmental variables for your selected visualization drivers and graphics systems. For example, the OpenGL driver may require to set `OGLHOME` which tells the place where the OpenGL libraries are installed. For more details, see Section 8.6 "**Visualization Drivers**" and WWW pages linked from there. See also `geant4/source/visualization/README`.

A sample set-up file

The following is a part of a sample `.cshrc` file at Linux platform to create Geant4 executables available for Geant4 visualization. See the files `source/visualization/README` for more details. See also `config/G4VIS_BUILD.gmk` and `config/G4VIS_USE.gmk`.

```
##############################################################
# Main Environmental Variables for GEANT4 with Visualization #
##############################################################

### Platform
setenv G4SYSTEM Linux-g++

### CLHEP root directory
setenv CLHEP_BASE_DIR /usr/local

### OpenGL root directory
setenv OGLHOME /usr/X11R6

### G4VIS_BUILD
###   Incorporation of OpenGL-Xlib and OpenGL-Motif drivers
###   into Geant4 libraries.
setenv G4VIS_BUILD_OPENGLX_DRIVER 1
setenv G4VIS_BUILD_OPENGLXM_DRIVER 1

### G4VIS_USE
###   Incorporation of OpenGL-Xlib and OpenGL-Motif drivers
###   into Geant4 executables.
setenv G4VIS_USE_OPENGLX       1
setenv G4VIS_USE_OPENGLXM      1

### Viewer for DAWNFILE driver
### Default value is "dawn".  You can change it to, say,
### "david" for volume overlapping tests
# setenv G4DAWNFILE_VIEWER david

### Viewer for VRMLFILE drivers
setenv G4VRMLFILE_VIEWER vrmlview

########## end
```

Source listing 8.5.1
Part of a sample `.cshrc` setup file for the Linux platform.

8.5.3 How to write the `main()` function

Now we explain how to write the `main()` function for Geant4 Visualization.

In order that your Geant4 executable is able to perform visualization, you must instantiate and initialize "your" Visualization Manager in the `main()` function. The core of the Visualization Manager is class *G4VisManager*, defined in the visualization category. This class requires you to implement one pure virtual function, namely, `void RegisterGraphicsSystems()`, which you do by writing a class, e.g., *MyVisManager*, inheriting *G4VisManager*. In the implementation of `RegisterGraphicsSystems()`, procedures of registering candidate visualization drivers are described.

You can use the sample implementation of the class *MyVisManager* defined in the files `MyVisManager.hh` and `MyVisManager.cc`, which are placed in the directory `visualization/management/include`. However, you are free to write your own derived class and implement its method `RegisterGraphicsSystems()` to your requirements.

Source listing 8.5.2 shows the style for the `main()` function.

```
//----- C++ source codes: Instantiation and initialization of G4VisManager

.....
// Your Visualization Manager
#include "MyVisManager.hh"
.....

// Instantiation and initialization of the Visualization Manager
#ifdef G4VIS_USE
G4VisManager* visManager = new MyVisManager;
visManager -> initialize ();
#endif

.....
#ifdef G4VIS_USE
delete visManager;
#endif

//----- end of C++
```

Source listing 8.5.2
The style for the `main()` function.

Alternatively, you can implement an empty `RegisterGraphicsSystems()` function, and register visualization drivers you want directly in your `main()` function. See Source listing 8.5.3.

```
//----- C++ source codes: How to register a visualization driver directly
//                        in main() function

.....
G4VisManager* visManager = new MyVisManager;
visManager -> RegisterGraphicsSystem (new MyGraphicsSystem);
.....
delete visManager

//----- end of C++
```

Source listing 8.5.3
An alternative style for the `main()` function.

DO NOT FORGET to delete the instantiated Visualization Manager by yourself. Note that a graphics system for Geant4 Visualization may run as a different process. In such a case, the destructor of *G4VisManager* might have to terminate the graphics system and/or close the connection.

In the instantiation, initialization, and deletion of the Visualization Manager, the use of macro is recommended. The macro `G4VIS_USE` is automatically defined unless an environment variable

G4VIS_NONE is set, assuming that you are compiling your Geant4 executable with GNUmakefile placed in the `config` directory.

Source listing 8.5.4 shows an example of the `main()` function available for Geant4 Visualization.

```
//----- C++ source codes: An example of main() for visualization
.....
#include "MyVisManager.hh"
.....

int main()
{
     // Run Manager
     G4RunManager * runManager = new G4RunManager;

     // Detector components
     runManager->set_userInitialization(new MyDetectorConstruction);
     runManager->set_userInitialization(new MyPhysicsList);

     // UserAction classes.
     runManager->set_userAction(new MyRunAction);
     runManager->set_userAction(new MyPrimaryGeneratorAction);
     runManager->set_userAction(new MyEventAction);
     runManager->set_userAction(new MySteppingAction);

#ifdef G4VIS_USE
     G4VisManager* visManager = new MyVisManager;
     visManager -> initialize ();
#endif

     // Event loop
     // Define (G)UI terminal
     G4UIsession * session = new G4UIterminal
     session->sessionStart();

     delete session;
     delete runManager;

#ifdef G4VIS_USE
     delete visManager;
#endif

     return 0;
}

//----- end of C++
```

Source listing 8.5.4
An example of the `main()` function available for Geant4 Visualization.

One more note. Useful information on incorporated visualization drivers can be displayed in initializing the Visualization Manager. You can do it by setting the verbosity flag to a positive integer value. For example, in your `main()` function, write codes as follows:

```
...
G4VisManager* visManager = new MyVisManager ();
visManager -> SetVerboseLevel (1);
visManager -> Initialize ();
...
```

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8.6 Visualization Drivers

Many kinds of visualization drivers are available by default. You can choose one or more drivers during compilation of your Geant4 executable, depending on your visualization requirements. Features and notes on each driver are briefly described here. More details are described in linked WWW pages. Some advanced and/or driver-dependent features are also described in Section 8.10 "**More About Visualization**".

If you want to experience a quick tour of Geant4 visualization, you can skip this section, but we strongly recommend that you read this section before you really start work using Geant4 Visualization.

8.6.1 DAWN drivers

DAWN drivers are interfaces to Fukui Renderer DAWN, which has been developed by Satoshi Tanaka, Minato Kawaguti et al (Fukui University). It is a vectorized 3D PostScript processor, and so well suited to prepare technical high quality outputs for presentation and/or documentation. It is also useful for precise debugging of detector geometry. Remote visualization, off-line re-visualization, cut view, and many other useful functions of detector simulation are supported. A DAWN process is automatically invoked as a co-process of Geant4 when visualization is performed, and 3D data are passed with inter-process communication, via a file, or the TCP/IP socket.

When Geant4 Visualization is performed with the DAWN driver, the visualized view is automatically saved to a file named `g4.eps` in the current directory, which describes a vectorized (Encapsulated) PostScript data of the view.

There are two kinds of the DAWN drivers, the DAWNFILE driver and the DAWN-Network driver. Usually, it is recommended to use DAWNFILE driver, since it is faster and safer in a sense that it is not affected by network conditions.

The DAWNFILE driver sends 3D data to DAWN via an intermediate file, named `g4.prim` in the current directory. The file `g4.prim` is able to be re-visualized later without the help of Geant4. It is done by invoking DAWN by hand:

```
     % dawn g4.prim
```

The DAWN-Network driver is almost the same as the DAWNFILE driver except that

- 3D data are passed to DAWN via the TCP/IP the socket (default) or the named pipe, and that,
- it is applicable to perform remote visualization (see Section 8.10 "**More about visualization**" for details).

If you have not set up network configurations of your host machine, set the environment variable `G4DAWN_NAMED_PIPE` to "1", e.g., `% setenv G4DAWN_NAMED_PIPE 1`. This setting switches the default socket connection to the named-pipe connection within the same host machine. The DAWN-Network driver also saves the 3D data to the file `g4.prim` in the current directory.

Further information:

- Fukui Renderer DAWN:
  http://geant4.kek.jp/GEANT4/vis/DAWN/About_DAWN.html
- The DAWNFILE driver :
  http://geant4.kek.jp/GEANT4/vis/GEANT4/DAWNFILE_driver.html
- The DAWN-Network driver :
  http://geant4.kek.jp/GEANT4/vis/GEANT4/DAWNNET_driver.html
- Environmental variables to customize DAWN and DAWN drivers:
  http://geant4.kek.jp/GEANT4/vis/DAWN/DAWN_ENV.html
  http://geant4.kek.jp/GEANT4/vis/GEANT4/g4vis_on_linux.html
- DAWN format (g4.prim format) manual:
  http://geant4.kek.jp/GEANT4/vis/DAWN/G4PRIM_FORMAT_24/
- Geant4 Fukui University Group Home Page:
  http://geant4.kek.jp/GEANT4/vis/

8.6.2 HepRepFile driver

The HepRepFile driver creates a HepRep file suitable for viewing by the WIRED Event Display client. The HepRep graphics format is further described at http://heprep.freehep.org. The version of HepRep produced by this driver is HepRep Version 1. Each call to /vis/viewer/update rewrites the file G4HepRep.xml. View the file using the WIRED Event Display, available from: http://www.slac.stanford.edu/BFROOT/www/Computing/Graphics/Wired/. WIRED can read xml files in zipped format as well as unzipped, so you can save space by applying gzip to the xml file. This will reduce the file to about five percent of its original size.

Further information:

- WIRED homepage:
  http://www.slac.stanford.edu/BFROOT/www/Computing/Graphics/Wired/.
- HepRep graphics format:
  http://heprep.freehep.org

8.6.3 OPACS driver

OPACS is a visualization environment based on X windows and OpenGL. It has been developed at LAL (Orsay, France) mainly by Guy Barrand. It is written in ANSI C and is highly portable (UNIX, NT/X11, VMS).

This environment comes with a widget manager: the Wo package which is used by a Geant4 GUI session. Wo permits one to interactively create interpreted Xt widget hierarchies. Widget callbacks are also interpreted. The Bourne shell syntax "osh" interpreter is provided by default, but others, like the G4 command interpreter, could be declared to Wo.

The Xo widget set contains the XoCamera 3D viewer used as a G4 visualization driver. This widget views scenes handled by the Go graphical package. Go uses OpenGL to do its rendering. The Xo/Go team offers interactive scene manipulation, picking facilities, easy file production in the PostScript, GIF, VRML, DAWN formats.

The strength of OPACS is the flexibility and the coherency between user interface and graphics. See also the sections on the interfaces category, where Wo G4UI session is described.

Further information:

- http://www.lal.in2p3.fr/OPACS

8.6.4 OpenGL drivers

These drivers have been developed by John Allison and Andrew Walkden (University of Manchester). It is an interface to the de facto standard 3D graphics library, OpenGL. It is well suited for real-time fast visualization and demonstration. Fast visualization is realized with hardware acceleration, reuse of shapes stored in a display list, etc. NURBS visualization is also supported.

