Geant 4

Detector Response

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Overview

- **Concepts**
  - Readout geometry
  - Sensitive detector
  - Hits
  - Digis
- **Details**
  - Hit class
  - Sensitive detector class
  - Hits Collection class and its use
- **Basic features**
  - Digitizer module and digit
  - Touchable

Basic concepts

Extracting information from the simulation

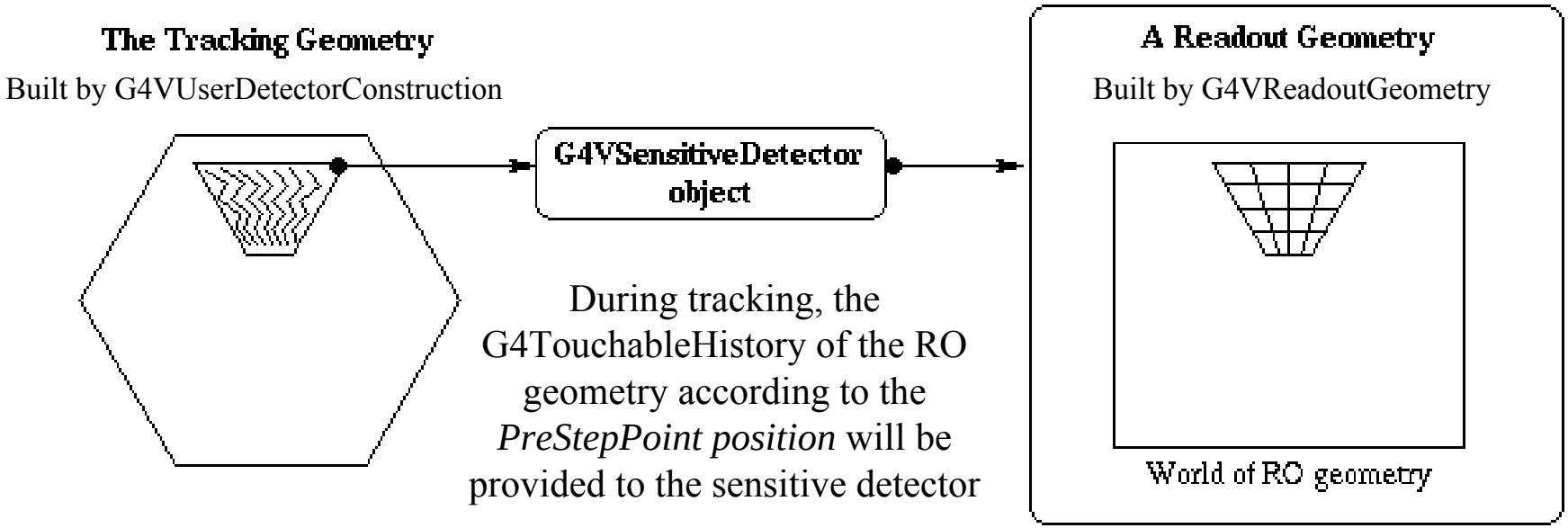
- Once the mandatory classes *(DetectorConstruction, PhysicsList, PrimaryGeneration)* are implemented, the Geant4 application does not yet include functionality to extract information produced in the simulation

- A user **must provide his/her own code**
  - **To extract information** relevant to the simulation application
  - **To describe the detector response**

- Geant4 concepts for such functionality are
  - **Sensitive Detector** (optionally with **Readout Geometry**)
  - **Hits** and **Hits Collections**
  - **Digis** and **Digis Collections**

Readout geometry

- Readout geometry is a **virtual** and **artificial** geometry which can be defined in parallel to the real detector geometry
- Tracks will be tracked in the “real” geometry, but the sensitive detector can have its own geometry for readout purposes
  - e.g. to find the cell the current hit belongs to
- The readout geometry is **optional**; on may have more than one
  - Each one should be associated to a sensitive detector
  - But a sensitive detector is not required to have a readout geometry
- **A step is not limited by** the boundary of **the readout geometry**



How to create a ReadOut Geometry

- Derive your own concrete class from the **G4VReadoutGeometry** abstract base class
- The geometry setup is done in the **same way** as for the “real” tracking geometry:
  - Create solids, logical and physical volumes
- However, the materials used in the RO geometry are **dummy materials**
  - i.e. they are not used
- A **sensitive detector** for the RO geometry must be defined but is not used
  - This means that you need to declare the sensitive parts of the RO geometry by setting a non-NULL sensitive detector pointer to the logical volume

