Retrieving information from the simulation

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Partially based on a presentations by A. Lechner, J. Apostolakis, M. Asai, G. Cosmo and A. Howard

Part I: Sensitive Detectors

Sensitive Detector (SD)

- A logical volume becomes sensitive if it has a pointer to a **sensitive detector** (**`G4VSensitiveDetector`**)
  - A sensitive detector can be instantiated several times, where the instances are assigned to different logical volumes
    - Note that 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 many functionalities)
- Two possibilities to make use of the SD functionality:
  - Create your own sensitive detector (using class inheritance → see next slides)
    - Highly **customizable**
  - Use Geant4 built-in tools: Primitive scorers

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", 1.0 * cm, 1.0 * cm, 1.0 * cm);

G4LogicalVolume* boxLog =
    new  G4LogicalVolume( boxSolid, matSilicon, "aBoxLog", 0, 0, 0);

G4VSensitiveDetector* sensitiveBox =
                                  new MySensitiveDetector("/MyDetector");   } create instance
G4SDManager* SDManager = G4SDManager::GetSDMPointer();
 SDManager -> AddNewDetector(sensitiveBox);   } register to SD manager
 boxLog -> SetSensitiveDetector(sensitiveBox);   } assign to logical volume
```

Part II: User-defined sensitive detectors: Hits and Hits Collection

The ingredients of user SD

- A powerful and flexible way of extracting information from the physics simulation is to **define your own SD**
- Derive **your own concrete classes** from the base classes and customize them according to your needs

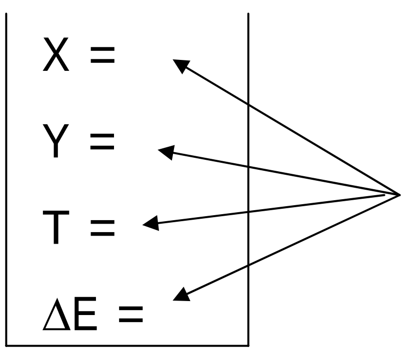
	Concrete class	Base class
Sensitive Detector	MySensitiveDetector	G4VSensitiveDetector
Readout geometry	MyROGeometry (opt)	G4VReadoutGeometry
Hit	MyHit	G4VHit
		Template class
Hits collection		G4THitsCollection<MyHit*>

Hit class - 1

- Hit is a user-defined class which derives from the base class **`G4VHit`**. Two virtual methods
  - `Draw()`
  - `Print()`
- You can store various types of information by implementing your own concrete Hit class
- Typically, one may want to record information like
  - Position, time and ΔE of a step
  - Momentum, energy, position, volume, particle type of a given track
  - Etc.

Hit class - 2

A “Hit” is like a “container”, a **empty box** which contains the information retrieved step by step



The Hit **concrete class** (derived by **`G4VHit`**) must be written by the user: the user must decide **which variables** and/or information the hit should store and **when** store them

The Hit objects are **created** and **filled** by the **`SensitiveDetector`** class (invoked at each step in detectors defined as sensitive). **Stored** in the “**HitCollection**”, attached to the **`G4Event`**: can be retrieved at the EndOfEvent

Hit class - 3

Example

```
// header file: MyHit.hh

#include "G4VHit.hh"

class MyHit : public G4VHit {

 public:
   MyHit();
   virtual ~MyHit();
  ...

   inline void SetEnergyDeposit(G4double energy) { energyDeposit = energy; }

   inline G4double GetEnergyDeposit() { return energyDeposit;}

  ... // more get and set methods

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

public methods to handle data member

data member (private)

Geant4 Hits

Since in the simulation one may have different sensitive detectors in the same setup (e.g. a calorimeter and a Si detector), it is possible to define **many Hit classes** (all derived by **`G4VHit`**) storing different information

X =
Y =
T =
ΔE =

Class Hit1 : public G4VHit

Z =
Pos =
Dir =

Class Hit2 : public G4VHit

Hits Collection - 1

At each step in a detector defined as sensitive, the method **`ProcessHit()`** of the user SensitiveDetector class is inkoved: it must **create**, **fill** and **store** the Hit objects

