Hands on 3: Build detector, retrieve simulation results

Introduction

In this third hands-on you will learn how to:

- Create a semi-realistic geometry
- Collect simulation output from sensitive detectors in hits
- Use the event user-action to dump event information from hits on screen

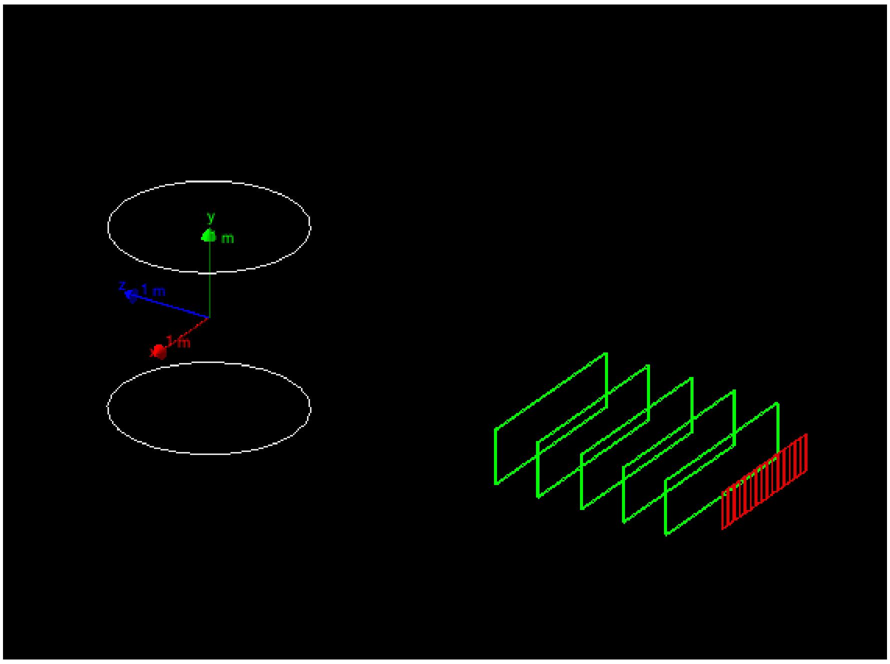
The code for this hands-on session is here (for your reference, the complete solution is also availavble here). Copy the the tar ball to your local area.

Follow the instructions of Hands On 1 to configure with `cmake` the code and build it. Try out the application:

```
$ cd <tutorial>
$ tar xzf HandsOn3.tar.gz
$ cd HandsOn3
$ cmake .
$ make -j 2 -f Makefile
$ ./G4tut
```

Note: Ignore compiler warning messages. They disappear once you complete the exercise.

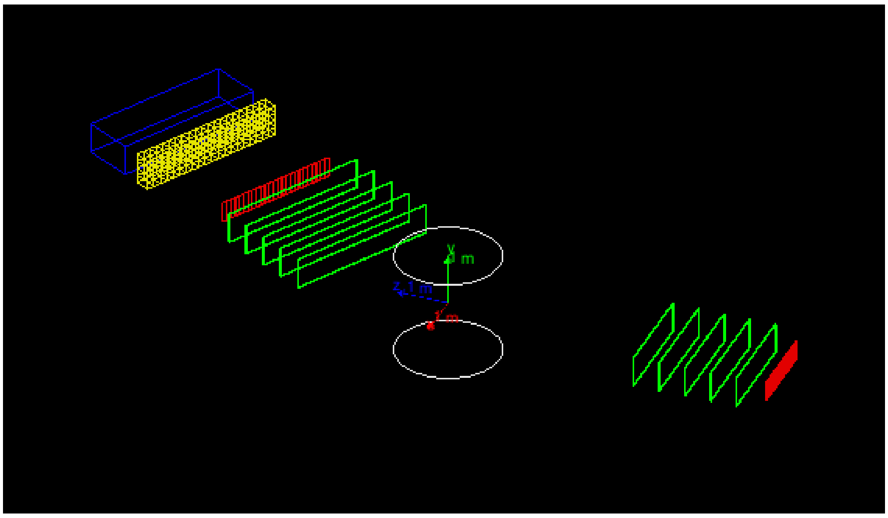
This geometry should be displayed:



The geometry is same as Hands On 2, as we will start from here to build a two-arm spectrometer. The first arm is already defined, and in the first exercise you will build the second arm completed with a calorimeter:

- Each arm includes 5 drift-chamber planes to measure the position of the passing particles (in green).
- Each arm includes a hodoscope made of scintillator plates to measure the time-of-flight of the incoming particles (in red).
- A central magnetic system to deflect the charged particles (white cylinder).
- **Exercise:** An electromagnetic calorimeter composed of CsI crystals (yellow in the picture).
- **Exercise:** An hadronic *sampling* calorimeter composed of Lead as absorber and Scintillator as active material (blue).