Several versions of the OpenGL drivers are prepared. Versions for Xlib, Motif and Win32 platforms are available by default. For each version, there are two modes: immediate mode and stored mode. The former has no limitation on data size, and the latter is fast for visualizing large data repetitively, and so is suitable for animation.

Further information (OpenGL and Mesa):

- http://www.opengl.org/
- http://www.ssec.wisc.edu/~brianp/Mesa.html

8.6.5 OpenInventor drivers

These drivers have been developed by Jeff Kallenbach (FNAL) based on the "Hepvis class library" originated by Joe Boudreau (Pittsburgh University). The OpenInventor drivers and the Hepvis class library are based on the well-established OpenInventor technology for scientific visualization. They have high extendibility. They support high interactivity, e.g., attribute editing of picked objects. Virtual-reality visualization can be realized with them.

It is also possible to save a visualized 3D scene as an OpenInventor-formatted file, and re-visualize the scene afterwards.

The OpenInventor driver is also available with the free Inventor kernel "SoFree" developed at LAL co-working with the Hepvis class library.

Further information (OpenInventor driver, Hepvis, and SoFree):

- http://cactus.phyast.pitt.edu/~joe/hepvis/hepvis.html
- http://www.lal.in2p3.fr/Inventor

Further information (OpenInventor):

- http://www.sgi.com/Technology/Inventor.html
- Josie Wernecke, "The Inventor Mentor", Addison Weslay (ISBN 0-201-62495-8)
- Josie Wernecke, "The Inventor Toolmaker", Addison Weslay (ISBN 0-201-62493-1)
- "The Open Inventor C++ Reference Manual", Addison Weslay (ISBN 0-201-62491-5)

8.6.6 *RayTracer* driver

This driver has been developed by Makoto Asai and Minamimoto (Hirosihma Instutute of Technology). It performs ray-tracing visualization using the tracking routines of Geant4. It is, therefore, available for debugging tracking routines. It is well suited for photo-realistic high quality output for presentation, and for intuitive debugging of detector geometry.

Further information:

- http://hitds1.cc.it-hiroshima.ac.jp/Geant4/g4ray/whatisg4r_J.html

8.6.7 VRML drivers

These drivers have been developed by Satoshi Tanaka and Yasuhide Sawada (Fukui University). They generate VRML files, which describe 3D scenes to be visualized with a proper VRML viewer, at either a local or a remote host. It realizes virtual-reality visualization with your WWW browser. There are many excellent VRML viewers, which enable one to perform interactive spinning of detectors, walking and/or flying inside detectors or particle showers, interactive investigation of detailed detector geometry etc.

There are two kinds of VRML drivers: the VRMLFILE driver, and the VRML-Network driver. Usually, it is recommended to use VRMLFILE driver, since it is faster and safer in a sense that it is not affected by network conditions.

The VRMLFILE driver sends 3D data to your VRML viewer, which is running in the same host machine as Geant4, via an intermediate file named `g4.wrl` created in the current directory. This file is available for re-visualization afterwards. In visualization, you should specify a name of the VRML viewer by setting the environment variable `G4VRML_VIEWER` beforehand. For example,

```
% setenv G4VRML_VIEWER  "netscape"
```

Its default value is `NONE`, which means that no viewer is invoked and only the file `g4.wrl` is generated.

The VRML-Network driver is for remote graphics. See Section 8.10 "**More about visualization**" and the WWW page below for details.

Further information (VRML drivers):

- http://geant4.kek.jp/GEANT4/vis/GEANT4/VRML_file_driver.html
- http://geant4.kek.jp/GEANT4/vis/GEANT4/VRML_net_driver.html

Sample VRML files:

- http://geant4.kek.jp/GEANT4/vis/GEANT4/VRML2_FIG/

Further information (VRML language and browsers):

- http://www.vrml.org/

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8.7 Interactive Visualization

Visualization commands frequently used during an interactive simulation session are described here. For simplicity, it has been assumed that the Geant4 executable was compiled incorporating the DAWNFILE and the OpenGL-Xlib drivers. For details on creating an executable for visualization see Section 8.5 .

8.7.1 Scene, scene handler, and viewer

You can perform almost all kinds of Geant4 visualization with interactive visualization commands. In using the visualization commands, it is useful to know the concept of "scene", "scene handler", and "viewer". A "scene" is a set of visualizable raw 3D data. A "scene handler" is a graphics-data modeler, which processes raw data in a scene for later visualization. And a "viewer" generates images based on data processed by a scene handler. Roughly speaking, a set of a scene handler and a viewer corresponds to a visualization driver.

The typical steps of performing Geant4 visualization are:

Step 1. Create a scene handler and a viewer.
Step 2. Create an empty scene.
Step 3. Add raw 3D data to the created scene.
Step 4. Attach the current scene handler to the current scene.
Step 5. Set camera parameters, drawing style (wireframe/surface), etc.

Step 6. Make the viewer execute visualization.
Step 7. Declare the end of visualization for flushing.

Note that the above list does not mean that you have to execute 7 commands for visualization. You can use "compound commands" which can execute plural visualization commands at one time.

8.7.2 Invoking visualization drivers: `/vis/open` command

Command "`/vis/open`" invokes a visualization driver, which corresponds to Step 1.

- **Command**
  `/vis/open [driver_tag_name]`
- **Argument**
  A name of (a mode of) an available visualization driver.
- **Action**
  Create a visualization driver, i.e. a set of a scene hander and a viewer.
- **Example: Create the OpenGL-Xlib driver with its immediate mode**
  `Idle> /vis/open OGLIX`
- **Additional notes**
  How to list available driver_tag_name:

  ```
  Idle> help /vis/open
  ```
  or
  ```
  Idle> help /vis/sceneHandler/create
  ```

  The list is, for example, displayed as follows:
  .....
  ```
  Candidates : DAWNFILE OGLIX OGLSX
  ```
  .....

8.7.3 Basic camera workings: `/vis/viewer/` commands

Commands in the command directory "`/vis/viewer/`" set camera parameters and drawing style of the current viewer, which corresponds to Step 5. Note that the camera parameters and the drawing style should be set for each viewer. They can be initialized to the default values with command "`/vis/viewer/reset`".

- **Command**
  `/vis/viewer/reset`
- **Action**
  Reset camera parameters and drawing style to the default setting.

- **Command**
  `/vis/viewer/set/viewpointThetaPhi [<theta>] [<phi>] [<deg|rad>]`
- **Arguments**
  Arguments "theta" and "phi" are polar and azimuthal camera angles, respectively. The default unit is "degree".

- **Action**
  Set a view point in direction of (theta, phi).
- **Example: Set the viewpoint in direction of (70 deg, 20 deg)**
  `Idle> /vis/viewer/set/viewpointThetaPhi 70 20`
- **Additional notes**
  Camera parameters should be set for each viewer. They are initialized with command "`/vis/viewer/reset`".

- **Command**
  `/vis/viewer/zoom [<scale_factor>]`
- **Argument**
  The scale factor. The command multiplies magnification of the view by this factor.
- **Action**
  Zoom up/down of view.
- **Example: Zoom up by factor 1.5**
  `Idle> /vis/viewer/zoom 1.5`
- **Additional notes**
  Camera parameters should be set for each viewer. They are initialized with command "`/vis/viewer/reset`".

- **Command**
  `/vis/viewer/set/style [style_name]`
- **Arguments**
  Candidate values of the argument are "wireframe" and "surface". ("w" and "s" also work.)
- **Action**
  Set a drawing style to wireframe or surface.
- **Example: Set the drawing style to "surface"**
  `Idle> /vis/viewer/set/style surface`
- **Additional notes**
  Drawing style should be set for each viewer. The drawing style is initialized with command "`/vis/viewer/reset`".

- **Command**
  `/vis/viewer/flush`
- **Action**
  Declare the end of visualization for flushing.
- **Additional notes**
  Command "`/vis/viewer/flush`" should follow "/vis/drawVolume", "/vis/specify", etc in order to complete visualization. It corresponds to Step 7.

8.7.4 Visualization of a physical volume: `/vis/drawVolume` command

Command "`/vis/drawVolume`" visualizes a physical volume. This command do Steps 2, 3, 4 and 6. Command "`/vis/viewer/flush`" should follow in order to do the final Step 7.

- **Commands**
  ```
  /vis/drawVolume [<physical-volume-name>]
  .....
  Idle> /vis/viewer/flush
  ```
- **Argument**
  A physical-volume name. The default value is "world", which is omittable.
- **Action**
  Creates a scene consisting of the given physical volume and asks the current viewer to draw it. The scene becomes current. Command "`/vis/viewer/flush`" should follow this command in order to declare end of visualization.
- **Example: Visualization of the whole world with coordinate axes**
  ```
  Idle> /vis/drawVolume
  Idle> /vis/scene/add/axes 0 0 0 500 mm
  Idle> /vis/viewer/flush
  ```

8.7.5 Visualization of a logical volume: `/vis/specify` command

Command "`/vis/specify`" visualizes a logical volume. This command do Steps 2, 3, 4 and 6. Command "`/vis/viewer/flush`" should follow the command in order to do the final Step 7.

- **Command**
  ```
  /vis/specify [logical-volume-name]
  ```
- **Argument**
  A logical-volume name.
- **Action**
  Creates a scene consisting of the given logical volume and asks the current viewer to draw it. The scene becomes current.
- **Example (visualization of a selected logical volume with coordinate axes)**
  ```
  Idle> /vis/specify Absorber
  Idle> /vis/scene/add/axes 0 0 0 500 mm
  Idle> /vis/scene/add/text 0 0 0 mm 40 -100 -200 LogVol:Absorber
  Idle> /vis/viewer/flush
  ```

8.7.6 Visualization of trajectories: `/vis/scene/add/trajectories` command

Command "`/vis/scene/add/trajectories`" adds trajectories to the current scene. Note that you have to store the trajectory by executing "`/tracking/storeTrajectory 1`" beforehand. The visualization is performed with the command "`/run/beamOn`".

- **Command**
  ```
  /vis/scene/add/trajectories
  ```
- **Action**
  The command adds trajectories to the current scene. Trajectories are drawn at end of event when the scene in which they are added is current.
- **Example: Visualization of trajectories**
  ```
  Idle> /tracking/storeTrajectory 1
  Idle> /vis/scene/add/trajectories
  Idle> /run/beamOn 10
  ```

- **Additional note 1**
  In examples/novice/N03, command "`/vis/scene/add/trajectories`" need not be executed, since the C++ method `G4Trajectory::DrawTrajectory()` is explicitly described in the event action. Therefore the command need not be executed though (G)UI.
- **Additional note 2**
  In order that the command visualization with `/run/beamOn` works, the run action and/or event action should be implemented properly. In `examples/novice/N03`, the following implementations are described:

```
     void ExN03RunAction::BeginOfRunAction(const G4Run* aRun)
     {
       .....

       if (G4VVisManager::GetConcreteInstance())
       {
         G4UImanager* UI = G4UImanager::GetUIpointer();
         UI->ApplyCommand("/vis/scene/notifyHandlers");
       }
     }

     void ExN03RunAction::EndOfRunAction(const G4Run* )
     {
       if (G4VVisManager::GetConcreteInstance()) {
          G4UImanager::GetUIpointer()->ApplyCommand("/vis/viewer/update");
       }
     }
```

8.7.7 How to save a visualized views to PostScript files

Most of the visualization drivers offer ways to save visualized views to PostScript files (or Encapsulated PostScript (EPS) files) by themselves.