Step 1	Step 2	Step 3	.....	Step N
X = 1	X = 2	X = 3		X = 3
Y = 2	Y = 0	Y = 2		Y = 2
T =3	T =3.1	T =4		T =6
ΔE = 1	ΔE = 2	ΔE = 3		ΔE = 1

Hits collection (= vector<Hit>)

Hits Collection - 2

- Once created in the sensitive detectors, objects of the concrete hit class **must be stored** in a **dedicated collection**
  - Template class **`G4THitsCollection<MyHit>`**, which is actually an array of **`MyHit*`**
- The hits collections can be accesses in different phases of tracking
  - At the end of each event, through the `G4Event` (*a-posteriori event analysis*)
  - During event processing, through the Sensitive Detectr Manager `G4SDManager` (*event filtering*)

The HCofThisEvent

Remember that you may have **many kinds of Hits** (and Hits Collections)

X = 1
Y = 2
T =3
ΔE = 1

X = 2
Y = 0
T =3.1
ΔE = 2

X = 3
Y = 2
T =4
ΔE = 3

.....

X = 3
Y = 2
T =6
ΔE = 1

Z = 5
Pos = (0,1,1)
Dir =(0,1,0)

Z = 5.2
Pos = (0,0,1)
Dir =(1,1,0)

.....

Z = 5.4
Pos = (0,1,2)
Dir =(0,1,1)

HCofThisEvent

Attached to `G4Event*`

Hits Collections of an event

- A `G4Event` object has a `G4HCofThisEvent` object at the end of the event processing (if it was successful)
  - The pointer to the `G4HCofThisEvent` object can be retrieved using the **`G4Event::GetHCofThisEvent()`** method
- The `G4HCofThisEvent` stores all hits collections creted within the event
  - Hits collections are accessible and can be processes e.g. in the `EndOfEventAction()` method of the User Event Action class

SD and Hits

- Using information from particle steps, a sensitive detector either
  - constructs, fills and stores one (or more) **hit object**
  - accumulates values to existing hits
- Hits objects can be filled with information in the **`ProcessHits()`** method of the SD concrete user class → next slides
  - This method has pointers to the current **`G4Step`** and to the **`G4TouchableHistory`** of the ReadOut geometry (if defined)

Sensitive Detector (SD)

- A specific feature to Geant4 is that a user can provide his/her own implementation of the detector and **its response** → customized

- 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 (see also next slide):
    - **`Initialize()`**
    - **`ProcessHits()`** (Invoked for each step if step starts in logical volume having the SD attached)
    - **`EndOfEvent()`**

Sensitive Detector

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

abstract base class

pure virtual method

```
// 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;
    G4int collectionID;
};
```

User concrete SD class

SD implementation: constructor

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

```
MySensitiveDetector::MySensitiveDetector(G4String detectorUniqueName)
                        : G4VSensitiveDetector(detectorUniquename),
                          collectionID(-1) {

  collectionName.insert(“collection_name");
}
```

Base class

```
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
 ...
};
```

SD implementation: Initialize()

- The `Initialize()` method is invoked at the beginning of each event
- Construct all hits collections and insert them in the `G4HCofThisEvent` object, 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 collect.
                                          // as stored in the collectionName
  hitsCollection = new MyHitsCollection
                  (SensitiveDetectorName, collectionName[0]);

  HCE -> AddHitsCollection(collectionID, hitsCollection);
}
```

SD implementation: ProcessHits()

- This **`ProcessHits()`** method is invoked for every step in the volume(s) which hold a pointer to this SD (= each volume defined as "**sensitive**")
- 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"