The second arm can be rotated between runs. The magnetic-field value can also be changed. User defined UI commands allow to change arm rotation and magnetic field value at run time.
At the end of this hands on the complete geometry will look like:



Building the geometry

There are 6 steps involved in this exercise to build the geometry.
The application will compile and work correctly only when the first 5 steps are completed (however it is a good idea to try to compile at each step to fix early trivial errors).
The last step is optional because it has the goal to change visualization attributes (colors of geometry elements) and has no effect on simulation results.

Reminder on different ways to create a geometry setup:

- After creating solids and logical volumes you can place physical volumes via `G4PVPlacement` (these have been already covered in Hands On 2).
- You you can place multiple copies of the same logical volumes via multiple placements.
- Or you can use of `G4PVParametrised` to place multiple copies of the same volume with dimensions/position *parametrised* by the *copy number*.
- You can also use replicas to *slice* a larger volume in smaller pieces.

Check the `DetectorConstruction.hh` file, since many variables you will need are already defined there.

Exercise 1 Step 1

Implement the second hodoscope.

The second hodoscope is composed of 25 planes of dimensions: 10x40x1 cm. The hodoscopes tiles are composed of scintillator material. Instantiate a single shape and a single logical volume. Place 25 physical volume placements in the second arm *mother volume* (this mother volume is already created). Each tile is positioned at Y=Z=0 with respect to the mother volume, while the X coordinates depends on the tile numnber.
Hint: Check what is done for the hodoscope of the first arm. Remember dimensions passed to Geant4 solid classes are half dimensions.

Solution

DetectorConstruction.cc File:

```
// ============================================
// Exercise 1
// Complete the full geometry.
// Note that second arm, by default is rotated of
// 30 deg.
// Step 1: Add an hodoscope with dimensions (X,Y,Z):
// (10,40,1)cm made of scintillator.
// There are 25 planes placed at Y=Z=0 (w.r.t. mother volume)
// hodoscopes in second arm
G4VSolid* hodoscope2Solid = new G4Box("hodoscope2Box",5.*cm,20.*cm,0.5*cm);
fHodoscope2Logical = new G4LogicalVolume(hodoscope2Solid,scintillator,"hodoscope2Logical");
for (G4int i=0;i<25;i++)
{
  G4double x2 = (i-12)*10.*cm;
  new
G4PVPlacement(0,G4ThreeVector(x2,0.,0.),fHodoscope2Logical,"hodoscope2Physical",secondArmLogical,false,i,checkOverlaps);
}
```

Exercise 1 Step 2

Build the drift chambers.

The second arm contains 5 drift chambers made of argon gas with dimensions 300x60x2 cm. These are equally spaced inside the second arm starting from -2.5 m to -0.5 m along the Z coordinate.
Hint: Use same methods used for step 1.

Solution

DetectorConstruction.cc File:

```
// Step 2: Add 5 drift chambers made of argon, with dimensions (X,Y,Z):
// (300,60,2)cm
// These are placed equidistant inside the second arm at distances from -2.5m
// to -0.5m
// drift chambers in second arm
G4VSolid* chamber2Solid = new G4Box("chamber2Box",1.5*m,30.*cm,1.*cm);
G4LogicalVolume* chamber2Logical = new G4LogicalVolume(chamber2Solid,argonGas,"chamber2Logical");
for (G4int i=0;i<5;i++)
{
  G4double z2 = (i-2)*0.5*m - 1.5*m;
  new G4PVPlacement(0,G4ThreeVector(0.,0.,z2),chamber2Logical,"chamber2Physical",secondArmLogical,false,i,checkOverlaps);
}
```

Exercise 1 Step 3

Add a virtual wire plane in the drift chambers.

Add a plane of wires in the drift chambers of step 2. To simplify our problem we do not describe the single wires, instead we add a new argon-filled volume of dimensions 300x60x0.02 cm in the center of each of the five drift chambers.
This exercise is technically simple (a single placement), however it shows a very useful concept: we create a single instance of this volume and we place it once inside the mother logical volume (the drift chamber logical volume), since the mother volume is repeated five times, each chamber gets its own wire plane. We are reducing the number of class instances needed for the description of our geometry (and thus reducing the memory footprint of our application, beside making the code more compact and readable).