The DAWNFILE driver, which co-works with Fukui Renderer DAWN, generates "vectorized" PostScript data with "analytical hidden-line/surface removal", and so it is well suited for technical high-quality outputs for presentation, documentation, and debugging geometry. In the default setting of the DAWNFILE drivers, EPS files named "`g4_00.eps, g4_01.eps, g4_02.eps`,..." are automatically generated in the current directory each time when visualization is performed, and then a PostScript viewer "`gv`"is automatically invoked to visualize the generated EPS files.

For large data sets, it may take time to generate the vectorized PostScript data. In such a case, visualize the 3D scene with a faster visualization driver beforehand for previewing, and then use the DAWNFILE drivers. For example, the following visualizes the whole detector with the OpenGL-Xlib driver (immediate mode) first, and then with the DAWNFILE driver to generate an EPS file `g4_XX.eps` to save the visualized view:

```
# Invoke the OpenGL visualization driver in its immediate mode
/vis/open OGLIX

# Camera setting
/vis/viewer/set/viewpointThetaPhi 20 20

# Camera setting
/vis/drawVolume
```

```
/vis/viewer/flush

# Invoke the DAWNFILE visualization driver
/vis/open DAWNFILE

# Camera setting
/vis/viewer/set/viewpointThetaPhi 20 20

# Camera setting
/vis/drawVolume
/vis/viewer/flush
```

This is a good example to show that the visualization drivers are complementary to each other.

In the OPACS driver, it is sufficient to select the "PostScript" item of the right-button pop-up menu of its Xo viewer, in order to produce an EPS file (out.ps) as a hard copy of a visualized view. The EPS file is generated in the current directory.

In the OpenInventor drivers , you can simply click the "Print" button on their GUI to generate a PostScript file as a hard copy of a visualized view.

The OpenGL-Motif driver also has a menu to generate PostScript files. It can generate either vectorized or rasterized PostScript data. In generating vectorized PostScript data, hidden-surface removal is performed, based on the painter's algorithm after dividing facets of shapes into small sub-triangles.

8.7.8 Culling

"Culling" means to skip visualizing parts of a 3D scene. Culling is useful for avoiding complexity of visualized views, keeping transparent features of the 3D scene, and for quick visualization.

Geant4 Visualization supports the following 3 kinds of culling:

- Culling of invisible physical volumes
- Culling of low density physical volumes.
- Culling of covered physical volumes by others

In order that one or all types of the above culling are on, i.e., activated, the global culling flag should also be on.

Table 8.3 summarizes the default culling policies.

Culling Type	Default Value
global	ON
invisible	ON
low density	OFF
covered daughter	OFF

Table 8.3
The default culling policies.

The default threshold density of the low-density culling is 0.01 g/cm^3.

The default culling policies can be modified with the following interactive visualization commands. (Below the argument `flag` takes a value of `true` or `false`.)

```
# global
/vis/viewer/set/culling  global  flag

# invisible
/vis/viewer/set/culling  invisible  flag

# low density
#   "value" is a proper value of a treshold density
#   "unit" is either g/cm3, mg/cm3 or kg/m3
/vis/viewer/set/culling  density  flag  value  unit

# covered daughter
/vis/viewer/set/culling  coveredDaughters  flag     density
```

8.7.9 Cut view

Sectioning

"Sectioning" means to make a thin slice of a 3D scene around a given plane. At present, this function is supported by the OpenGL drivers. The sectioning is realized by setting a sectioning plane before performing visualization. The sectioning plane can be set by the command,

```
/vis/viewer/set/sectionPlane x y z units nx ny nz
```

where the vector (x,y,z) defines a point on the sectioning plane, and the vector (nx,ny,nz) defines the normal vector of the sectioning plane. For example, the following sets a sectioning plane to a yz plane at x = 2 cm:

```
Idle> /vis/viewer/set/sectionPlane  2.0  0.0  0.0  cm  1.0  0.0  0.0
```

Cutting away

"Cutting away" means to remove a half space, defined with a plane, from a 3D scene. At present, cutting away is supported by the DAWNFILE driver. Do the following:

- Perform visualization with the DAWNFILE driver to generate a file `g4.prim`, describing the whole 3D scene.
- Make the application "DAWNCUT" read the generated file to make a view of cutting away.

See the following WWW page for details:
http://geant4.kek.jp/GEANT4/vis/DAWN/About_DAWNCUT.html.

8.7.10 Visualization of detector geometry tree

Geant4 also support the "tree drivers", which visualize a detector geometry tree. At present, two tree drivers are implemented:

- The ASCII tree driver
- The GAG tree driver

The ASCII tree driver visualizes the tree on display with proper indentation of physical volume names. The GAG tree driver does the same thing witin the GAG GUI (http://erpc1.naruto-u.ac.jp/~geant4). The XML tree driver, which generates the trees with the XML format, will appear soon.

Note that you have to register your selected tree drivers in your Visualization Manager class in order to use them:

```
     RegisterGraphicsSystem (new G4ASCIITree);
     RegisterGraphicsSystem (new G4GAGTree  );
```

See `examples/novice/N03/src/ExN03VisManager.cc`, too.

- **Command**
  `/vis/drawTree [<physical_volume_name>] [<driver_name>]`
  The candidate driver names are "ATree" (ASCII tree, default) and "GAGTree".
- **Action**
  Visualize a detector geometry tree.
- **Arguments**
  A Physical volume of the top hierarchy of a tree, and a tree-driver name.
- **Example: Visualization of the whole geometry**

```
Idle> /vis/drawTree ! ATree
.....
"Calorimeter", copy no. 0
    "Layer", copy no. -1 (10 replicas)
        "Absorber", copy no. 0
            "Gap", copy no. 0
.....
```

- **Additional note**

The character '!' in the above example means "the default argument". It is the convention of the Geant4 interactive commands.

- **Command**
  `/vis/XXXTree/verbose [<verbosity>]`

  "XXX" is "`ASCIITree`" for the ASCII tree driver, and "`GAG`" for the GAG tree driver. The verbosity is from 0 (default) to 10:

  ```
  < 10: - does not print daughters of repeated logical volumes.
        - does not repeat replicas.
  >= 10: prints all physical volumes.
  >=  0: prints physical volume name.
  >=  1: prints logical volume name.
  >=  2: prints solid name and type.
  ```

- **Action**
  Customize the detail level of the visualized tree.
- **Example:**

  ```
       Idle> /vis/ASCIITree/verbose 1
       Idle> /vis/drawTree ! ATree
       .....
       "Calorimeter", copy no. 0, belongs to logical volume "Calorimeter"
         "Layer", copy no. -1, belongs to logical volume "Layer" (10 replicas)
           "Absorber", copy no. 0, belongs to logical volume "Absorber"
             "Gap", copy no. 0, belongs to logical volume "Gap"
       .....
  ```

8.7.11 Tutorial macros

The followings are tutorial macros in the directory `examples/novice/N03/visTutor/`:

- exN03Vis0.mac:
  A simplest macro to demonstrate visualization of detector geometry and events
- exN03Vis1.mac:
  A basic macro for visualization of detector geometry
- exN03Vis2.mac:
  A basic macro for visualization of events
- exN03Vis3.mac:
  A basic macro for demonstrating various drawing styles
- exN03Vis4.mac:
  An example of visualizing logical volumes
- exN03Vis5.mac:
  A basic macro for demonstrating the OPACS/Xo driver
- exN03Vis6.mac:
  A basic macro for demonstrating the OpenInventor driver
- exN03Vis7.mac:
  A basic macro for demonstrating the VRMLFILE driver
- exN03Vis8.mac:

A macro to demonstrate "batch" visualization to generate PostScript files with the DAWNFILE driver
- exN03Vis9.mac:
  A macro to demonstrate creation of a "multi-page" PostScript file with the DAWNFILE driver
- exN03Tree0.mac:
  A macro to demonstrate ASCII tree.
- exN03Tree1.mac:
  A macro to demonstrate GAG tree.

8.7.12 What else?

Some advanced and/or driver-dependent topics are described in Section 8.10.

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8.8 Non-interactive Visualization

While a Geant4 simulation is running, visualization can be performed without user intervention. This is accomplished by calling methods of the Visualization Manager from methods of the user action classes (*G4UserRunAction* and *G4UserEventAction*, for example). In this section methods of the class *G4VVisManager*, which is part of the `intercoms` category, are described and examples of their use are given.

8.8.1 Class *G4VVisManager*

The Visualization Manager is implemented by classes *G4VisManager* and *MyVisManager*. See Section 8.5 "**Making a Visualization Executable**". In order that your Geant4 be compilable either with or without the visualization category, you should not use these classes directly in your C++ source code, other than in the `main()` function. Instead, you should use their abstract base class *G4VVisManager*, defined in the `intercoms` category.

The pointer to the concrete instance of class *MyVisManager*, i.e., to the real Visualization Manager, can be obtained as follows:

```
  //----- Getting a pointer to the concrete Visualization Manager instance
  G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance();
```

The method `G4VVisManager::GetConcreteInstance()` returns `NULL` if Geant4 is not ready for visualization. Thus your C++ source code should be protected as follows:

```
  //----- How to protect your C++ source codes in visualization
  if (pVVisManager) {
      ....
      pVVisManager ->Draw (...);
      ....
  }
```

8.8.2 Visualization of detector components

If you have already constructed detector components with logical volumes to which visualization attributes are properly assigned, you are almost ready for visualizing detector components. All you have to do is to describe proper visualization commands within your C++ codes, using the `ApplyCommand()` method.

For example, the following is sample C++ source codes to visualize the detector components:

```
  //----- C++ source code: How to visualize detector components (2)
  //                       ... using visualization commands in source codes

  G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance() ;

  if(pVVisManager)
  {
      ... (camera setting etc) ...
      G4UImanager::GetUIpointer()->ApplyCommand("/vis/drawVolume");
      G4UImanager::GetUIpointer()->ApplyCommand("/vis/viewer/flush");
  }

  //-----  end of C++ source code
```

In the above, you should also describe `/vis/open` command somewhere in your C++ codes or execute the command from (G)UI at the executing stage.

8.8.3 Visualization of trajectories

In order to visualize trajectories, you can use the mothod `void G4Trajectory::DrawTrajectory()` defined in the tracking category. In the implementation of this method, the following drawing method of *G4VVisManager* is used:

```
    //----- A drawing method of G4Polyline
    virtual void G4VVisManager::Draw (const G4Polyline&, ...) ;
```

The real implementation of this method is described in the class *G4VisManager*.