Readout Geometry

```
class G4VReadoutGeometry {
  protected:
  virtual G4VPhysicalVolume* Build() = 0;
...
};
```

abstract base class

```
// header file: MyReadOutGeometry.hh
#include "G4VReadoutGeometry.hh"
...
class MyReadOutGeometry : public G4VReadoutGeometry {
public:
  MyReadoutGeometry();
  virtual ~MyReadoutGeometry();
  virtual G4VPhysicalVolume* Build(); // must return the physical world
                                      // volume of the readout geometry
private:
....
;
```

your RO geometry class

Hit

- Hit is a **user-defined** class, which derives from the G4VHit base class

- You can store various kind of information by implementing your own concrete Hit class
- Typically one records quantities like:
  - Position and time of the step
  - Momentum and energy of the track
  - Energy deposit in the step
  - Geometrical information
  - etc.

Example of a Hit class

```
// header file: MyHit.hh

#include "G4VHit.hh"

class MyHit : public G4VHit {
public:
MyHit();
virtual ~MyHit();
...
inline void SetEnergyDeposit(double energy) { energyDeposit = energy; }
inline double GetEnergyDeposit() { return energyDeposit;}
... // more member functions

private:
G4double energyDeposit;
... // more data members
};
```

Sensitive Detector

- A logical volume becomes **sensitive** if it has a pointer to a **SensitiveDetector (SD)**
- A SensitiveDetector **can be instantiated several times**, where the instances are assigned to different logical volumes
  - SD objects must have unique detector names
  - A **logical volume can only have one SD object** attached
  - But you can implement your detector to have multiple functionality
- Two possibilities to make use of the SD functionality
  - **Create your own sensitive detector**
    - Highly customizable
  - **Use Geant4 built-in tools**
    - Primitive Scorers

Creating your own sensitive detector

- A powerful way of extracting information from the physics simulation is to define your own SD
- The ingredients of the scoring setup are:

	Base class	**Concrete class**
Sensitive Detector Readout Geometry Hit	*G4VSensitiveDetector* *G4VReadoutGeometry* *G4VHit*	MySensitiveDetector MyReadoutGeometry MyHit
		Template class
Hits Collection		G4THitsCollection<your hit class>

- Derive your own concrete classes from the base classes and customize them according to your needs

Basic strategy to retrieve information - 1

- Assume that you have already created the detector geometry
  - Shape and size (Solid) of your detector, Material
  - Logical volumes
  - Physical volumes
- **Implement a sensitive detector** and **assign an instance of it to the *logical volume*** of your detector geometry setup
  - Then this volume becomes sensitive
  - The sensitive detector will become "active" for each particle step, if the step starts inside this logical volume
- *Optionally:* **implement a readout geometry** and **attach it to the sensitive detector**

Adding sensitivity to a logical volume

- Create an instance of a sensitive detector
- Register the sensitive detector to the SD manager
- Assign the pointer of your SD to the logical volume of your detector geometry

```
G4VSolid* boxSolid = new G4Box( “aBoxSolid“, 1.* cm, 1.* cm, 1.* cm);
G4LogicalVolume* boxLog =
        new G4LogicalVolume( boxSolid, materialSilicon, “aBoxLog“, 0, 0, 0);
G4VSensitiveDetector* sensitiveBox = new MySensitiveDetector(“MyDetector”);
G4SDManager* SDManager = G4SDManager::GetSDMPointer();
SDManager ->AddNewDetector(sensitiveBox);
boxLog ->SetSensitiveDetector(sensitiveBox);
```

Basic strategy to retrieve information - 2

- Then, create **Hit** objects in your sensitive detector using information from particle steps
- **Hit** is a snapshot of the physical interaction of a track or an accumulation of interactions of tracks in the sensitive or interesting region of your detector
  - *You should create hit class(es) according to your needs*
- Use **Touchable** of the **Readout Geometry** to retrieve geometrical information associated with hits
- Store your hits in **Hit Collections**
  - hit collections are automatically associated to the G4Event object
- Finally, process the information associated with hits in User Action classes (G4UserEventAction,G4UserRunAction etc.) to obtain a summary of the relevant event/run features

Using built-in scorers

- Alternatively, you can use a predefined sensitive detector **G4MultiFunctionalDetector** and primitive scorers:

	Concrete class
Sensitive Detector Primitive Scorers	G4MultiFunctionalDetector G4PSEnergyDeposit, G4PSTracklength, ...
	Template class
Hits Collection	G4THitsMap<G4double>

- Each primitive scorer stores **one physics quantity** for each ***physical volume*** (accumulated over an event)
- Many scorers are provided by Geant4
  - energy deposit, flux, ...