Solution

DetectorConstruction.cc File:

```
// Step 3: Add a virtual wire plane of (300,60,0.02)cm
// at (0,0,0) in the drift chamber
// virtual wire plane
G4VSolid* wirePlane2Solid = new G4Box("wirePlane2Box",1.5*m,30.*cm,0.1*mm);
fWirePlane2Logical = new G4LogicalVolume(wirePlane2Solid,argonGas,"wirePlane2Logical");
new G4PVPlacement(0,G4ThreeVector(0.,0.,0.),fWirePlane2Logical, "wirePlane2Physical",chamber2Logical,false,0,checkOverlaps);
```

Exercise 1 Step 4

Build an electromagnetic calorimeter.

An electromagnetic calorimeter has the goal to measure the energy of absorbed particles. Its dimensions are such that an electron or gamma of the typical beam energy is fully absorbed, while hadrons (such as protons), only leave a fraction of their energy in an electromagnetic calorimeter (because it is *too short*). In our example we implement a homogeneous calorimeter made of a matrix of CsI crystals (a charged particles emits light when interacting with this material, the quantity

of light produced is proportional to the energy lost by the particle).
Build a 300x60x30 cm CsI calorimeter. The calorimeter is made of a matrix of 15x15x30 cm crystals. Instead of using placements we show how to use *parametrised* solids. The idea is that the position of the placement is a function of the crystal number. The parametrization class is already available for you in `CellParametrisation`. Check the method `CellParameterisation::ComputeTransformation(...)` to understand how the calorimeter cells are implemented.
The calorimeter should be placed at 2 m downstream along Z in the second arm mother volume.

Solution

DetectorConstruction.cc File:

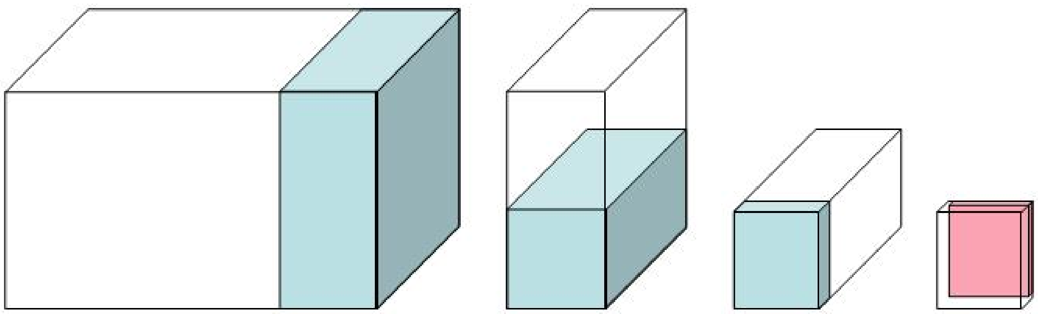
```
  // Step 4: Build CsI EM-calorimeter of (300,60,30)cm
  // placed at (0,0,2)m in the second arm.
  // The calorimeter is made of 80 cells,
  // parametrised according to CellParametrisation
  // G4VPVParameterisation concrete instance.
  // This class parametrize the position of each cell depending
  // on its copy number.
  // The cells have dimensions 15x15x30 cm.
  // (you could use placements or replicas, but here
  // we show how to use parametrisations to build geometry)
  // CsI calorimeter
  G4VSolid* emCalorimeterSolid = new G4Box("EMcalorimeterBox",1.5*m,30.*cm,15.*cm);
  G4LogicalVolume* emCalorimeterLogical = new G4LogicalVolume(emCalorimeterSolid,csI,"EMcalorimeterLogical");
  new
G4PVPlacement(0,G4ThreeVector(0.,0.,2.*m),emCalorimeterLogical,"EMcalorimeterPhysical",secondArmLogical,false,0,checkOverlaps);

  // EMcalorimeter cells
  G4VSolid* cellSolid = new G4Box("cellBox",7.5*cm,7.5*cm,15.*cm);
  fCellLogical = new G4LogicalVolume(cellSolid,csI,"cellLogical");
  G4VPVParameterisation* cellParam = new CellParameterisation();
  new G4PVParameterised("cellPhysical",fCellLogical,emCalorimeterLogical,kXAxis,80,cellParam);
```

Exercise 1 Step 5

Implement the hadronic calorimeter

This is a sampling calorimeter made of lead as absorber material (used for its high density) interleaved with plates of scintillator (the active material). It is called sampling because only a fraction of the energy lost by the particles is measured (the one lost in the active material), this is proportional to the total energy loss and hence to the impinging particle energy (you may be aware of the problem of non-compensation, but we will not discuss it here).
Implement the calorimeter using replicas to slice a larger volume into smaller units. Each cell has 20 layers of 4 cm thick lead plate and 1 cm thick scintillator plate. The size of the plate is 30 cm square. The calorimeter has 10 towers of 2 cells each. Here is a schematic drawing of the calorimeter. From left to right: the full calorimeter with a single tower; a single tower is divided in two cells; the third picture shows a single cell with a single layer; finally a single layer with the active scintillator tile. Beam is perpendicular to the screen.



