IEEE Nuclear Science Symposium and Medical Imaging Conference

Short Course

Simulation Techniques Using Geant4

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http://www.ge.infn.it/geant4/events/nss2008/geant4course.html

This course exploits training material developed by several Geant4 Collaboration members: thanks to all of them!

Geant4 User Application

Basic concepts of developing a Geant4-based simulation application

Toolkit + User application

- Geant4 is a **toolkit**
  - i.e. you cannot “run” it out of the box
  - You must write an application, which uses Geant4 tools
- Consequences
  - There are no such concepts as “Geant4 defaults”
  - You must provide the necessary information to configure your simulation
  - You must deliberately choose which Geant4 tools to use
- Guidance: we provide many **examples**
  - **Novice Examples**: overview of Geant4 tools
  - **Advanced Examples**: Geant4 tools in real-life applications

Basic concepts

- What you **MUST** do:
  - Describe your **experimental set-up**
  - Provide the **primary particles** input to your simulation
  - Decide which **particles** and **physics models** you want to use out of those available in Geant4 and the precision of your simulation (cuts to produce and track secondary particles)

- You may also want
  - To interact with Geant4 kernel to **control** your simulation
  - To **visualise** your simulation configuration or results
  - To produce **histograms, tuples** etc. to be further analysed

Interaction with Geant4 kernel

- Geant4 design provides **tools** for a user application
  - To tell the kernel about your simulation configuration
  - To interact with Geant4 kernel itself
- Geant4 tools for user interaction are **base classes**
  - You create **your own concrete class** derived from the base classes
  - Geant4 kernel handles your own derived classes transparently through their base class interface (polymorphism)
- **Abstract base classes** for user interaction
  - User derived concrete classes are **mandatory**
- **Concrete base classes** (with virtual dummy methods) for user interaction
  - User derived classes are **optional**