Basic strategy to retrieve information

- Assume that you have already created the detector geometry
  - Shape and size (Solid) of your detector, Material
  - Logical volumes
  - Physical volumes
- **Assign** an instance of the Geant4 **multifunctional detector** (G4MultiFunctionalDetector) to the ***logical volume*** of your detector geometry set-up
- **Register** instances of the required **primitive scorers** to your **multifunctional detector**
- Finally, **process** the content of **hit maps**

Sensitive Detector and Hits in detail

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Sensitive Detector

- A user can provide his/her own implementation of the detector and its response
- To create a sensitive detector, derive your own concrete class from the **G4VSensitiveDetector** abstract base class
  - The principal purpose of the sensitive detector is to create hit Objects
- Overload the following methods:
  - **Initialize()**
  - **ProcessHits()** *(invoked for each step, if step starts in logical volume)*
  - **EndOfEvent()**

Sensitive Detector

abstract base class

```
class G4VSensitiveDetector {
public:
...
virtual void Initialize(G4HCofThisEvent*);
virtual void EndOfEvent(G4HCofThisEvent*);
…
virtual G4bool ProcessHits(G4Step* ,G4TouchableHistory*) = 0;
...
};
```

your Sensitive Detector class

```
// header file: MySensitiveDetector.hh
#include “G4VSensitiveDetector.hh“
...
class MySensitiveDetector : public G4VSensitiveDetector {
public:
MySensitiveDetector(G4String name);
virtual ~MySensitiveDetector();
virtual void Initialize(G4HCofThisEvent*HCE);
virtual G4bool ProcessHits(G4Step* step,G4TouchableHistory* ROhist);
virtual void EndOfEvent(G4HCofThisEvent*HCE);
private:
MyHitsCollection * hitsCollection;
int collectionID;
```

Sensitive Detector and Hits

- Using information from particle steps, a sensitive detector either
  - constructs one or more hits objects

  or
  - accumulates values to existing hits
    - e.g. a tracker detector stores position, time of hit etc.
    - a calorimeter stores energy deposit etc.
- Hit objects can be supplied information in the **ProcessHits** method of the concrete class of the SD
  - This function has pointers to the current G4Step object and the G4TouchableHistory of the RO geometry (if defined) as arguments

Sensitive Detector - Constructor

- Specify a Hit Collection (by its unique name) for each type of hits considered in the sensitive detector
- Insert the name(s) in the collectionName vector

```
class G4VSensitiveDetector {
...
protected:
G4CollectionNameVector collectionName;
// This protected name vector must be filled in
// the constructor of the concrete class for
// registering names of hits collections
...
};
```

base class

```
MySensitiveDetector::MySensitiveDetector(G4String detectorUniqueName)
: G4VSensitiveDetector(detectorUniquename),
  collectionID(1)
{
  collectionName.insert("collection_name");
}
```

your Sensitive Detector class

Sensitive Detector - Initialize

- The Initialize() method is invoked at the beginning of each event
- Construct all hits collections and insert them in the G4HCofThisEventobject, which is passed as argument to Initialize()
- The AddHitsCollection method of G4HCofThisEvent requires the collection ID
- The unique collection ID can be obtained with GetCollectionID():
  - GetCollectionID() cannot be invoked in the constructor of this SD class
  - it is required that the SD is instantiated and registered to the SD manager first
- Hence, we defined a private data member (collectionID), which is set at the first call of the Initialize() function

```
void MySensitiveDetector::Initialize(G4HCofThisEvent* HCE) {
  if (collectionID < 0)
  collectionID = GetCollectionID(0); // Argument : order of collection
                                     // as stored in the collectionName vector
  hitsCollection = new MyHitsCollection(sensitiveDetectorName, collectionName[0]);
  HCE -> AddHitsCollection(collectionID, hitsCollection);
}
```

Sensitive Detector - ProcessHits

- This ProcessHits() method is invoked for every step in the volume(s) which hold a pointer to this SD
- The principal mandate of this method is to generate hit(s) or to accumulate data to existing hit objects, by using information from the current step
  - Note: Geometry information must be derived from the "PreStepPoint".

```
void MySensitiveDetector::ProcessHits(G4Step* step, G4TouchableHistory*ROhist)
{
  MyHit* hit = new MyHit();
...
  // associate physics information, e.g.:
  G4double energyDeposit = step ->GetTotalEnergyDeposit();
  hit ->SetEnergyDeposit(energyDeposit); // See implementation of our Hit class
...
  hitsCollection -> insert(hit);
  return true;
}
```