- The whole Hadronic calorimeter box is made of lead. The size is 3 m in width, 60 cm in height, and 1 m in depth. It should be placed 3 m downstream inside the second arm.
- Replica is defined along one Cartesian axis, define a tower of 30 cm width. It is also made of lead. The height and depth of this column are equal to the full calorimeter dimensions.
- A cell made of lead has half height of a tower.
- Each layer in a cell is 5 cm thick. It is made of lead as well.
- Finally a scintillator tile should be placed inside each layer.

You can now test the setup, use UI commands `/tutorial/detector/armAngle`, `/tutorial/field/value` to move the second arm and set the magnetic field. Note that geometry can be changed only between runs. The methods `DefineCommands` gives an example on how to define application specific commands (this is an advanced topic not discussed in this Hands-On's). Use the `help` UI command to get help on commands.

Solution

DetectorConstruction.cc File:

```
// Step 5: Add a "sandwich" hadronic calorimeter of dimensions:
// (300,60,100)cm.
// The calorimeter absorber is made of lead. It is divided in
// towers of (30,60,100)cm. Use replica along X-axis
// for towers.
// A tower is composed of cells, "stacked" along Y-axis
// Each cell has dimension (30,30,100)cm.
// A cells has "layers" along Z-axis. Each layer has dimensions
// (30,30,5)cm. Also in this case use replicas.
// Finally in each layer there is a tile of scintillator material
// of dimensions (30,30,1)cm
// hadron calorimeter
G4VSolid* hadCalorimeterSolid = new G4Box("HadCalorimeterBox",1.5*m,30.*cm,50.*cm);
G4LogicalVolume* hadCalorimeterLogical = new G4LogicalVolume(hadCalorimeterSolid,lead,"HadCalorimeterLogical");
new
G4PVPlacement(0,G4ThreeVector(0.,0.,3.*m),hadCalorimeterLogical,"HadCalorimeterPhysical",secondArmLogical,false,0,checkOverlaps);

// hadron calorimeter column
G4VSolid* HadCalColumnSolid = new G4Box("HadCalColumnBox",15.*cm,30.*cm,50.*cm);
G4LogicalVolume* HadCalColumnLogical = new G4LogicalVolume(HadCalColumnSolid,lead,"HadCalColumnLogical");
new G4PVReplica("HadCalColumnPhysical",HadCalColumnLogical,hadCalorimeterLogical,kXAxis,10,30.*cm);

// hadron calorimeter cell
G4VSolid* HadCalCellSolid = new G4Box("HadCalCellBox",15.*cm,15.*cm,50.*cm);
G4LogicalVolume* HadCalCellLogical = new G4LogicalVolume(HadCalCellSolid,lead,"HadCalCellLogical");
new G4PVReplica("HadCalCellPhysical",HadCalCellLogical,HadCalColumnLogical,kYAxis,2,30.*cm);

// hadron calorimeter layers
G4VSolid* HadCalLayerSolid = new G4Box("HadCalLayerBox",15.*cm,15.*cm,2.5*cm);
G4LogicalVolume* HadCalLayerLogical = new G4LogicalVolume(HadCalLayerSolid,lead,"HadCalLayerLogical");
new G4PVReplica("HadCalLayerPhysical",HadCalLayerLogical,HadCalCellLogical,kZAxis,20,5.*cm);

// scintillator plates
G4VSolid* HadCalScintiSolid = new G4Box("HadCalScintiBox",15.*cm,15.*cm,0.5*cm);
fHadCalScintiLogical = new G4LogicalVolume(HadCalScintiSolid,scintillator,"HadCalScintiLogical");
new
G4PVPlacement(0,G4ThreeVector(0.,0.,2.*cm),fHadCalScintiLogical,"HadCalScintiPhysical",HadCalLayerLogical,false,0,checkOverlaps);
```

Exercise 1 Step 6 (Optional)

Provide visualization attributes for the second arm volumes.