```
G4bool MySensitiveDetector::ProcessHits(G4Step* step,
                                        G4TouchableHistory*ROhist) {
  MyHit* hit = new MyHit();      // 1) create hit
...
  // some set methods, e.g. for a tracking detector:
  G4double energyDeposit = step -> GetTotalEnergyDeposit();    // 2) fill hit
  hit -> SetEnergyDeposit(energyDeposit); // See implement. of our Hit class
...
  hitsCollection -> insert(aHit);  // 3) insert in the collection
  return true;
}
```

SD implementation: EndOfEvent()

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

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

Processing hit information - 1

- Retrieve the pointer of a hits collection with the **`GetHC()`**method of `G4HCofThisEvent` collection using the collection index (a G4int number)
- Index numbers of a hit collection are **unique** and don't change for a run. The number can be obtained by **`G4SDManager::GetCollectionID("name");`**
- Notes:
  - if the collection(s) are not created, the pointers of the collection(s) are **NULL**: **check** before trying to access it
  - Need an explicit cast from `G4VHitsCollection` (see code)

Processing hit information - 2

- Loop through the entries of a hits collection to **access individual hits**
  - Since the HitsCollection is a vector, you can use the **[] operator** to get the hit object corresponding to a given index
- **Retrieve** the information contained in this hit (e.g. using the Get/Set methods of the concrete user Hit class) and process it
- Store the output in analysis objects

Process hit: example

```
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* hitsColl = 0;
 if(HCE)  hitsColl = (MyHitsCollection*)(HCE->GetHC(index));

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

   for(int i1= 0; i1 < numberHits ; i1++) {
     MyHit* hit = (*hitsColl)[i1];
     // Retrieve information from hit object, e.g.
     G4double energy = hit -> GetEnergyDeposit;
     ... // Further process and store information
   }
 }
}
```

retrieve index

retrieve all hits collections

retrieve hits collection by index

cast

loop over individual hits, retrieve the data

The HCofThisEvent

Remember that you may have **many kinds of Hits** (and Hits Collections)

X = 1
Y = 2
T =3
ΔE = 1

X = 2
Y = 0
T =3.1
ΔE = 2

X = 3
Y = 2
T =4
ΔE = 3

.....

X = 3
Y = 2
T =6
ΔE = 1

Z = 5
Pos = (0,1,1)
Dir =(0,1,0)

Z = 5.2
Pos = (0,0,1)
Dir =(1,1,0)

.....

Z = 5.4
Pos = (0,1,2)
Dir =(0,1,1)

HCofThisEvent

Attached to `G4Event*`

Recipe and strategy - 1

- Create your detector geometry
  - Solids, logical volumes, physical volumes
- Implement a sensitive detector and assign an instance of it to the ***logical volume*** of your geometry set-up
  - Then this volume becomes "sensitive"
  - Sensitive detectors are active for each particle steps, if the step starts in this volume
- Optionally, implement a read-out geometry and attach it to the sensitive detector

Recipe and strategy - 2

- Create hits objects in your sensitive detector using information from the particle step
  - You need to create the hit class(es) according to **your requirements**
  - Use Touchable of the read-out geometry to retrieve geometrical info associated with this
- **Store** hits in hits collections (automatically associated to the `G4Event` object)
- Finally, process the information contained in the hit in user action classes (e.g. **`G4UserEventAction`**) to obtain results to be stored in the analysis object

Part III: Native Geant4 scoring

Extract useful information

- Alternatively to user-defined sensitive detectors, primitive scorers provided by Geant4 can be used
- Geant4 provides a number of **primitive scorers**, each one accumulating one physics quantity (e.g. total dose) for an event
- It is convenient to use primitive scorers instead of user-defined sensitive detectors when:
  - you are not interested in recording each individual step, but accumulating physical quantities for an event or a run
  - you have not too many scorers

G4MultiFunctionalDetector

- **`G4MultiFunctionalDetector`** is a concrete class derived from **`G4VSensitiveDetector`**
- It should be **assigned to a logical volume** as a **kind of** (ready-for-the-use) **sensitive detector**
- It takes an arbitrary number of `G4VPrimitiveSensitivity` classes, to define the scoring quantities that you need
  - Each `G4VPrimitiveSensitivity` accumulates one physics quantity for each physical volume
  - E.g. `G4PSDoseScorer` (a concrete class of `G4VPrimitiveSensitivity` provided by Geant4) accumulates dose for each cell
- By using this approach, **no need to implement sensitive detector** and **hit classes**!

G4VPrimitiveSensitivity

- Primitive scorers (classes derived from G4VPrimitiveSensitivity) have to be registered to the `G4MultiFunctionalDetector`
- They are designed to **score one kind of quantity** (surface flux, total dose) and to **generate one hit collection** per event
  - automatically named as

    `<MultiFunctionalDetectorName>/<PrimitiveScorerName>`
  - hit collections can be retrieved in the EventAction or RunAction (as those generated by sensitive detectors)
  - do **not** share the same primitive score object among multiple G4MultiFunctionalDetector objects (results may mix up!)

For example ...