Sensitive Detector - EndOfEvent

- This **EndOfEvent()** method is invoked at the end of each event **before** the *EndOfEvent* function of the *G4UserEventAction* class

```
void MySensitiveDetector::EndOfEvent(G4HCofThisEvent* HCE) {
…
}
```

Hits Collection

- Once created in the sensitive detector, instances of the concrete hit class must be stored in a dedicated collection
  - Template class **G4THitsCollection**
  - the template parameter is the concrete hit class: G4THitsCollection<MyHit>
- Hit collections can be accessed in various phases of the simulation
  - At the end of each event through the G4Event object
    - to analyse the event and store useful information
  - During event processing through the sensitive detector manager, G4SDManager
    - to perform event filtering

HitCollections and Event

- A **G4Event** object holds a **G4HCofThisEvent** object at the end of event processing
- You can get the pointer to the G4HCofThisEvent object by using the **GetHCofThisEvent** method of G4Event
- The **G4HCofThisEvent** object stores all hits collections created within the event
- At the end of an event, you can process the hits of hits collections contained in G4HCofThisEvent in your implementation of the **EndOfEventAction** method of the **user EventAction** class

Hit information processing

- Retrieve the **pointer to a hit collection** with the **GetHC** method of **G4HCofThisEvent** collection by using the collection index
  - Index numbers of a hit collection are unique and do not change for a run
  - The index number can be obtained by *G4SDManager::GetCollectionID("detName/colName");*

- NOTE
  - If hit collection(s) were not created in a particular event, the pointers to the collection are NULL; pointers should be checked before attempting to access hit objects
  - Hits collection pointers are of **G4VHitsCollection type** in G4HCofThisEvent
  - After retrieving them, it is required to **cast** them to the types of individual concrete classes

Hit information processing

- Loop over the entries of a hit collection to access individual hits
- You can use the **[ ] operator** of the hits collection class to get the pointer to a hit object (corresponding to the specified index)
- Retrieve the information associated with hits
  - and process the information, if required
- Store the output in **analysis objects** *(optional)*
  - Histograms, tuples etc.
  - NOTE: in the exercises we use AIDA objects to store the simulation output
- Store hits objects through a **persistency** mechanism for further processing *(optional)*

Example of processing hits

```
void MyEventAction::EndOfEventAction(const G4Event* event) {
  // index is a data member, representing the hits collection index of the considered collection
  // It was initialized to 1 in the class constructor
  if (index < 0) index = G4SDManager::GetSDMpointer() ->GetCollectionID("myDet/myColl");
  G4HCofThisEvent* HCE = event->GetHCofThisEvent();

 MyHitsCollection* hitsCollection = 0;
 if (HCE) hitsCollection = (MyHitsCollection*)(HCE->GetHC(index));   // cast

 if (hitsCollection) {
    int numberHits = hitsCollection->entries();

    for  (int j= 0; j < numberHits ; j++) {
       MyHit* hit = (*hitsCollection)[j];

       // Retrieve information from hit object, e.g.
       double energy = hit ->GetEnergyDeposit();
       // Further process and store information…
       // Fill histograms etc.
      }
   }
}
```

Digis

- A Hit is created when a particle step is inside a detector, and typically is responsible for physical observables
- A **Digit** represents the output of a detector
  - e.g. ADC/TDC count, trigger signal, ...
- It is created from the information from hits and/or other digits
- Similarly as for hits, you need to implement customized digit class(es) of your own
- The base class of digits is **G4VDigi**
- Digit objects are stored in digit collections
  - Template class **G4TDigiCollection**
- G4Event has a **GDCofThisEvent** object, that is a container for digit collections
- *Note the similarity with Hits*

Digitization

- Digits are created in a **digitizer module**
- Create your digitizer module by inheriting from the base class **G4VDigitizerModule**
  - Overload the pure virtual method **Digitize()**: Create digit objects in this function and store them in digit collections
- NOTE: In contrast to the ProcessHits() function, the Digitize() method is **NOT automatically called** by the Geant4 kernel
  - You should invoke this function yourself explicitly
    - e.g. in the user action classes

Touchable

- Each G4StepPoint object has
  - Position in world coordinate system
  - Global and local time
  - Material
  - G4TouchableHistory for geometrical information
- G4TouchableHistory object provides information on the geometrical hierarchy
  - copy number
  - transformation / rotation to its mother