Note that hadronic calorimeter sub-structure is by default made invisible to reduce visual clutter. This is helpful to hide the geometry details less important to the simulation.

Solution

DetectorConstruction File:

```
// visualization attributes ------------------------------------------------
// Step 6: uncomment visualization attributes of the newly created volumes
G4VisAttributes* visAttributes = new G4VisAttributes(G4Colour(1.0,1.0,1.0));
visAttributes->SetVisibility(false);
worldLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.9,0.9,0.9)); // LightGray
fMagneticLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(1.0,1.0,1.0));
visAttributes->SetVisibility(false);
firstArmLogical->SetVisAttributes(visAttributes);
secondArmLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.8888,0.0,0.0));
fHodoscope1Logical->SetVisAttributes(visAttributes);
fHodoscope2Logical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.0,1.0,0.0));
chamber1Logical->SetVisAttributes(visAttributes);
chamber2Logical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.0,0.8888,0.0));
visAttributes->SetVisibility(false);
fWirePlane1Logical->SetVisAttributes(visAttributes);
fWirePlane2Logical->SetVisAttributes(visAttributes);
```

```
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.8888,0.8888,0.0));
visAttributes->SetVisibility(false);
emCalorimeterLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.9,0.9,0.0));
fCellLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.0, 0.0, 0.9));
hadCalorimeterLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);

visAttributes = new G4VisAttributes(G4Colour(0.0, 0.0, 0.9));
visAttributes->SetVisibility(false);
HadCalColumnLogical->SetVisAttributes(visAttributes);
HadCalCellLogical->SetVisAttributes(visAttributes);
HadCalLayerLogical->SetVisAttributes(visAttributes);
fHadCalScintiLogical->SetVisAttributes(visAttributes);
fVisAttributes.push_back(visAttributes);
```

Sensitive Detectors and Hits

In this exercise we will cover basic aspects of retrieving physics quantities from the simulation kernel. The basic simulation output is called *hit* (a user-defined class inheriting from `G4VHit`): an energy deposit in space and time. Typically we are not interested in hits in all detector elements, but instead we want to retrieve information only for the relevant detector components, to simulate the detector read-out (e.g. the scintillator tiles in the hadronic calorimeter, and not the lead absorber).

In Geant4 this is achieved with the concepts of *hits* and *sensitive detectors* (SD): you can attach a SD (a user class inheriting from `G4VSensitiveDetector`) to a logical volume, in this way Geant4 will call your user-code when a particle is tracked in this specific volume. Information can be retrieved from the `G4Step` (e.g. energy deposited along the step) and a new hit is created (or an existing hit is updated). Geant4 will keep track of all hits created in the application. These can be retrieved at the end of the event for further post-processing and writing to output.
We will show how to measure a quantity, for each event, from the hodoscopes. The goal is to measure at what time and in which hodoscope tile there was a hit.
The exercise is divided in three parts, and you will have to modify four files:

- `HodoscopeHit.hh` and `HodoscopeHit.cc` files implement the hit class for the hodoscope.
- `HodoscopeSD.cc` implements the hodoscope sensitive detector.
- `DetectorConstruction.cc` instantiates the sensitive detector and attaches it to the correct logical volume.

Exercise 2 Step 1

Create a hit class.

This concrete Hit class represents a data container for only two quantities: an integer value, representing the index of the hodoscope tile that fired; and a double value, representing the time in which the hodoscope tile fired. Reminder: a hodoscope is a simple set of scintillators that measure the time in which a charged particle passes through it. It can be used to performed time-of-flight measurement and coarse-granularity position measurements.
You will need to modify the `HodoscopeHit` class. The class skeleton is already prepared, you should add two data members that identify which hodoscope tile has fired and register the time of the hit.
Note, that empty Constructor, the operators new and delete have been already implemented. You should remove the empty implementation and implement the correct methods. Implement/modify the `Print` method to dump the hit content.
Important note on `operator new` and `operator delete`: hits can put some pressure on CPU, because, for each event, many hits may be created and deleted at the end of the event. Allocating on the heap is a (relatively) CPU-intensive operation, thus the handling of hits may cause some performance degradation in a complex application.
To mitigate this we use an *allocator* that allows for an efficient re-use memory and avoid many calls to new/delete.
The first time a hit is created a memory *pool* is created that can hold (like in an array) many hits. Each time a hit is created with new operator we first look in this pool for an available *pre-allocated memory location*. If an empty slot is available, we re-use it, otherwise we grow the pool to contain more hits.
With this technique we reduce substantially the new/delete cycles needed for the simulation.
An additional complication is that in multi-threading environments special attention is needed for the use of allocators. We recognize this is an advanced topic that requires some more advanced knowledge of C++. If you do not feel comfortable with this discussion, you can remove from the HodoscopeHit.hh file the lines defining the new and delete operators, the application will work perfectly and since the hits are very simple and the simulation program is not too complex you will not see any CPU penalty.