```
MyDetectorConstruction::Construct()
{ …  G4LogicalVolume* myCellLog =  new G4LogicalVolume(…);
    G4MultiFunctionalDetector* myScorer = new
      G4MultiFunctionalDetector("myCellScorer");
    G4SDManager::GetSDMpointer()->
      AddNewDetector(myScorer);
    myCellLog->SetSensitiveDetector(myScorer);
    G4VPrimitiveSensitivity* totalSurfFlux = new
      G4PSFlatSurfaceFlux("TotalSurfFlux");
    myScorer->Register(totalSurfFlux);
    G4VPrimitiveSensitivity* totalDose = new
      G4PSDoseDeposit("TotalDose");
    myScorer->Register(totalDose);
}
```

instantiate multi-functional detector and register in the SD manager

attach to volume

create a primitive scorer (surface flux) and register it

create a primitive scorer (total dose) and register it

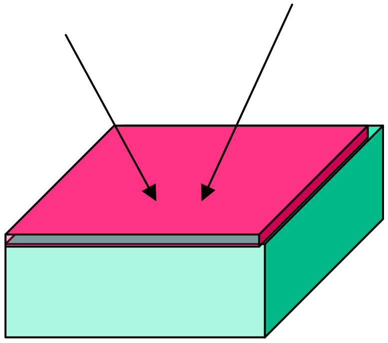
Some primitive scorers that you may find useful

- Concrete Primitive Scorers (→ Application Developers Guide 4.4.6)
  - Track length
    - G4PSTrackLength, G4PSPassageTrackLength
  - Deposited energy
    - G4PSEnergyDepsit, G4PSDoseDeposit
  - Current/Flux
    - G4PSFlatSurfaceCurrent, G4PSSphereSurfaceCurrent,G4PSPassageCurrent, G4PSFlatSurfaceFlux, G4PSCellFlux, G4PSPassageCellFlux
  - Others
    - G4PSMinKinEAtGeneration, G4PSNofSecondary, G4PSNofStep, G4PSCellCharge

A closer look at some scorers

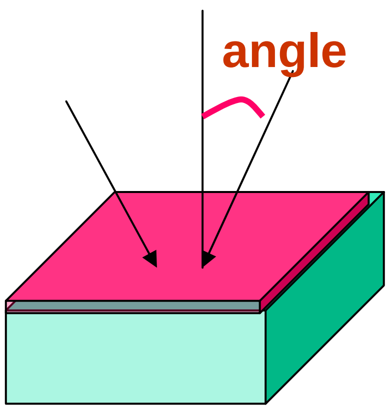
SurfaceCurrent :

Count number of injecting particles at defined surface.



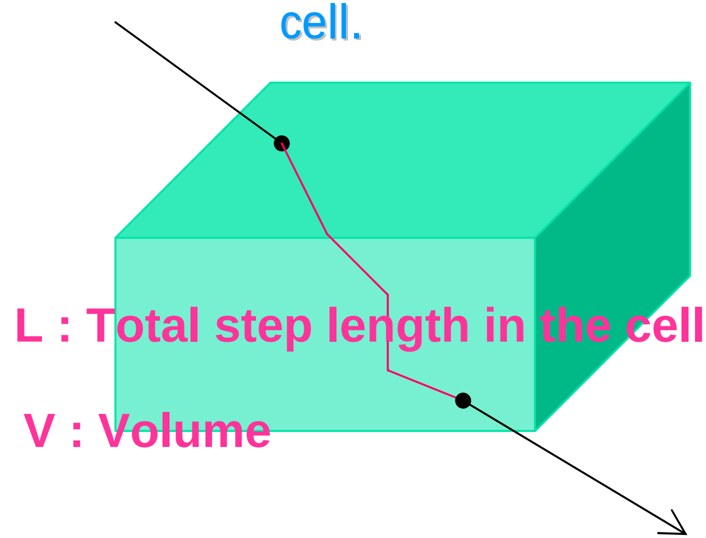
CellFlux :

Sum of L / V of injecting particles in the geometrical cell.



SurfaceFlux :

Sum up 1/cos(angle) of injecting particles at defined surface



V : Volume

G4VSDFilter

- A **`G4VSDFilter`** can be attached to `G4VPrimitiveSensitivity` to define **which kind of tracks** have to be scored (e.g. one wants to know surface flux of protons only)
  - `G4SDChargeFilter` (accepts only charged particles)
  - `G4SDNeutralFilter` (accepts only neutral particles)
  - `G4SDKineticEnergyFilter` (accepts tracks in a defined range of kinetic energy)
  - `G4SDParticleFilter` (accepts tracks of a given particle type)
  - `G4VSDFilter` (base class to create user-customized filters)

For example ...

