Basic Concepts and Structure of Geant4

Shigeyuki Tajima

Duke/NCCU and TUNL

Slides courtesy of SLAC GEANT4 Team
Special thanks to Makoto Asai

GEANT4 Terminology

- The following keywords are often used in GEANT4:
  - Run, Event, Track, Step ...
  - Processes: (At rest, Along step, post step)
  - Cut (Production threshold)

This slide based on a SLAC Geant4 tutorial slide

Run in Geant4

- As an analogy of the real experiment, a run of Geant4 starts with “Beam On”.
- Within a run, the user cannot change
  - detector setup
  - settings of physics processes
- Conceptually, a run is a collection of events which share the same detector and physics conditions.
  - A run consists of one event loop.
- At the beginning of a run, geometry is optimized for navigation and cross-section tables are calculated according to materials appear in the geometry and the cut-off values defined.
- G4RunManager class manages processing a run, a run is represented by G4Run class or a user-defined class derived from G4Run.
  - A run class may have a summary results of the run.
- G4UserRunAction is the optional user hook.

Slide from SLAC Geant4 tutorial course in ‘06

Event in Geant4

- An event is the basic unit of simulation in Geant4.
- At beginning of processing, primary tracks are generated. These primary tracks are pushed into a stack.
- A track is popped up from the stack one by one and "tracked". Resulting secondary tracks are pushed into the stack.
  - This "tracking" lasts as long as the stack has a track.
- When the stack becomes empty, processing of one event is over.
- G4Event class represents an event. It has following objects at the end of its (successful) processing.
  - List of primary vertices and particles (as input)
  - Hits and Trajectory collections (as output)
- G4EventManager class manages processing an event. G4UserEventAction is the optional user hook.

Slide from SLAC Geant4 tutorial course in '06

Track in Geant4

- Track is a snapshot of a particle.
  - It has physical quantities of current instance only. It does not record previous quantities.
  - Step is a "delta" information to a track. Track is not a collection of steps. Instead, a track is being updated by steps.
- Track object is deleted when
  - it goes out of the world volume,
  - it disappears (by e.g. decay, inelastic scattering),
  - it goes down to zero kinetic energy and no "AtRest" additional process is required, or
  - the user decides to kill it artificially.
- No track object persists at the end of event.
  - For the record of tracks, use trajectory class objects.
- G4TrackingManager manages processing a track, a track is represented by G4Track class.
- G4UserTrackingAction is the optional user hook.

Slide from SLAC Geant4 tutorial course in '06

Run, Event and Tracks

- One Run consists of:

  Event #1 (track #1, #2, ... track $\#N_1$)