This exercise implements a single sensitive detector and one hit type. In Hands On 4 additional sensitive detectors are used with hits in the drift chambers and in the calorimeters. You can study that code to see additional types of hits (calorimeter hits are of some interest since *accumulate* energy from several steps instead of creating a new hit at each step).

Solution

HodoscopeHit.hh file:

```
class HodoscopeHit : public G4VHit
 {
 public:
  HodoscopeHit(G4int i,G4double t);
  virtual ~HodoscopeHit() {}

  inline void *operator new(size_t);
  inline void operator delete(void*aHit);

  void Print();

  G4int GetID() const { return fId; }

  void SetTime(G4double val) { fTime = val; }
  G4double GetTime() const { return fTime; }

 private:
  G4int fId;
  G4double fTime;
};

 typedef G4THitsCollection<HodoscopeHit> HodoscopeHitsCollection;

 extern G4ThreadLocal G4Allocator<HodoscopeHit>* HodoscopeHitAllocator;

 inline void* HodoscopeHit::operator new(size_t)
 {
    if (!HodoscopeHitAllocator)
      HodoscopeHitAllocator = new G4Allocator<HodoscopeHit>;
    return (void*)HodoscopeHitAllocator->MallocSingle();
 }

 inline void HodoscopeHit::operator delete(void*aHit)
 {
    HodoscopeHitAllocator->FreeSingle((HodoscopeHit*) aHit);
 }
```

HodoscopeHit.cc file:

```
 G4ThreadLocal G4Allocator<HodoscopeHit>* HodoscopeHitAllocator;

 HodoscopeHit::HodoscopeHit(G4int i,G4double t)
 : G4VHit(), fId(i), fTime(t)
 {}

 void HodoscopeHit::Print()
 {
    G4cout << " Hodoscope[" << fId << "] " << fTime/ns << " (nsec)" << G4endl;
 }
```

Exercise 2 Step 2

Create and manipulate hodoscope hits.

For this exercise you will modify `HodoscopeSD.cc` file. Some part of the code is already implemented, in particular the initialization of the hits collection, use this code as a reference for your future applications: it is important to understand the details of how the registering of hits with the Geant4 kernel works.
What you need to do for this exercise is to modify the method `ProcessHits` and implement the logic to extract time and position. This is the method that Genat4 kernel will call every time a particle passes through the volume associated with this SD. The `G4Step` object encodes the information regarding the simulation step in the geometry volume.
Hint 1: Given a `G4Step` two points are defined (`G4StepPoint`) that delimit the step itself (pre- and post-). From each point you can retrieve which volume the step belongs to via the touchable history:

```
G4TouchableHistory* touchable = static_cast<G4TouchableHistory*>( stepPoint->GetTouchable() );
G4int copyNumber = touchable->GetVolume()->GetCopyNo();
```

These two lines allows you to get the copy number of the volume touched by the step (in our case the copy number for the hodoscope is the tile number, see file `DetectorConstruction.cc`).
Hint 2: There are two `G4StepPoint` defining a `G4Step`, which one of the two should you use, pre- or post- step point? Why?

The answer to this question is one of the most trickiest part of Geant4 for a new user, be sure to understand the reason why the two points are not equivalent!

Hint 3: We are simulating a scintillator detector that will trigger only if some energy has been deposited (i.e. via ionization), for example if a neutron passes through the detector (without making interactions) its passage should not be recorded. Check the energy deposited in the step, if zero do not do anything.

Hint 4: More than one step can be done by the same particle in a single volume (why?), in addition secondaries produced in the volume will also make steps in the SD. This mean that for a given primary particle we can have more than one call to the `ProcessHits`. A realistic detector electronics will responds with a single measurement: to simulate this behavior every time a new step is processed we check if the hit for the hodoscope tile that fired already exists, if so we update the time information if the new hit happens earlier than the already recorded one.