At the end of one event, a set of trajectories can be stored as a list of *G4Trajectory* objects. Therefore you can visualize trajectories, for example, at the end of each event, by implementing the method `MyEventAction::EndOfEventAction()` as follows:

```
  //----- C++ source codes
  void ExN03EventAction::EndOfEventAction(const G4Event* evt)
  {
    .....
    // extract the trajectories and draw them
    if (G4VVisManager::GetConcreteInstance())
      {
       G4TrajectoryContainer* trajectoryContainer = evt->GetTrajectoryContainer();
       G4int n_trajectories = 0;
       if (trajectoryContainer) n_trajectories = trajectoryContainer->entries();

       for (G4int i=0; iGetTrajectoryContainer()))[i]);
            if (drawFlag == "all") trj->DrawTrajectory(50);
            else if ((drawFlag == "charged")&&(trj->GetCharge() != 0.))
                                 trj->DrawTrajectory(50);
            else if ((drawFlag == "neutral")&&(trj->GetCharge() == 0.))
                                 trj->DrawTrajectory(50);
          }
    }
  }
  //----- end of C++ source codes
```

8.8.4 Visualization of hits

Hits are visualized with classes *G4Square* or *G4Circle*, or other user-defined classes inheriting the abstract base class *G4VMarker*. Drawing methods for hits are not supported by default. Instead, ways of their implementation are guided by virtual methods, `G4VHit::Draw()` and `G4VHitsCollection::DrawAllHits()`, of the abstract base classes *G4VHit* and *G4VHitsCollection*. These methods are defined as empty functions in the `digits+hits` category. You can overload these methods, using the following drawing methods of class *G4VVisManager*, in order to visualize hits:

```
  //----- Drawing methods of G4Square and G4Circle
  virtual void G4VVisManager::Draw (const G4Circle&, ...) ;
  virtual void G4VVisManager::Draw (const G4Square&, ...) ;
```

The real implementations of these `Draw()` methods are described in class *G4VisManager*.

The overloaded implementation of `G4VHits::Draw()` will be held by, for example, class *MyTrackerHits* inheriting *G4VHit* as follows:

```
  //----- C++ source codes: An example of giving concrete implementation of
  //       G4VHit::Draw(), using  class MyTrackerHit : public G4VHit {...}
  //
 void MyTrackerHit::Draw()
 {
    G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance();
    if(pVVisManager)
    {
      // define a circle in a 3D space
      G4Circle circle(pos);
      circle.SetScreenSize(0.3);
      circle.SetFillStyle(G4Circle::filled);

      // make the circle red
      G4Colour colour(1.,0.,0.);
      G4VisAttributes attribs(colour);
      circle.SetVisAttributes(attribs);

      // make a 3D data for visualization
      pVVisManager->Draw(circle);
    }
  }

  //----- end of C++ source codes
```

The overloaded implementation of `G4VHitsCollection::DrawAllHits()` will be held by, for example, class *MyTrackerHitsCollection* inheriting class *G4VHitsCollection* as follows:

```
  //----- C++ source codes: An example of giving concrete implementation of
  //       G4VHitsCollection::Draw(),
  //       using  class MyTrackerHit : public G4VHitsCollection{...}
  //
  void MyTrackerHitsCollection::DrawAllHits()
  {
    G4int n_hit = theCollection.entries();
    for(G4int i=0;i< n_hit;i++)
    {
      theCollection[i].Draw();
    }
  }

  //----- end of C++ source codes
```

Thus, you can visualize hits as well as trajectories, for example, at the end of each event by implementing the method `MyEventAction::EndOfEventAction()` as follows:

```
  void MyEventAction::EndOfEventAction()
  {
    const G4Event* evt = fpEventManager->get_const_currentEvent();

    G4SDManager * SDman = G4SDManager::get_SDMpointer();
    G4String colNam;
    G4int trackerCollID = SDman->get_collectionID(colNam="TrackerCollection");
    G4int calorimeterCollID = SDman->get_collectionID(colNam="CalCollection");

    G4TrajectoryContainer * trajectoryContainer = evt->get_trajectoryContainer();
    G4int n_trajectories = 0;
    if(trajectoryContainer)
    { n_trajectories = trajectoryContainer->entries(); }

    G4HCofThisEvent * HCE = evt->get_HCofThisEvent();
    G4int n_hitCollection = 0;
    if(HCE)
    { n_hitCollection = HCE->get_capacity(); }

    G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance();

    if(pVVisManager)
    {

      // Declare begininng of visualization
      G4UImanager::GetUIpointer()->ApplyCommand("/vis/scene/notifyHandlers");

      // Draw trajectories
      for(G4int i=0; i< n_trajectories; i++)
      {
          (*(evt->get_trajectoryContainer()))[i]->DrawTrajectory();
      }
      // Construct 3D data for hits
      MyTrackerHitsCollection* THC
        = (MyTrackerHitsCollection*)(HCE->get_HC(trackerCollID));
      if(THC) THC->DrawAllHits();
      MyCalorimeterHitsCollection* CHC
        = (MyCalorimeterHitsCollection*)(HCE->get_HC(calorimeterCollID));
      if(CHC) CHC->DrawAllHits();

      // Declare end of visualization
      G4UImanager::GetUIpointer()->ApplyCommand("/vis/viewer/update");

    }

  }

  //----- end of C++ codes
```

You can re-visualize a physical volume, where a hit is detected, with a highlight color, in addition to the whole set of detector components. It is done by calling a drawing method of a physical volume directly. The method is:

```
  //----- Drawing methods of a physical volume
  virtual void Draw (const G4VPhysicalVolume&, ...) ;
```

This method is, for example, called in a method `MyXXXHit::Draw()`, describing the visualization of hits with markers. The following is an example for this:

```
  //----- C++ source codes: An example of visualizing hits with
  void MyCalorimeterHit::Draw()
  {
    G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance();
    if(pVVisManager)
    {
      G4Transform3D trans(rot,pos);
      G4VisAttributes attribs;
      G4LogicalVolume* logVol = pPhys->GetLogicalVolume();
      const G4VisAttributes* pVA = logVol->GetVisAttributes();
      if(pVA) attribs = *pVA;
      G4Colour colour(1.,0.,0.);
      attribs.SetColour(colour);
      attribs.SetForceSolid(true);

      //----- Re-visualization of a selected physical volume with red color
      pVVisManager->Draw(*pPhys,attribs,trans);

    }
  }

  //----- end of C++ codes
```

8.8.5 Visualization of text

In Geant4 Visualization, a text, i.e., a character string, is described by class *G4Text* inheriting *G4VMarker* as well as *G4Square* and *G4Circle*. Therefore, the way to visualize text is the same as for hits. The corresponding drawing method of *G4VVisManager* is:

```
  //----- Drawing methods of G4Text
  virtual void G4VVisManager::Draw (const G4Text&, ...);
```

The real implementation of this method is described in class *G4VisManager*.

8.8.6 Visualization of polylines and tracking steps

Polylines, i.e., sets of successive line segments, are described by class *G4Polyline*. For *G4Polyline*, the following drawing method of class *G4VVisManager* is prepared:

```
   //----- A drawing method of G4Polyline
    virtual void G4VVisManager::Draw (const G4Polyline&, ...) ;
```

The real implementation of this method is described in class *G4VisManager*.

Using this method, C++ source codes to visualize *G4Polyline* are described as follows:

```
 //----- C++ source code: How to visualize a polyline
  G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance();

  if (pVVisManager) {
      G4Polyline polyline ;

      ..... (C++ source codes to set vertex positions, color, etc)

      pVVisManager -> Draw(polyline);

  }

  //----- end of C++ source codes
```

Tracking steps are able to be visualized based on the above visualization of *G4Polyline*. You can visualize tracking steps at each step automatically by writing a proper implementation of class *MySteppingAction* inheriting *G4UserSteppingAction*, and also with the help of the Run Manager.

First, you must implement a method, `MySteppingAction::UserSteppingAction()`. A typical implementation of this method is as follows:

```
  //----- C++ source code: An example of visualizing tracking steps
  void MySteppingAction::UserSteppingAction()
  {
      G4VVisManager* pVVisManager = G4VVisManager::GetConcreteInstance();

      if (pVVisManager) {

        //----- Get the Stepping Manager
        const G4SteppingManager* pSM = GetSteppingManager();

        //----- Define a line segment
        G4Polyline polyline;
        G4double charge = pSM->GetTrack()->GetDefinition()->GetPDGCharge();
        G4Colour colour;
        if      (charge < 0.) colour = G4Colour(1., 0., 0.);
        else if (charge > 0.) colour = G4Colour(0., 0., 1.);
        else                  colour = G4Colour(0., 1., 0.);
        G4VisAttributes attribs(colour);
        polyline.SetVisAttributes(attribs);
        polyline.push_back(pSM->GetStep()->GetPreStepPoint()->GetPosition());
        polyline.push_back(pSM->GetStep()->GetPostStepPoint()->GetPosition());

        //----- Call a drawing method for G4Polyline
        pVVisManager -> Draw(polyline);

      }
  }

  //----- end of C++ source code
```

Next, in order that the above C++ source code works, you have to pass the information of the *MySteppingAction* to the Run Manager in the `main()` function:

```
  //----- C++ source code: Passing what to do at each step to the Run Manager

  int main()
  {
     ...

     // Run Manager
     G4RunManager * runManager = new G4RunManager;

     // User initialization classes
     ...
     runManager->set_userAction(new MySteppingAction);
     ...
  }

  //----- end of C++ source code
```

Thus you can visualize tracking steps with various visualization attributes, e.g., color, at each step, automatically.

As well as tracking steps, you can visualize any kind 3D object made of line segments, using class *G4Polyline* and its drawing method, defined in class *G4VVisManager*. See, for example, the implementation of the `/vis/scene/add/axes` command.

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8.9 Built-in Visualization Commands

Geant4 has various built-in visualization commands. An up-to-date summary of built-in commands and the principles by which they operate are maintained in the file `geant4/source/visualization/README.built_in_commands`.

8.10 More About Visualization

8.10.1 Remote visualization

Visualization in Geant4 is considered to be "remote" when it is performed on a machine other than the Geant4 host. Some of the visualization drivers support this feature.

Usually, the visualization host is your local host, while the Geant4 host is a remote host where you login, for example, with the `telnet` command. This enables distributed processing of Geant4 Visualization, avoiding transferring large amounts of visualized view data to your terminal display via the network.

In the following, we assume that you perform Geant4 Visualization on your local host, while the Geant4 process is running on a remote host.

Remote visualization with the VRML-Network driver

This section describes how to perform remote Geant4 Visualization with the VRML-Network driver.

In order to perform remote visualization with the VRML-Network driver, you have to install the followings on your local host beforehand:

1. a VRML viewer
2. the Java application `g4vrmlview`.

As for 2., the Java application `g4vrmlview` is included in the following place as part of the Geant4 package:

```
source/visualization/VRML/g4vrmlview/
```

Installation instructions for `g4vrmlview` can be found in the `README` file, located there, or in the WWW page below. In the following discussion, we assume that you have already installed it properly.