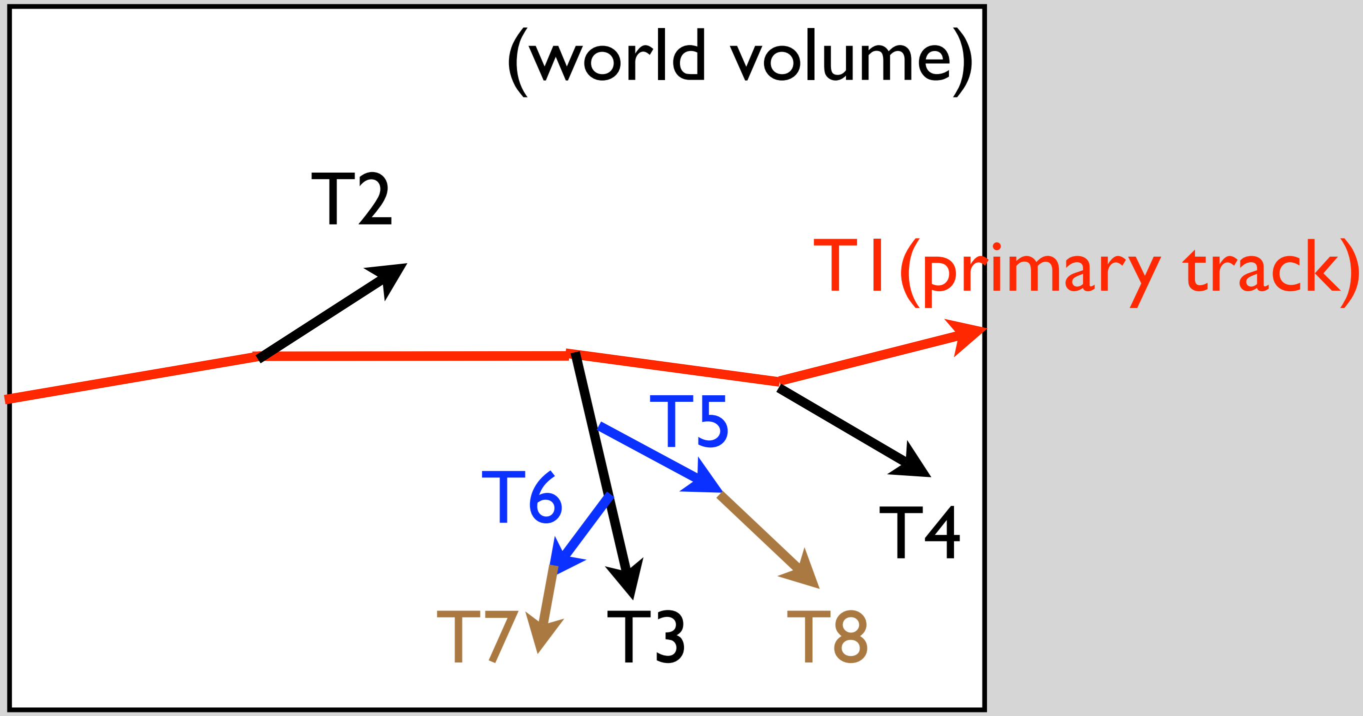
  Event #2 (track #1, #2, ... track $\#N_2$)

  ...

  ...

  Event #N (track #1, #2, ... track $\#N_N$)

A Event and Tracks (example)

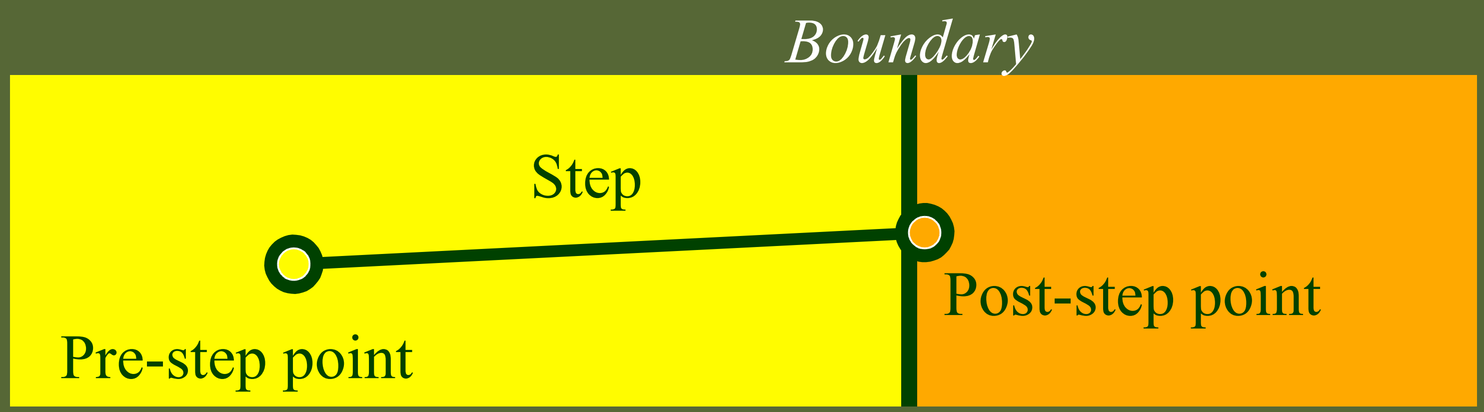


- Tracking order follows ‘last in first out’ rule:

T1 ->T4 -> T3 ->T6->T7 -> T5 ->T8-> T2

Step in Geant4

- Step has two points and also "delta" information of a particle (energy loss on the step, time-of-flight spent by the step, etc.).
- Each point knows the volume (and material). In case a step is limited by a volume boundary, the end point physically stands on the boundary, and it logically belongs to the next volume.
  - Because one step knows materials of two volumes, boundary processes such as transition radiation or refraction could be simulated.
- G4SteppingManager class manages processing a step, a step is represented by G4Step class.
- G4UserSteppingAction is the optional user hook.



Slide from SLAC Geant4 tutorial course in '06

Particle in Geant4

- Particle in general has the following three properties:
  - Particle position, geometrical info
    ==> G4Track class (representing a particle to be tracked)
  - Dynamic properties (momentum, energy, spin, etc)
    ==> G4DynamicParticle class (representing an individual particle)
  - Static properties (rest mass, charge, life time, etc)
    ==> G4ParticleDefinition class
- All G4DynamicParticle objects of the same kind of particle share the same G4ParticleDefinition

This slide based on a SLAC Geant4 tutorial slide

Processes in Geant4

- In Geant4, particle transportation is a process as well, by which a particle interacts with geometrical volume boundaries and field of any kind.
  - Because of this, shower parameterization process can take over from the ordinary transportation without modifying the transportation process.
- Each particle has its own list of applicable processes. At each step, all processes listed are invoked to get proposed physical interaction lengths.
- The process which requires the shortest interaction length (in space-time) limits the step.
- Each process has one or combination of the following natures.
  - AtRest
    - e.g. muon decay at rest
  - AlongStep (a.k.a. continuous process)
    - e.g. Celenkov process
  - PostStep (a.k.a. discrete process)
    - e.g. decay on the fly

Slide from SLAC Geant4 tutorial course in '06

Cuts in Geant4

- A Cut in Geant4 is a production threshold.
  - Not tracking cut, which does not exist in Geant4 as default.
    - All tracks are traced down to zero kinetic energy.
  - It is applied only for physics processes that have infrared divergence
- Much detail will be given at later talks on physics.