Solution

HodoscopeSD.cc file:

```
G4bool HodoscopeSD::ProcessHits(G4Step* step, G4TouchableHistory*)
{
   G4double edep = step->GetTotalEnergyDeposit();
   if (edep==0.) return true;

   G4StepPoint* preStepPoint = step->GetPreStepPoint();

   G4TouchableHistory* touchable = (G4TouchableHistory*)(preStepPoint->GetTouchable());
   G4int copyNo = touchable->GetVolume()->GetCopyNo();
   G4double hitTime = preStepPoint->GetGlobalTime();

   // check if this finger already has a hit
   G4int ix = -1;
   for (size_t i=0;i<fHitsCollection->entries();i++)
   {
     if ((*fHitsCollection)[i]->GetID()==copyNo)
     {
       ix = i;
       break;
     }
   }

   if (ix>=0) // if it has, then take the earlier time
   {
     if ((*fHitsCollection)[ix]->GetTime()>hitTime)
     { (*fHitsCollection)[ix]->SetTime(hitTime); }
   }
   else // if not, create a new hit and set it to the collection
   {
     HodoscopeHit* hit = new HodoscopeHit(copyNo,hitTime);
     fHitsCollection->insert(hit);
   }
   return true;
}
```

Exercise 2 Step 3

Construct the SD and attach it to the correct logical volume.

We can now create an instance of the HodoscopeSD and attach it to the correct logical volume. Add a separate instance of the SD to each arm hodoscope. Give the names "/hodoscope1" and "/hodoscope2" to these SDs. The same class is used for two logical volumes, the two instances are recognized by Geant4 only via their names.

We are going to modify the method `ConstructSDandField` in the DetectorCostruction class. If you are already a user of older version of Geant4 (up to version 9.6) this is one of the new main features introduced in version 10.0 to be compatible with multi-threading. To reduce memory consumption geometry is shared among threads, but sensitive-detectors are not.

Solution

DetectorConstruction.cc file:

```
void DetectorConstruction::ConstructSDandField()
{
  // sensitive detectors -----------------------------------------------------
  G4SDManager* SDman = G4SDManager::GetSDMpointer();
  G4String SDname;

  G4VSensitiveDetector* hodoscope1 = new HodoscopeSD(SDname="/hodoscope1");
  SDman->AddNewDetector(hodoscope1);
  fHodoscope1Logical->SetSensitiveDetector(hodoscope1);

  G4VSensitiveDetector* hodoscope2 = new HodoscopeSD(SDname="/hodoscope2");
  SDman->AddNewDetector(hodoscope2);
```

```
  fHodoscope2Logical->SetSensitiveDetector(hodoscope2);

  // magnetic field ----------------------------------------------------------------
  fMagneticField = new MagneticField();
  fFieldMgr = new G4FieldManager();
  fFieldMgr->SetDetectorField(fMagneticField);
  fFieldMgr->CreateChordFinder(fMagneticField);
  G4bool forceToAllDaughters = true;
  fMagneticLogical->SetFieldManager(fFieldMgr, forceToAllDaughters);

}
```

User Actions I

In this exercise we modify one of the user-actions to print on screen the information collected from hodoscopes at the end of each event.
User actions allow to interact with the simulation to retrieve and control the simulation results at specific points during the simulation of a run. Different user action provides specific interfaces to control the different aspects of the simulation. For example, the `G4UserEventAction` class provides interfaces to interact with Geant4 at the beginning and at the end of each event. `G4UserRunAction` allows for the creation of a user-custom `G4Run` object and it executes user-code at the beginning and at the end of a run (this will be covered in the [Hands On 4]). `G4VUserPrimaryGeneratorAction` controls the creation of primaries, `G4UserSteppingAction` allows to retrieve information at each step (indipendentely of sensitive detectors), `G4UserTrackingAction` allows for interaction with each `G4Track` and finally `G4UserStackingAction` allows to control the *urgency* of each new `G4Track` (advanced).

Note for users of older versions of Geant4: Multi-threading requires user actions to be thread-private (differently from initialization classes that are shared among threads). A new user initialization class is available in version 10: `G4VUserActionInitialization` this provides a method `Build()` in which all user actions are instantiated (this method is called by each worker thread). A second method `BuildForMaster` is called by the master thread. Among all user actions the `G4UserRunAction` is the only one that can also be instantiated for the master thread, this is to allow for [reduction] of results from worker threads to master thread (e.g. sum the partial results of each thread into a *global* result). This will be covered in the [Hands On 4].

Exercise 3

Using a `G4UserEventAction` print on screen the number of hits and the time registered in the hodoscopes.

For this exercise you will need to modify in file `EventAction.cc` the method `EndOfEventAction`, this method is called by Geant4 at the end of the simulation of each event. The pointer to the current `G4Event` is passed to the user-code. From this object you will retrieve the hits collections for the two hodoscopes and dump to screen the collected information.
Part of the `EventAction` code is already implemented.
In particular take a moment to study the method `BeginOfEventAction`: in this method we retrieve the IDs of the two collections. Note the `if` statement that allows for an efficient search of the IDs, given the collection names, only once. Searching with strings is a time consuming operation, this method allows for reducing the CPU time, if many collections are created this is an important optimization to consider.