The following steps realize remote Geant4 Visualization displayed with your local VRML browser:

1. Invoke the g4vrmlview on your local host, giving a VRML viewer name as its argument:

   ```
   Local_Host> java g4vrmlview  VRML_viewer_name
   ```

   For example, if you want to use the Netscape browser as your VRML viewer, execute `g4vrmlview` as follows:

   ```
   Local_Host> java g4vrmlview  netscape
   ```

   Of course, the command path to the VRML viewer should be properly set.

2. Login to the remote host where a Geant4 executable is placed.

3. Set an environment variable on the remote host as follows:

   ```
   Remote_Host> setenv G4VRML_HOST_NAME local_host_name
   ```

   For example, if you are working on the local host named "arkoop.kek.jp", set this environment variable as follows:

   ```
   Remote_Host> setenv G4VRML_HOST_NAME arkoop.kek.jp
   ```

   This tells a Geant4 process running on the remote host where Geant4 Visualization should be performed, i.e., where the visualized views should be displayed.

4. Invoke a Geant4 process and perform visualization with the VRML-Network driver. For example:

   ```
   Idle> /vis/open VRML2
   Idle> /vis/drawVolume
   Idle> /vis/viewer/update
   ```

Performing step 4, 3D scene data are sent from the remote host to the local host as VRML-formatted data, and the VRML viewer specified in step 3 is invoked by the `g4vrmlview` process to visualize the VRML data. The transferred VRML data are saved as a file named `g4.wrl` in the current directory of the local host.

Further information:

- http://geant4.kek.jp/~tanaka/GEANT4/VRML_net_driver.html

Remote visualization with the DAWN-Network driver

This section describes how to perform remote Geant4 Visualization with the DAWN-Network driver. In order to do it, you have to install the Fukui Renderer DAWN on your local host beforehand. See Section 8.6 Visualization Drivers for more information.

The following steps realize remote Geant4 Visualization viewed by DAWN.

1. Invoke DAWN with "-G" option on your local host:

   ```
   Local_Host> dawn -G
   ```

   This invokes DAWN with the network connection mode.

2. Login to the remote host where a Geant4 executable is placed.

3. Set an environment variable on the remote host as follows:

   ```
   Remote_Host> setenv G4DAWN_HOST_NAME local_host_name
   ```

   For example, if you are working in the local host named "arkoop.kek.jp", set this environment variable as follows:

   ```
   Remote_Host> setenv G4DAWN_HOST_NAME arkoop.kek.jp
   ```

   This tells a Geant4 process running on the remote host where Geant4 Visualization should be performed, i.e., where the visualized views should be displayed.

4. Invoke a Geant4 process and perform visualization with the DAWN-Network driver. For example:

   ```
   Idle> /vis/open DAWN
   Idle> /vis/drawVolume
   Idle> /vis/viewer/flush
   ```

Performing step 4, 3D scene data are sent from the remote host to the local host as DAWN-formatted data, and the local DAWN will visualize the data. The transferred data are saved as a file named `g4.prim` in the current directory of the local host.

Further information:

- http://geant4.kek.jp/~tanaka/DAWN/About_DAWN.html
- http://geant4.kek.jp/~tanaka/DAWN/G4PRIM_FORMAT_24/

8.10.2 Visualization of a detector geometry tree

Further information:

- http://geant4.kek.jp/GEANT4/vis/GEANT4/GENOVA/visgenova.htm

---

8.10.3 Hints for an impressive demonstration

You may demonstrate Geant4 Visualization in seminars, conferences, and other places. In a demonstration, the following are required:

Quick response

You should use a powerful machine with a graphics card for hardware processing of OpenGL commands, then Geant4 Visualization with OpenGL driver, OpenInventor driver, etc. will be accelerated to a great extent.

Interactive operation of views

The OpenGL-Motif driver, the OpenInventor drivers, and the OPACS driver support their own Graphical User Interfaces (GUI) for interactive operation of views. Many VRML viewers also support it.

Impressive effects

For example, some OpenInventor viewers support "stereoscopic" effects, in which audiences can experience vivid 3D views while wearing colored glasses. It is also effective to enlarge a small part of a generated vectorized PostScript figure, using a function of your PostScript viewer, to show details clearly.

It may be a good idea to demonstrate Geant4 Visualization off-line. You can save visualized views to OpenInventor files, VRML files, PostScript files, etc. beforehand, and visualize them with proper viewers in your demonstration.

---

9. Examples

9.1 Novice Examples

The Geant4 toolkit includes several fully coded examples which demonstrate the implementation of the user-classes required to build a customized simulation. Six "novice" examples are provided ranging from the simulation of a non-interacting particle and a trivial detector, to the simulation of electromagnetic and hadronic physics processes in a complex detector. Each example may be used as a base from which more detailed applications can be developed. A set of "extended" examples implement simulations of actual high energy physics detectors and require some libraries in addition to those of Geant4. The "advanced" examples cover cases useful to the developement of the Geant4 toolkit itself.

The examples can be compiled and run without modification. Most of them can be run both in interactive and batch mode using the input macro files (`*.in`) and reference output files (`*.out`) provided. These examples are run routinely as part of the validation, or testing, of official releases of the Geant4 toolkit.

9.1.1 Novice Example Summary

Descriptions of the six novice examples are provided here along with links to the code.

`ExampleN01` (Description below)

- Mandatory user classes
- Demonstrates how Geant4 kernel works

`ExampleN02` (Description below)

- Simplified tracker geometry with uniform magnetic field
- Electromagnetic processes

`ExampleN03` (Description below)

- Simplified calorimeter geometry
- Electromagnetic processes
- Various materials

`ExampleN04` (Description below)

- Simplified collider detector with a readout geometry
- Full ‘‘ordinary’’ processes
- PYTHIA primary events
- Event filtering by stack

`ExampleN05` (Description below)

- Simplified BaBar calorimeter
- EM shower parametrisation

`ExampleN06` (Description below)

- Optical photon processes

Tables 9.1.1 and 9.1.2 display the ‘‘item charts’’ for the examples currently prepared in the novice level.

	`ExampleN01`	`ExampleN02`	`ExampleN03`
comments	minimal set for geantino transportation	fixed target tracker geometry	EM shower in calorimeter
Run	`main()` for hard coded batch	`main()` for interactive mode	`main()` for interactive mode
			SetCut and Process On/Off
Event	event generator selection (particleGun)	event generator selection (particleGun)	event generator selection (particleGun)
			‘‘end of event’’ simple analysis in *UserEventAction*
Tracking	hard coded verbose level setting	selecting secondaries	select trajectories
Geometry	geometry definition (CSG)	geometry definition (includes Parametrised volume)	geometry definition (includes replica)
		uniform magnetic field	uniform magnetic field
Hits/Digi	-	tracker type hits	calorimeter-type hits

PIIM	minimal particle set	EM particles set	EM particles set
	single element material	mixtures and compound elements	mixtures and compound elements
Physics	transportation	EM physics	EM physics
Vis	-	detector & trajectory drawing	detector & trajectory drawing
		tracker type hits drawing	
(G)UI	-	GUI selection	GUI selection
Global	-	-	-

Table 9.1.1
The ‘‘item chart’’ for novice level examples `N01`, `N02` and `N03`.

	`ExampleN04`	`ExampleN05`	`ExampleN06`
comments	simplified collider geometry	parametrised shower example	Optical photon example
Run	`main()` for interactive mode	`main()` for interactive mode	`main()` for interactive mode
Event	event generator selection (HEPEvtInterface)	event generator selection (HEPEvtInterface)	event generator selection (particleGun)
	Stack control		
Tracking	select trajectories	-	-
	selecting secondaries		
Geometry	geometry definition (includes Param/Replica)	Ghost volume for shower parametrisation	geometry definition (BREP with rotation)
	non-uniform magnetic field		

Hits/Digi	Tracker/calorimeter/counter types	Sensitive detector for shower parametrisation	-
	ReadOut geometry		
PIIM	Full particle set	EM set	EM set
	mixtures and compound elements	mixtures and compound elements	mixtures and compound elements
Physics	Full physics processes	Parametrized shower	Optical photon processes
Vis	detector & hit drawing	detector & hit drawing	-
	calorimeter type hits drawing	-	-
(G)UI	define user commands	define user commands	define user commands
Global	-	-	random number engine

Table 9.1.2
The ‘‘item chart’’ for novice level examples `N04`, `N05` and `N06`.

9.1.2 Example N01

Basic concepts
    minimal set for geantino transportation

Classes

`main()` (source file)

- hard coded batch
- construction and deletion of *G4RunManager*
- hard coded verbose level setting to *G4RunManager*, *G4EventManager* and *G4TrackingManager*
- construction and set of mandatory user classes
- hard coded `beamOn()`
- Hard coded UI command application

ExN01DetectorConstruction

(header file) (source file)

- derived from G4VUserDetectorConstruction
- definitions of single element materials
- CSG solids
- *G4PVPlacement* without rotation

ExN01PhysicsList

(header files) (source file)

- derived from *G4VUserPhysicsList*
- definition of geantino
- assignment of transportation process

ExN01PrimaryGeneratorAction

(header file) (source file)

- derived from *G4VPrimaryGeneratorAction*
- construction of *G4ParticleGun*
- primary event generation via particle gun

9.1.3 Example N02

Basic concepts
    Detector: fixed target type
    Processes: EM
    Hits: tracker type hits

Classes

`main()` (source file)

- `main()` for interactive mode (and batch mode via macro file)
- construction of (G)UI session and *VisManager*
- random number engine
- construction and deletion of *G4RunManager*
- construction and set of mandatory user classes

ExN02DetectorConstruction

(header file) (source file)

- derived from *G4VUserDetectorConstruction*
- definitions of single-element, mixture and compound materials
- CSG solids
- Uniform magnetic field: construction of *ExN02MagneticField*
- Physical Volumes
  - *G4Placement* volumes with & without rotation.
  - *G4PVParameterised* volumes without rotation

ExN02MagneticField

(header file) (source file)

- derived from *G4MagneticField*
- Uniform field. *ExN02MagneticField*

ExN02PhysicsList

(header file) (source file)

- derived from *G4VUserPhysicsList*
- definition of geantinos, electrons, positrons, gammas
- utilisation of transportation and ’standard’ EM-processes
- Interactivity: chooses processes interactively (=> messenger class)

ExN02PrimaryGeneratorAction

(header file) (source file)

- derived from *G4VPrimaryGeneratorAction*
- construction of *G4ParticleGun*
- primary event generation via particle gun

ExN02RunAction

(header file) (source file)

- derived from *G4VUserRunAction*
- draw detector

ExN02EventAction

(header file) (source file)

- derived from *G4VUserEventAction*
- print time information

ExN02TrackerSD

(header file) (source file)

- derived from *G4VSensitiveDetector*
- tracker-type hit generation

ExN02TrackerHit

(header file) (source file)

- derived from *G4VHit*
- draw hit point

ExN02VisManager

(header file) (source file)

- derived from *G4VisManager*
- Example Visualization Manager implementing virtual function

---

9.1.4 Example N03

Basic concepts
    Visualize Em processes.
    Interactivity: build messenger classes.
    Gun: shoot particle randomly.
    Tracking: collect energy deposition, total track length

Classes

`main()` (source file)

- `main()` for interactive mode and batch mode via macro file
- construction and deletion of *G4RunManager*
- construction and set of mandatory user classes
- automatic initialization of geometry and visualization via a macro file

ExN03DetectorConstruction

(header file) (source file)

- derived from *G4VUserDetectorConstruction*
- definitions of single materials and mixtures
- CSG solids
- *G4PVPlacement* without rotation
- Interactivity: change detector size, material, magnetic field. (=>messenger class)
- visualization

ExN03PhysicsList

(header file) (source file)

- derived from *G4VUserPhysicsList*
- definition of geantinos, gamma, leptons, light mesons barions and ions
- Transportation process, ’standard’ Em processes, Decay
- Interactivity: *SetCut*, process on/off. (=> messenger class)

ExN03PrimaryGeneratorAction

(header file) (source file)

- derived from *G4VPrimaryGeneratorAction*
- construction of *G4ParticleGun*
- primary event generation via particle gun
- Interactivity: shoot particle randomly. (=> messenger class)

ExN03RunAction

(header file) (source file)

- derived from *G4VUserRunAction*
- draw detector and tracks
- Interactivity: *SetCut*, process on/off.
- Interactivity: change detector size, material, magnetic field .