```
MyDetectorConstruction::Construct()
{
   G4VPrimitiveSensitivity* protonSurfFlux
   = new G4PSFlatSurfaceFlux("pSurfFlux");
    G4VSDFilter* protonFilter = new
      G4SDParticleFilter("protonFilter");
    protonFilter->Add("proton");

    protonSurfFlux->SetFilter(protonFilter);

    myScorer->Register(protonSurfFlux);
}
```

create a primitive scorer (surface flux), as before

create a particle filter and add protons to it

register the filter to the primitive scorer

register the scorer to the multifunc detector (as shown before)

Command-based scoring

Under development!

Thanks to the newly developed parallel navigation, an **arbitrary scoring mesh geometry** can be defined which is independent to the volumes in the mass geometry. Also, G4MultiFunctionalDetector and primitive scorer classes now offer the built-in scoring of most-common quantities

UI commands for scoring → no C++ required, apart from instantiating `G4ScoringManager` in `main()`

- Define a scoring mesh
  - /score/create/boxMesh <mesh_name>
  - /score/open, /score/close
- Define mesh parameters
  - /score/mesh/boxsize <dx> <dy> <dz>
  - /score/mesh/nbin <nx> <ny> <nz>
  - /score/mesh/translate,
- Define primitive scorers
  - /score/quantity/eDep <scorer_name>
  - /score/quantity/cellFlux <scorer_name>
  - currently **20 scorers** are available
- Define filters
  - /score/filter/particle <filter_name> <particle_list>
  - /score/filter/kinE <filter_name> <Emin> <Emax> <unit>
  - currently **5 filters** are available
- Output
  - /score/draw <mesh_name> <scorer_name>
  - /score/dump, /score/list

How to learn more about built-in scoring

Have a look at the **dedicated extended examples** released with Geant4:

examples/extended/runAndEvent/RE02

(use of primitive scorers)

examples/extended/runAndEvent/RE03

(use of UI-based scoring)

Part IV: Summary and outlook

Conclusions

- Indeed, the final goal of any MC simulation is to retrieve physical information
- Geant4 provides a **powerful** and **flexible** system to retrieve and score information during the run
  - Based on
    - Sensitive Detectors (attached to logical volumes)
    - Hits
    - Hits Collections (attached to the G4Event)
  - Require **concrete classes** written by the user to work
- An other possibility is to use built-in Geant4 scorers
  - Less work to do but much less flexible
  - Suggested only in case you need a limited amount of information and/or for a restricted scope