Important: The code assumes you have called the two SDs: "/hodoscope1" and "/hodoscope2" and that they create a hit collection called "hodosopeColl". Change these if you have modified the names.

The `EventAction` is instantiated in the `ActionInitialization` class. Take a look at it and see how the `EventAction` is created.
The solution shows how to introduce some run-time checks of the effective existence of the hits. While this is not necessary in this simple code, this is a good code practice: in large applications the presence of hits collections may be decided at run time depending on the job configuration.

Solution

EventAction.cc file:

```
void EventAction::EndOfEventAction(const G4Event* event)
{
 // ============================================
 // Exercise 3
 // Print on screen the hits of the hodoscope
 // Step 1: Get the hits collection of this event
 G4HCofThisEvent* hce = event->GetHCofThisEvent();
 if (!hce)
 {
   G4ExceptionDescription msg;
   msg << "No hits collection of this event found.\n";
```

```
    G4Exception("EventAction::EndOfEventAction()","Code001", JustWarning, msg);
    return;
  }
  // Step 2: Using the memorised IDs get the collections
  // corresponding to the two hodoscopes
  // Get hits collections
  HodoscopeHitsCollection* hHC1 = static_cast<HodoscopeHitsCollection*>(hce->GetHC(fHHC1ID));
  HodoscopeHitsCollection* hHC2 = static_cast<HodoscopeHitsCollection*>(hce->GetHC(fHHC2ID));
  if ( (!hHC1) || (!hHC2) )
  {
    G4ExceptionDescription msg;
    msg << "Some of hits collections of this event not found.₩n";
    G4Exception("EventAction::EndOfEventAction()","Code001", JustWarning, msg);
    return;
  }
  //
  // Print diagnostics
  //
  G4int printModulo = G4RunManager::GetRunManager()->GetPrintProgress();
  if ( printModulo==0 || event->GetEventID() % printModulo != 0) return;

  G4PrimaryParticle* primary = event->GetPrimaryVertex(0)->GetPrimary(0);
  G4cout << G4endl
    << ">>> Event " << event->GetEventID() << " >>> Simulation truth : "
    << primary->GetG4code()->GetParticleName()
    << " " << primary->GetMomentum() << G4endl;

  // Step 3: Loop on the two collections and dump on screen hits
  // Hodoscope 1
  G4int n_hit = hHC1->entries();
  G4cout << "Hodoscope 1 has " << n_hit << " hits." << G4endl;
  for (G4int i=0;i<n_hit;i++)
  {
    HodoscopeHit* hit = (*hHC1)[i];
    hit->Print();
  }
  // Hodoscope 2
  n_hit = hHC2->entries();
  G4cout << "Hodoscope 2 has " << n_hit << " hits." << G4endl;
  for (G4int i=0;i<n_hit;i++)
  {
    HodoscopeHit* hit = (*hHC2)[i];
    hit->Print();
  }
}
```

With successful execution (try, e.g., `/run/beamOn 100`), you should see printout like this (actual numbers should vary):

```
G4WT0>
G4WT0> >>> Event 96 >>> Simulation truth : proton (-16.232228069311,0,994.22834019976)
G4WT0> Hodoscope 1 has 1 hits.
G4WT0> Hodoscope[7] 6.8585277990143 (nsec)
G4WT0> Hodoscope 2 has 1 hits.
G4WT0> Hodoscope[8] 59.288664870039 (nsec)
G4WT0> --> Event 97 starts with initial seeds (47098457,35307784).
G4WT0>
G4WT0> >>> Event 97 >>> Simulation truth : proton (-5.5136395233946,0,990.67454918706)
G4WT0> Hodoscope 1 has 1 hits.
G4WT0> Hodoscope[7] 6.8697647503318 (nsec)
G4WT0> Hodoscope 2 has 1 hits.
G4WT0> Hodoscope[8] 59.535676954411 (nsec)
G4WT0> Thread-local run terminated.
G4WT0> Run Summary
G4WT0> Number of events processed : 49
G4WT0> User=0.360000s Real=0.184613s Sys=0.000000s [Cpu=195.0%]
Run terminated.
Run Summary
Number of events processed : 100
User=0.360000s Real=0.185584s Sys=0.010000s [Cpu=199.4%]
```

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