ExN03EventAction

(header file) (source file)

- derived from *G4VUserEventAction*
- store trajectories
- print end of event information (energy deposited, etc.)

ExN03SteppingAction

(header file) (source file)

- derived from *G4VUserSteppingAction*
- collect energy deposition, etc.

ExN03VisManager

(header file) (source file)

- derived from *G4VisManager*

- Example Visualization Manager implementing virtual function

---

9.1.5 Example N04

Basic concepts
  Simplified collider experiment geometry
  Full hits/digits/trigger

Classes

`main()` (source file)

- construction and deletion of *ExN04RunManager*
- construction of (G)UI session and *VisManager*
- construction and set of user classes

ExN04DetectorConstruction

(header file) (source file)

- derived from *G4VUserDetectorConstruction*
- construction of *ExN04MagneticField*
- definitions of mixture and compound materials
- material-dependent CutOff
- simplified collider geometry with Param/Replica
- tracker/muon -- parametrised
- calorimeter -- replica

ExN04TrackerParametrisation

(header file) (source file)

- derived from *G4VPVParametrisation*
- parametrised sizes

ExN04CalorimeterParametrisation

(header file) (source file)

- derived from *G4VPVParametrisation*
- parametrized position/rotation

ExN04MagneticField

(header file) (source file)

- derived from *G4MagneticField*
- solenoid and toroidal fields

ExN04TrackerSD

(header file) (source file)

- derived from *G4VSensitiveDetector*
- tracker-type hit generation

ExN04TrackerHit

(header file) (source file)

- derived from *G4VHit*
- draw hit point

ExN04CalorimeterSD

(header file) (source file)

- derived from *G4VSensitiveDetector*
- calorimeter-type hit generation

ExN04CalorimeterHit

(header file) (source file)

- derived from *G4VHit*
- draw physical volume with variable color

ExN04MuonSD

(header file) (source file)

- derived from *G4VSensitiveDetector*
- Scintillator-type hit generation

ExN04MuonHit

(header file) (source file)

- derived from *G4VHit*
- draw physical volume with variable color

ExN04PhysicsList

(header file) (source file)

- derived from *G4VUserPhysicsList*
- definition of full particles
- assignment of full processes

ExN04PrimaryGeneratorAction

(header file) (source file)

- derived from *G4VPrimaryGeneratorAction*
- construction of *G4HEPEvtInterface*
- primary event generation with PYTHIA event

ExN04EventAction

(header file) (source file)

- store the initial seeds

ExN04StackingAction

(header file) (source file)

- derived from *G4UserStackingAction*
- ‘‘stage’’ control and priority control
- event abortion

ExN04StackingActionMessenger

(header file) (source file)

- derived from *G4UImessenger*
- define abortion conditions

ExN04TrackingAction

(header file) (source file)

- derived from *G4UserTrackingAction*
- select trajectories
- select secondaries

9.1.6 Example N05

Basic concepts
    Use of shower parameterisation:

* definition of an EM shower model
* assignment to a Logical Volume
* (definition of ghost volume when ready)

Interactivity: build of messengers classes

Hits/Digi: filled from detailed and parameterised simulation (calorimeter type hits ?)

Classes

`main()` (source file)

- `main()` for interactive mode
- construction and deletion of *G4RunManager*
- construction and set of mandatory user classes
- construction of the *G4GlobalFastSimulationmanager*
- construction of a *G4FastSimulationManager* to assign fast simulation model to a logical volume (envelope)
- (definition of ghost volume for parameterisation)
- construction EM physics shower fast simulation model

ExN05EMShowerModel

(header file) (source file)

- derived from *G4VFastSimulationModel*
- energy deposition in sensitive detector

ExN05PionShowerModel

(header file) (source file)

- derived from *G4VFastSimulationModel*
- energy deposition in sensitive detector

ExN05DetectorConstruction

(header file) (source file)

- derived from *G4VUserDetectorConstruction*
- definitions of single materials and mixtures
- CSG solids
- *G4PVPlacement*

ExN05PhysicsList

(header file) (source file)

- derived from *G4VUserPhysicsList*
- assignment of *G4FastSimulationManagerProcess*

ExN05PrimaryGeneratorAction

(header file) (source file)

- derived from *G4VPrimaryGeneratorAction*
- construction of *G4ParticleGun*
- primary event generation via particle gun

ExN05RunAction

(header file) (source file)

- derived from *G4VUserRunAction*
- draw detector
- (activation/deactivation of parameterisation ?)

ExN05EventAction

(header file) (source file)

- derived from *G4VUserEventAction*
- print time information

9.1.7 Example N06

Basic concepts
  Interactivity : build messenger classes.
  Event : Gun, shoot charge particle at Cerenkov Radiator and Scintillator.
  PIIM : material/mixture with optical and scintillation properties.
  Geometry : volumes filled with optical materials and possessing surface properties.
  Physics : define and initialize optical processes.
  Tracking : generate Cerenkov radiation, collect energy deposition to produce scintillation.
  Hits/Digi : PMT as detector.
  Visualization : geometry, optical photon trajectories.

Classes

`main()` (source file)

- `main()` for interactive mode and batch mode via macro file
- random number engine
- construction and deletion of *G4RunManager*
- construction and set of mandatory user classes
- hard coded `beamOn`

ExN06DetectorConstruction

(header file) (source file)

- derived from *G4VUserDetectorConstruction*
- definitions of single materials and mixtures
- generate and add Material Properties Table to materials
- CSG and BREP solids
- *G4PVPlacement* with rotation
- definition of surfaces
- generate and add Material Properties Table to surfaces
- visualization

ExN06PhysicsList

(header file) (source file)

- derived from *G4VUserPhysicsList*
- definition of gamma, leptons and optical photons
- transportation, 'standard' EM-processes, decay, Cerenkov, scintillation, 'standard' optical and boundary process
- modify/augment optical process parameters

ExN06PrimaryGeneratorAction

(header file) (source file)

- derived from *G4VPrimaryGeneratorAction*
- construction of *G4ParticleGun*
- primary event generation via particle gun

ExN06RunAction

(header file) (source file)

- derived from *G4VUserRunAction*
- draw detector

About the authors

9.2 Advanced Examples

9.2.1 Advanced Examples

Geant4 advanced examples illustrate realistic applications of Geant4 in typical experimental environments. Most of them also show the usage of analysis tools (such as histograms, ntuples and plotting), various visualisation features and advanced user interface facilities, together with the simulation core.
An overview of the common features of the advanced examples is available here.
The advanced examples include:

- **brachytherapy**, illustrating a typical medical physics application
- **gammaray_telescope**, illustrating an application to typical gamma ray telescopes with a flexible configuration
- **xray_telescope**, illustrating an application for the study of the radiation background in a typical X-ray telescope
- **xray_fluorescence**, illustrating the emission of X-ray fluorescence and PIXE
- **underground_physics**, illustrating an underground detector for dark matter searches

Further documentation about the analysis tools used in these examples is available at: AIDA (Abstract Interfaces for Data Analysis) and Anaphe/Lizard, JAS and OpenScientist.

These advanced examples have been developed in collaboration with Geant4 Low Energy Electromagnetic Physics Working Group.

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10. Appendix

10.1 Tips for Program Compilation

This section is dedicated to illustrate and justify some of the options used and fixed by default in the compilation of the Geant4 toolkit. It is also meant to be a simple guide for the user/installer to avoid or overcome problems which may occur on some compilers. Solutions proposed here are based on the experience gained while porting the Geant4 code to different architectures/compilers and are specific to the OS's and compiler's version valid at the current time of writing of this manual.

It's well known that each compiler adopts its own internal techniques to produce the object code, which in the end might be more or less perfomant and more or less optimised, depending on several factors also related to the system architecture which it applies to. A peculiarity of C++ compilers nowadays is the way templated instances are treated during the compilation/linkage process. Some C++ compilers need to store temporarily template instantiation files (object files or temporary source code files) in a "template repository" or directory that can be specified as unique or not directly from the compilation command (probably historically coming from the old cfront-based implementation of the C++ compiler).

In Geant4, the path to the template repository is specified by the environment variable $G4TREP, which is fixed and points by default to `$G4WORKDIR/tmp/$G4SYSTEM/g4.ptrepository/`, where `$G4SYSTEM` identifies the system-architecture/compiler currently used and `$G4WORKDIR` is the path to the user working directory for Geant4.

A secondary template repository `$G4TREP/exec` is created by default and can be used when building executables to isolate the main repository used for building the libraries in case of clashes provoked by conflicting class-names. This secondary template repository can be activated by defining in the environment (or in the GNUmakefile related to the test/example to be built) the flag `G4EXEC_BUILD`; once activated, the secondary repository will become the read/write one, while the primary repository will be considered read-only.

After the installation of the libraries, we strongly suggest to always distinguish between the installation directory (identified by $G4INSTALL) and the working directory (identified by $G4WORKDIR), in order not to alter the installation area for the template repository.

A good recommendation valid in general for all compilers making use of a template repository is to make use of a single template repository (specified by the `$G4TREP` environment variable) for building all Geant4 libraries; then use a secondary template repository (`$G4TREP/exec`, together with

`$G4EXEC_BUILD` flag) when building any kind of example or application.
It's always good practise to clean-up the secondary template repository from time to time.

10.1.1 HP

OS: HP-UX
Compiler: aCC

The default optimisation level to `+O2`.
The native STL implementation on HP-aCC works without using the *std* namespace. Therefore, no ISO/ANSI setup is adopted in this case.