Slide from SLAC Geant4 tutorial course in '06

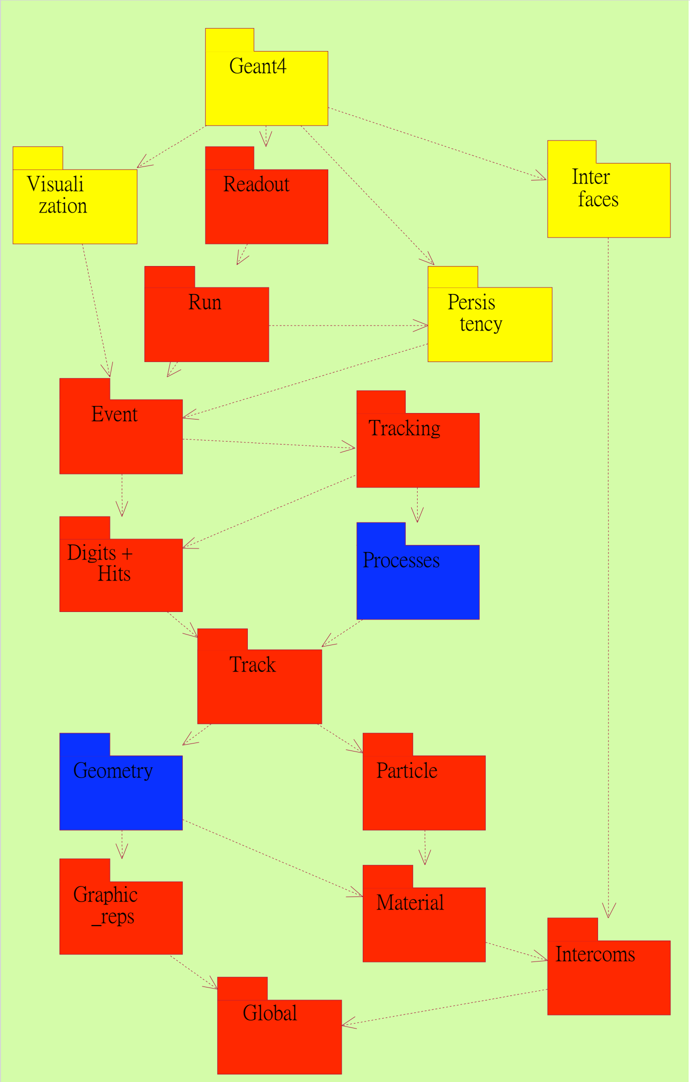
Extract useful information

- Given geometry, physics and primary track generation, Geant4 does proper physics simulation "silently".
  - You have to add a bit of code to extract information useful to you.
- There are two ways:
  - Use user hooks (G4UserTrackingAction, G4UserSteppingAction, etc.)
    - You have an access to almost all information
    - Straight-forward, but do-it-yourself
  - Use Geant4 scoring functionality
    - Assign G4VSensitiveDetector to a volume
    - Hits collection is automatically stored in G4Event object, and automatically accumulated if user-defined Run object is used.
    - Use user hooks (G4UserEventAction, G4UserRunAction) to get event / run summary

Slide from SLAC Geant4 tutorial course in '06

GEANT4 Kernel

- Geant4 consists of 17 categories
    - Each category is independently maintained by a working group
- Geant4 Kernel:
    - Handles run, event, track, step, hit, trajectory
    - Provides a frameworks of geometrical representation and physics process



This slide based on a SLAC Geant4 tutorial slide

Unit system

- Internal unit system used in Geant4 is completely hidden not only from user's code but also from Geant4 source code implementation.
- Each hard-coded number must be multiplied by its proper unit.

```
radius = 10.0 * cm;

kineticE = 1.0 * GeV;
```

- To get a number, it must be divided by a proper unit.

```
G4cout << eDep / MeV << " [MeV]" << G4endl;
```

- Most of commonly used units are provided and user can add his/her own units.
- By this unit system, source code becomes more readable and importing / exporting physical quantities becomes straightforward.
  - For particular application, user can change the internal unit to suitable alternative unit without affecting to the result.

Slide from SLAC Geant4 tutorial course in '06

Partial List of Available Units in GEANT4

- g, kg, mg, ...
- mm, cm, m, km, angstrom, fermi, cm2, m3, barn, ...
- s, ms, ns ...
- degree, radian, steradian, rad, mrad ...
- watt, newton, joule, eV, keV, MeV, GeV...
- kilovolt, volt, megavolt, ohm ...
- ampere, milliampere, microampere, nanoampere...
- weber, tesla, gauss, kilogauss, henry, farad...
- hertz, kilohertz, megahertz ...
- perCent
- kelvin, mole...

- Complete list of units is given in G4SystemOfUnits.hh

Basic types in GEANT4

- For basic types, different compiles and platforms use different value ranges. To make a program portable, the following basic types are used in GEANT4:

  G4int

  G4long

  G4double

  G4bool

  G4complex

  G4String

- These consists of simple ‘typedefs’ to respective types in CLHEP (Computing Libraries for High Energy Physics), etc

G4cout, G4cerr

- G4cout and G4cerr are ostream objects defined by Geant4.
  - G4endl is also provided.

```
G4cout << "Hello Geant4!" << G4endl;
```

- Some GUIs are buffering output streams so that they display print-outs on another window or provide storing / editing functionality.
  - The user should not use std::cout, etc.
- The user should not use std::cin for input. Use user-defined commands provided by intercoms category in Geant4.
  - Ordinary file I/O is OK.