10.1.2 DEC

OS: OSF
Compiler: cxx

The default optimisation level is `-O2`.
In some cases, to allow a successful compilation it might be required to extend the system datasize buffer. To achieve that, depending on the shell you're running you either execute one of these commands: *limit datasize 500000* or *ulimit -d 500000*.

10.1.3 Sun

OS: SunOS
Compiler: CC

The default optimisation level is `-O2`. This compiler makes use of a template repository to handle template instantiations, therefore consider the recommendations cited above.
Since version 5.0 of the compiler, native-STL is supported and ISO/ANSI compliance is required.

10.1.4 Unix/Linux - g++

OS: Linux
Compiler: GNU/gcc

On version 2.95.2 and higher of the gcc compiler, strict ISO/ANSI compilation is forced (`-ansi -pedantic` compiler flags), also code is compiled with high verbosity diagnostics (`-Wall` flag). For the old compiler egcs-1.1.2, non-ISO setup is adopted.

10.1.5 PC - MS Visual C++

OS: MS/Windows
Compiler: MS-VC++

See section 3 of the Installation Guide.

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10.2 Histogramming

Geant4 is independent of any histogram package. The Geant4 toolkit has no drivers for any histogram package, and no drivers are needed in Geant4 to use a histogram package. The code for generating histogramming should be compliant with the AIDA abstract interfaces for Data Analysis [1]

Consequently, you may use your favourite package together with the Geant4 toolkit.

10.2.1 JAS

Please refer to the JAS documentation on histogramming for using the JAVA Analysis Studio tool [2].

10.2.2 Lizard

Please refer to the Lizard documentation on histogramming for using the Lizard AIDA Interactive Analysis Environment [3].

10.2.3 Open Scientist Lab

Please refer to the Open Scientist Lab documentation on histogramming for using the Lab Analysis plug-in for the OnX package [4].

10.2.4 Examples

Examples in Geant4 showing how to use AIDA compliant tools for histogramming are available in the code distribution in `geant4/examples/extended/analysis` and `geant4/examples/advanced`.

---

[1] http://aida.freehep.org

[2] http://www-sldnt.slac.stanford.edu/jas/documentation.htm

[3] http://cern.ch/anaphe/Lizard/documentation.html

[4] http://www.lal.in2p3.fr/SI/Lab

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10.3 CLHEP and ANAPHE

10.3.1 CLHEP

CLHEP [1] represents Class Libraries for HEP and contains many basic classes specific to physics and HEP.

Both, a CLHEP Reference Guide [2] and a User Guide [3] are available.

Origin and current situation of CLHEP

CLHEP started 1992 as a library for fundamental classes mostly needed for, and in fact derived of, the MC event generator MC++ written in C++. Since then various authors added classes to this package, and finally it became one part of the ANAPHE software (former LHC++) [4].

Geant4 and CLHEP

The Geant4 project contributes to the ongoing development of CLHEP. The random number package, physics units, and some of the numeric and geometry classes had their origin in Geant4.

Geant4 also benefits from the development of CLHEP. In addition to the already mentioned classes for random numbers and numerics, we use the classes for points, vectors, and planes and their transformations in 3D space, and lorentz vectors and their transformations. Although these classes have Geant4 names like G4ThreeVector, these are just typedefs to the CLHEP classes.

10.3.2 ANAPHE

What is ANAPHE

The objectives of ANAPHE [4] are detailed in the LHC++ Project Execution Plan (PEP). In short ANAPHE offers to HEP experiments and others a similar -but superior- functionality as CERNlib did to FORTRAN users. The components of ANAPHE are modular and based on standards where possible.

Usage of ANAPHE Components in Geant4

Following the style of ANAPHE, Geant4 relies on the standard solutions proposed by ANAPHE where appropriate.

We make use of CLHEP in the kernel version. Optionally required are HepODBMS [5] and Objectivity/DB [6] for a persistent version based on HEPODBMS and OpenGL for the version using OpenGL graphics.

[1] http://wwwinfo.cern.ch/asd/lhc++/clhep

[2] http://wwwinfo.cern.ch/asd/lhc++/clhep/manual/RefGuide

[3] http://wwwinfo.cern.ch/asd/lhc++/clhep/manual/UserGuide

[4] http://cern.ch/anaphe

[5] http://cern.ch/db/objectivity/docs/hepodbms

[6] http://cern.ch/db/objectivity/docs

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10.4 C++ Standard Template Library

Overview

The Standard Template Library (STL) is a general-purpose library of generic algorithms and data structures. It is part of the C++ Standard Library. Nowadays, most compiler vendors include a version on STL in their products, and there are commercial implementations available as well.

Good books on STL are

Nicolai M. Josuttis: The C++ Standard Library. A Tutorial and Reference, Addison-Wesley, 1999, ISBN 0-201-37926-0.

David R. Musser, Atul Saini: STL Tutorial and Reference Guide / C++ Programming with the Standard Template Library, Addison-Wesley, 1996, ISBN 0-201-63398-1.

Resources available online include A Modest STL tutorial and the reference of the SGI implementation:

- Mumit's STL Newbie Guide is a kind of a FAQ, containing answers highlighting practical details of STL programming.
- SGI STL homepage , this is the bases of the native egcs STL implementation.

STL in Geant4

Since release Geant4.0.1, Geant4 supports STL, the Standard Template Library. From release 1.0, STL is required.
Native implementations of STL are supported on: DEC, HP, SUN, Windows and Linux platforms.

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10.5 Makefiles and Environment Variables

This section describes how the GNUmake infrastructure is implemented in Geant4 and provides a quick reference guide for the user/installer about the most important environment variables defined.

10.5.1 The GNUmake system in Geant4

As described in section 2.7.1.1 of this manual, the GNUmake process in Geant4 is mainly controlled by the following GNUmake script files (`*.gmk` scripts are placed in `$G4INSTALL/config`):

- `architecture.gmk`: defining all the architecture specific settings and paths. System settings are stored in `$G4INSTALL/config/sys` in separate files.
- `common.gmk`: defining all general GNUmake rules for building objects and libraries.

- `globlib.gmk`: defining all general GNUmake rules for building compound libraries.
- `binmake.gmk`: defining the general GNUmake rules for building executables.
- `GNUmake` scripts: placed inside each directory in the G4 distribution and defining directives specific to build a library (or a set of sub-libraries) or and executable.

To build a single library (or a set of sub-libraries) or an executable, you must explicitly change your current directory to the one you're interested to and invoke the "`gmake`" command from there ("`gmake global`" for building a compound library). Here is a list of the basic commands or GNUmake "targets" one can invoke to build libraries and/or executables:

- `gmake`
  This will start the compilation process for building a kernel library or a library associated to an example. Kernel libraries are built with maximum granularity, i.e. if a category is a compound one, this command will build all the related sub-libraries, _not_ the compound one. The top level `GNUmakefile` in `$G4INSTALL/source` will also build in this case a dependency map `libname.map` of each library to establish the linking order automatically at the `bin` step. The map will be placed in `$G4LIB/$G4SYSTEM`.
- `gmake global`
  It will start the compilation process to build a single compound kernel library per category. If issued sub-sequently to "gmake", both installations 'granular' and 'compound' libraries will be available (NOTE: will consistently increase the disk space required. Compound libraries will then be selected by default at link time, unless G4LIB_USE_GRANULAR is specified).
- `gmake bin` or `gmake` (only for examples/)
  It will start the compilation process to build an executable. This command will build implicitly the library associated to the example and link the final application. It assumes _all_ kernel libraries are already generated and placed in the correct `$G4INSTALL` path defined for them.
  The linking order is controlled automatically in case libraries have been built with maximum granularity, and the link list is generated on the fly.

`lib/` `bin/` and `tmp/` directories

The `$G4INSTALL` environment variable specifies where the installation of the Geant4 toolkit should take place, therefore kernel libraries will be placed in `$G4INSTALL/lib`. The `$G4WORKDIR` environment variable is set by the user and specifies the path to the user working directory; temporary files (object-files and data products of the installation process of Geant4) will be placed in `$G4WORKDIR/tmp`, according to the system architecture used. Binaries will be placed in `$G4WORKDIR/bin`, according to the system architecture used. The path to `$G4WORKDIR/bin/$G4SYSTEM` should be added to `$PATH` in the user environment.

10.5.2 Environment variables

Here is a list of the most important environment variables defined within the Geant4 GNUmake infrastructure, with a short explanation of their use. We recommend _not_ to override (explicitly or by accident) those environment variables listed here and marked with (!).

- System configuration

$CLHEP_BASE_DIR
Specifies the path where the CLHEP package is installed in your system.

$G4SYSTEM (!)
Defines the architecture and compiler currently used. This variable should be set automatically by the installer script "g4install" (in case of installation of Geant4) or by the script "g4config" (in case of pre-installed Geant4 and initial configuration of the user’s environment).

- Installation paths

  $G4INSTALL
  Defines the path where the Geant4 toolkit should be installed. It should be set by the system installer. By default, it sets to $HOME/geant4, assuming the Geant4 distribution is placed in $HOME.

  $G4BASE (!)
  Defines the path to the source code. Internally used to define $CPPFLAGS and $LDFLAGS for -I and -L directives. It has to be set to $G4INSTALL/src.

  $G4WORKDIR
  Defines the path for the user’s workdir for Geant4. It is set by default to $HOME/geant4, assuming the user’s working directory for Geant4 is placed in $HOME.

  $G4INCLUDE
  Defines the path where source header files may be mirrored at installation by issuing `gmake includes` (default is set to `$G4INSTALL/include`)

  $G4BIN, $G4BINDIR (!)
  Used by the system to specify the place where to store executables. By default they’re set to $G4WORKDIR/bin and $G4BIN/$G4SYSTEM respectively. The path to $G4WORKDIR/bin/$G4SYSTEM should be added to $PATH in the user environment. $G4BIN can be overridden.

  $G4TMP, $G4TMPDIR (!)
  Used by the system to specify the place where to store temporary files products of the compilation/build of a user application or test. By default they’re set to $G4WORKDIR/tmp and $G4TMP/$G4SYSTEM respectively. $G4TMP can be overridden.

  $G4LIB, $G4LIBDIR (!)
  Used by the system to specify the place where to store libraries. By default they’re set to $G4INSTALL/lib and $G4LIB/$G4SYSTEM respectively. $G4LIB can be overridden.

- Build specific

  $G4TARGET
  Specifies the target (name of the source file defining the main()) of the application/example to be built. This variable is set automatically for the examples and tests placed in

$G4INSTALL/examples.

$G4EXEC_BUILD
Flag specifying if to use a secondary template repository or not for handling template instantiations at the time of building a user application/example. For internal category tests in Geant4, this variable is already in the related GNUmakefile. It’s however not needed for examples and tests in $G4INSTALL/examples, where class names are already mangled and different each other. It applies only on those compilers which make use of template repositories (see Appendix A.2 of this Guide). The secondary template repository is set to $G4TREP/exec.