To use Geant4, you have to…

- Geant4 is a toolkit. You have to build an application.
- To make an application, you have to
  - Define your geometrical setup
    - Material, volume
  - Define physics to get involved
    - Particles, physics processes/models
    - Production thresholds
  - Define how an event starts
    - Primary track generation
  - Extract information useful to you
- You may also want to
  - Visualize geometry, trajectories and physics output
  - Utilize (Graphical) User Interface
  - Define your own UI commands
  - etc.

Slide from SLAC Geant4 tutorial course in ‘06

User classes

- main()
  - Geant4 does not provide main().
- Initialization classes
  - Use G4RunManager::SetUserInitialization() to define.
  - Invoked at the initialization
    - G4VUserDetectorConstruction
    - G4VUserPhysicsList
- Action classes
  - Use G4RunManager::SetUserAction() to define.
  - Invoked during an event loop
    - G4VUserPrimaryGeneratorAction
    - G4UserRunAction
    - G4UserEventAction
    - G4UserStackingAction
    - G4UserTrackingAction
    - G4UserSteppingAction

Note : classes written in yellow are mandatory.

Slide from SLAC Geant4 tutorial course in ‘06

The main program

- Geant4 does not provide the main().
- In your main(), you have to
  - Construct G4RunManager (or your derived class)
  - Set user mandatory classes to RunManager
    - G4VUserDetectorConstruction
    - G4VUserPhysicsList
    - G4VUserPrimaryGeneratorAction
- You can define VisManager, (G)UI session, optional user action classes, and/or your persistency manager in your main().

Slide from SLAC Geant4 tutorial course in '06

Three Mandatory Classes

- Three important classes that users must implement:
  - Define material and geometry
    ==> G4VUserDetectorConstruction class
  - Select appropriate particles and processes and define production threshold(s)
    ==> G4VUserPhysicsList class
  - Define the way of primary particle generation
    ==> G4VUserPrimaryGeneratorAction class

 This slide based on a SLAC Geant4 tutorial slide

Describe your detector

- Derive your own concrete class from G4VUserDetectorConstruction abstract base class.
- In the virtual method Construct(),
  - Instantiate all necessary materials
  - Instantiate volumes of your detector geometry
  - Instantiate your sensitive detector classes and set them to the corresponding logical volumes
- Optionally you can define
  - Regions for any part of your detector
  - Visualization attributes (color, visibility, etc.) of your detector elements

Slide from SLAC Geant4 tutorial course in ‘06

Select physics processes

- Geant4 does not have any default particles or processes.
  - Even for the particle transportation, you have to define it explicitly.
- Derive your own concrete class from G4VUserPhysicsList abstract base class.
  - Define all necessary particles
  - Define all necessary processes and assign them to proper particles
  - Define cut-off ranges applied to the world (and each region)
- Geant4 provides lots of utility classes/methods and examples.
  - "Educated guess" physics lists for defining hadronic processes for various use-cases.

Slide from SLAC Geant4 tutorial course in '06

Generate primary event

- Derive your concrete class from G4VUserPrimaryGeneratorAction abstract base class.
- Pass a G4Event object to one or more primary generator concrete class objects which generate primary vertices and primary particles.
- Geant4 provides several generators in addition to the G4VPrimaryParticlegenerator base class.
  - G4ParticleGun
  - G4HEPEvtInterface, G4HepMCInterface
    - Interface to /hepevt/ common block or HepMC class
  - G4GeneralParticleSource
    - Define radioactivity

Slide from SLAC Geant4 tutorial course in ‘06

Summary

- GEANT4 is a toolkit which consists of 17 categories.
- Run consists of Events, Tracks, and Steps.
- Track is a ‘snapshot’ of a particle:
- Particle is tracked until zero kinetic energy (production threshold must be set)
- Users need to implement three mandatory classes for materials&geometry, selecting physics processes, and primary particle generation

This slide based on a SLAC Geant4 tutorial slide