$G4DEBUG
Specifies to compile the code (libraries or examples) including symbolic information in the object code for debugging. The size of the generated object code can increase considerably. By default, code is compiled in optimised mode ($G4OPTIMISE set).

$G4NO_OPTIMISE
Specifies to compile the code (libraries or examples) without compiler optimisation.

$G4NO_STD_NAMESPACE
To avoid using the *std* namespace in the Geant4 libraries.

$G4NO_STD_EXCEPTIONS
To avoid throwing of exceptions in Geant4.

$G4_NO_VERBOSE
Geant4 code is compiled by default in high verbosity mode ($G4VERBOSE flag set). For better performance, verbosity code can be left out by defining $G4_NO_VERBOSE.

$G4LIB_BUILD_SHARED
Flag specifying if to build kernel libraries as shared libraries (libraries will be then used by default). If not set, static archive libraries are built by default.

$G4LIB_BUILD_STATIC
Flag specifying if to build kernel libraries as static archive libraries in addition to shared libraries (in case $G4LIB_BUILD_SHARED is set as well).

$G4LIB_USE_GRANULAR
To force usage of "granular" libraries against "compound" libraries at link time in case both have been installed. The Geant4 building system chooses "compound" libraries by default, if installed.

- UI specific

  The most relevant flags for User Interface drivers are just listed here. A more detailed description is given also in section 2. of this User’s Guide.

  G4UI_USE_TERMINAL
  Specifies to use dumb terminal interface in the application to be built (default).

G4UI_BUILD_XM_SESSION, G4UI_BUILD_XAW_SESSION
Specifies to include in kernel library the *XM* or *XAW* Motif-based user interfaces.

G4UI_USE_XM, G4UI_USE_XAW
Specifies to use the *XM* or *XAW* interfaces in the application to be built.

G4UI_BUILD_WO_SESSION, G4UI_USE_WO
Specifies to use the *WO* user interface associated to the OPACS tool.

G4UI_BUILD_WIN32_SESSION
Specifies to include in kernel library the WIN32 terminal interface for Windows systems.

G4UI_USE_WIN32
Specifies to use the WIN32 interfaces in the application to be built on Windows systems.

G4UI_NONE
If set, no UI sessions nor any UI libraries are built. This can be useful when running a pure batch job or in a user framework having its own UI system.

- Visualization specific

The most relevant flags for visualization graphics drivers are just listed here. A description of these variables is given also in section 2. of this User's Guide.

$G4VIS_BUILD_OPENGLX_DRIVER
Specifies to build kernel library for visualization including the OpenGL driver with X11 extension. It requires $OGLHOME set (path to OpenGL installation).

$G4VIS_USE_OPENGLX
Specifies to use OpenGL graphics with X11 extension in the application to be built.

$G4VIS_BUILD_OPENGLXM_DRIVER
Specifies to build kernel library for visualization including the OpenGL driver with XM extension. It requires $OGLHOME set (path to OpenGL installation).

$G4VIS_USE_OPENGLXM
Specifies to use OpenGL graphics with XM extension in the application to be built.

$G4VIS_BUILD_OI_DRIVER
Specifies to build kernel library for visualization including the OpenInventor driver. It requires $OIHOME and $HEPVISDIR set (paths to OpenInventor/HepVis installation).

$G4VIS_USE_OI
Specifies to use OpenInventor graphics in the application to be built.

$G4VIS_BUILD_OIX_DRIVER
Specifies to build the driver for the free X11 version of OpenInventor.

$G4VIS_USE_OIX
Specifies to use the free X11 version of OpenInventor.

$G4VIS_BUILD_OIWIN32_DRIVER
Specifies to build the driver for the free X11 version of OpenInventor on Windows systems.

$G4VIS_USE_OIWIN32
Specifies to use the free X11 version of OpenInventor on Windows systems.

$G4VIS_BUILD_OPACS_DRIVER
Specifies to build kernel library for visualization including the OPACS driver. It requires $OPACSHOME set (path to OPACS installation).

$G4VIS_USE_OPACS
Specifies to use OpenInventor graphics in the application to be built.

$G4VIS_BUILD_DAWN_DRIVER
Specifies to build kernel library for visualization including the driver for DAWN.

$G4VIS_USE_DAWN
Specifies to use DAWN as a possible graphics renderer in the application to be built.

$G4DAWN_HOST_NAME
To specify the hostname for use with the DAWN-network driver.

$G4VIS_NONE
If specified, no visualization drivers will be built or used.

- Analysis specific

  $G4ANALYSIS_USE
  Specifies to activate the appropriate environment for analysis, if an application includes code for histogramming based on *AIDA*. Additional setup variables are required ($G4ANALYSIS_AIDA_CONFIG_CFLAGS, $G4ANALYSIS_AIDA_CONFIG_LIBS) to define config options for AIDA ("aida-config --cflags" and "aida-config --libs"). See installation instructions of the specific analysis tools for details.

- Directory paths to Physics Data

  $NeutronHPCrossSections
  Path to external data set for Neutron Scaterring processes.

  $G4LEDATA
  Path to external data set for low energy electromagnetic processes.

  $G4LEVELGAMMADATA
  Path to the data set for Photon Evaporation.

$G4RADIOACTIVEDATA
Path to the data set for Radiative Decay processes.

10.5.3 Linking External Libraries with Geant4

The Geant4 GNUmake infrastructure allows to extend the link list of libraries with external (or user defined) packages which may be required for some user's applications to generate the final executable.

10.5.3.1 Adding external libraries which do *not* use Geant4

In the `GNUmakefile` of your application, before including `binmake.gmk`, specify the extra library in `EXTRALIBS` either using the `-L...-l...` syntax or by specifying the full pathname, e.g.:

```
  EXTRALIBS := -L<your-path>/lib -l<myExtraLib>
or
  EXTRALIBS := <your-path>/lib/lib<myExtraLib>.a
```

You may also specify `EXTRA_LINK_DEPENDENCIES`, which is added to the dependency of the target executable, and you may also specify a rule for making it, e.g.:

```
  EXTRA_LINK_DEPENDENCIES := <your-path>/lib/lib<myExtraLib>.a

  <your-path>/lib/lib<myExtraLib>.a:
        cd <your-path>/lib; $(MAKE)
```

Note that you almost certainly need to augment `CPPFLAGS` for the header files of the external library, e.g.:

```
  CPPFLAGS+=-I<your-path>/include
```

See table 10.5.1.

```
# --------------------------------------------------------------------
# GNUmakefile for the application "sim" depending on module "Xplotter"
# --------------------------------------------------------------------

name := sim
G4TARGET := $(name)
G4EXLIB := true

CPPFLAGS  += -I$(HOME)/Xplotter/include
EXTRALIBS += -L$(HOME)/Xplotter/lib -lXplotter
EXTRA_LINK_DEPENDENCIES := $(HOME)/Xplotter/lib/libXplotter.a

.PHONY: all

all: lib bin

include $(G4INSTALL)/config/binmake.gmk

$(HOME)/Xplotter/lib/libXplotter.a:
        cd $(HOME)/Xplotter; $(MAKE)
```

Table 10.5.1
An example of a customised GNUmakefile for an application or example using an external module not bound to Geant4.

10.5.3.2 Adding external libraries which use Geant4

In addition to the above, specify, in `EXTRALIBSSOURCEDIRS`, a list of directories containing source files in its `src/` subdirectory. Thus, your `GNUmakefile` might contain:

```
EXTRALIBS += $(G4WORKDIR)/tmp/$(G4SYSTEM)/<myApp>/lib<myApp>.a \
             -L<your-path>/lib -l<myExtraLib>
EXTRALIBSSOURCEDIRS += <your-path>/<myApp> <your-path>/<MyExtraModule>
EXTRA_LINK_DEPENDENCIES := $(G4WORKDIR)/tmp/$(G4SYSTEM)/<myApp>/lib<myApp>.a

MYSOURCES := $(wildcard <your-path>/<myApp>/src/*cc)
$(G4WORKDIR)/tmp/$(G4SYSTEM)/<myApp>/lib<myApp>.a: $(MYSOURCES)
      cd <your-path>/<myApp>; $(MAKE)
```

See Table 10.5.2.

```
# --------------------------------------------------------------------
# GNUmakefile for the application "phys" depending on module "reco"
# --------------------------------------------------------------------

name := phys
G4TARGET := $(name)
G4EXLIB := true

EXTRALIBS += $(G4WORKDIR)/tmp/$(G4SYSTEM)/$(name)/libphys.a \
             -L$(HOME)/reco/lib -lreco
EXTRALIBSSOURCEDIRS += $(HOME)/phys $(HOME)/reco
EXTRA_LINK_DEPENDENCIES := $(G4WORKDIR)/tmp/$(G4SYSTEM)/$(name)/libphys.a

.PHONY: all
all: lib bin

include $(G4INSTALL)/config/binmake.gmk

MYSOURCES := $(wildcard $(HOME)/phys/src/*cc)
$(G4WORKDIR)/tmp/$(G4SYSTEM)/$(name)/libphys.a: $(MYSOURCES)
        cd $(HOME)/phys; $(MAKE)
```

Table 10.5.2
An example of a customised GNUmakefile for an application or example using external modules bound to Geant4.

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10.6 Build for MS Visual C++

Geant4 can be compiled with the C++ compiler of MS Visual Studio C++ and the Cygwin toolset. Detailed instructions are given in the Installation manual. As the build system relies on `make` and other Unix tools using only the compiler of MS Visual Studio, the section on Makefile and environment variables applies also for building with MS Visual C++.

We do not support compilation directly under MS Visual Studio, i.e. we do not provide workspace files (`.dsw`) or project files (`.dsp`).

However the executables created are debuggable using the debugger of MS Visual Studio. You may have to help the debugger finding the path to source files the first time you debug a given executable.

10.7 Development and debug tools

1. UNIX

Although not in the scope of this user manual, in this appendix section we provide a set of references to rather known and established development tools and environments we think are useful for code development in C++ in general. It's a rather limited list, far from being complete of course.

- The KDevelop environment [1] on Linux systems.
- The GNU Data Display Debugger (DDD) [2].
- SUN Forte C++ environment (former Workshop) [3].
- Microsoft Visual Studio development environment [4].
- Parasoft Insure++ run-time debugger and memory checker [5]
- Parasoft Code Wizard source code analyzer [6].
- Rational Rose CASE tool [7].
- Together ControlCenter development environment [8].
- Logiscope tool for metrics analysis [9].
- Rational Unified Process (RUP) tool for Software engineering[10]

[1] http://www.kdevelop.org
[2] http://www.gnu.org/software/ddd
[3] http://www.sun.com/forte/cplusplus
[4] http://msdn.microsoft.com/vstudio
[5] http://www.parasoft.com/products/insure
[6] http://www.parasoft.com/products/wizard
[7] http://www.rational.com/products/rose
[8] http://www.togethersoft.com/products/controlcenter
[9] http://www.telelogic.com/products/logiscope
[10] http://www.rational.com/products/rup