User classes

Initialisation classes

- *G4VUserDetectorConstruction*
- *G4VUserPhysicsList*

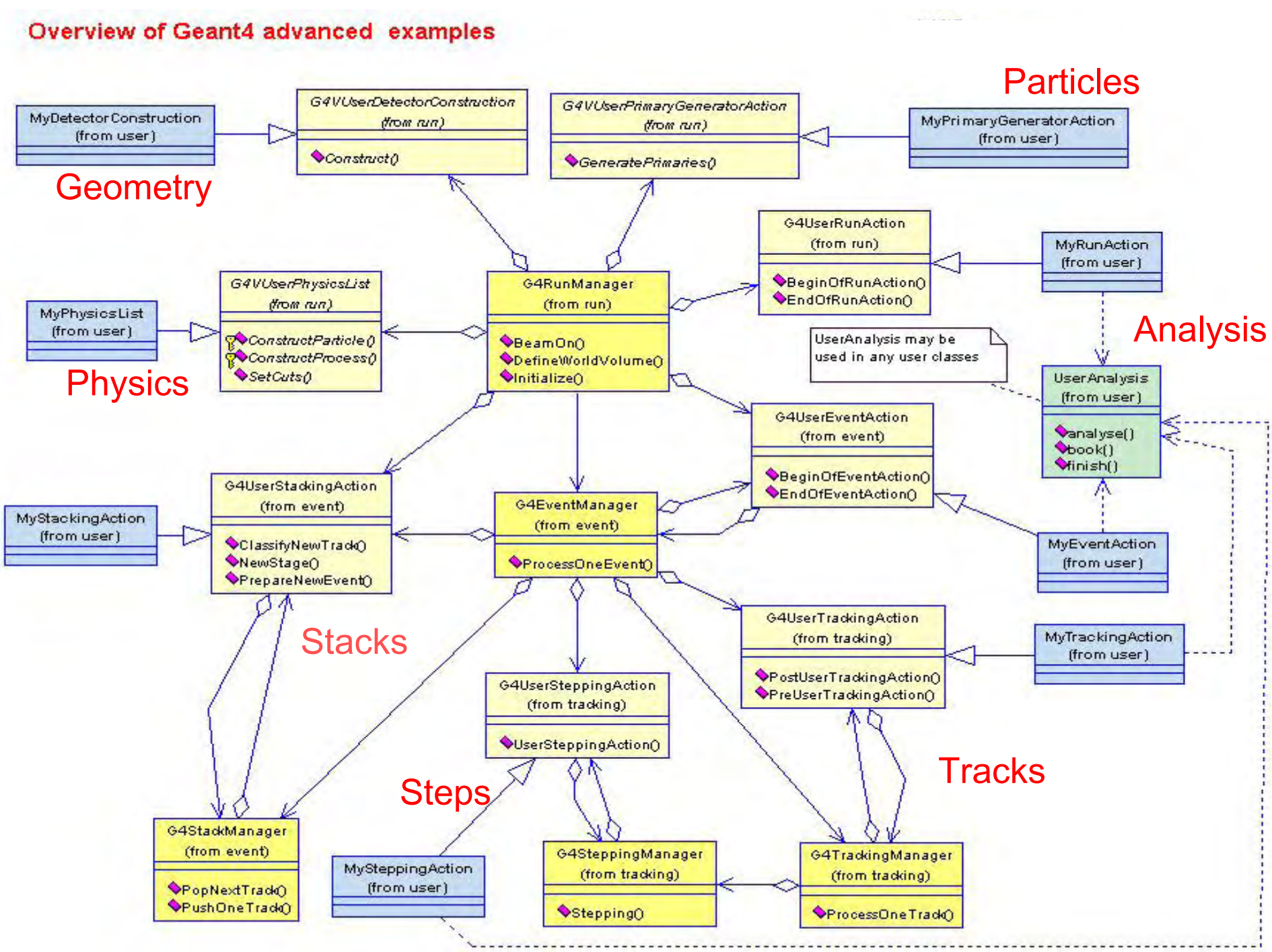
Action classes

Invoked during the execution loop

- *G4VUserPrimaryGeneratorAction*
- G4UserRunAction
- G4UserEventAction
- G4UserTrackingAction
- G4UserStackingAction
- G4UserSteppingAction

Mandatory classes:

- *G4VUserDetectorConstruction*
  describe the experimental set-up
- *G4VUserPhysicsList*
  select the physics you want to activate
- *G4VUserPrimaryGeneratorAction*
  generate primary events


Overview of Geant4 advanced examples
Particles
MyDetectorConstruction
(from user)
G4VUserDetectorConstruction
(from run)
Construct()
G4VUserPrimaryGeneratorAction
(from run)
GeneratePrimaries()
MyPrimaryGeneratorAction
(from user)
Geometry
G4UserRunAction
(from run)
BeginOfRunAction()
EndOfRunAction()
MyRunAction
(from user)
G4VUserPhysicsList
(from run)
ConstructParticle()
ConstructProcess()
SetCuts()
G4RunManager
(from run)
BeamOn()
DefineWorldVolume()
Initialize()
MyPhysicsList
(from user)
Analysis
UserAnalysis may be
used in any user classes
UserAnalysis
(from user)
analyse()
book()
finish()
Physics
G4UserEventAction
(from event)
BeginOfEventAction()
EndOfEventAction()
G4UserStackingAction
(from event)
ClassifyNewTrack()
NewStage()
PrepareNewEvent()
G4EventManager
(from event)
ProcessOneEvent()
MyStackingAction
(from user)
MyEventAction
(from user)
G4UserTrackingAction
(from tracking)
PostUserTrackingAction()
PreUserTrackingAction()
MyTrackingAction
(from user)
Stacks
G4UserSteppingAction
(from tracking)
UserSteppingAction()
Tracks
Steps
G4StackManager
(from event)
PopNextTrack()
PushOneTrack()
MySteppingAction
(from user)
G4SteppingManager
(from tracking)
Stepping()
G4TrackingManager
(from tracking)
ProcessOneTrack()

Development of a Geant4 application

- The following slides provide an overview of the basic concepts of a Geant4 user application

- Your application development will be greatly facilitated, if you adopt a sound **software process**
  - Vision of your simulation, clear user requirements
  - Documented architecture and detailed software design
  - Test process at various levels (unit, integration, system…)
  - Well defined, documented procedures
  - An iterative and incremental process to achieve your goals
  - etc.
- *We will not teach you software process in this course*
  - *(but we could in another course, if you are interested)*

The main function

- Geant4 does not provide the **main()**
  - Geant4 is a toolkit!
  - The main() is part of the user application
- In his/her main(), the user **must**
  - construct **G4RunManager** (or his/her own derived class)
  - notify the G4RunManager mandatory user classes derived from
    - ***G4VUserDetectorConstruction***
    - ***G4VUserPhysicsList***
    - ***G4VUserPrimaryGeneratorAction***
- The user may define in his/her main()
  - optional user action classes
  - VisManager, (G)UI session

main()

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

 // Set mandatory user initialization classes
  MyDetectorConstruction* detector = new MyDetectorConstruction;
  runManager->SetUserInitialization(detector);
  MyPhysicsList* physicsList = new MyPhysicsList;
  runManager->SetUserInitialization(myPhysicsList);

  // Set mandatory user action classes
  runManager->SetUserAction(new MyPrimaryGeneratorAction);

  // Set optional user action classes
  MyEventAction* eventAction = new MyEventAction();
   runManager->SetUserAction(eventAction);
  MyRunAction* runAction = new MyRunAction();
   runManager->SetUserAction(runAction);
  …
}
```

Describe the experimental set-up

- Derive your own concrete class from the ***G4VUserDetectorConstruction*** abstract base class

- Implement the **Construct()** method
  - construct all necessary **materials**
  - define **shapes/solids** required to describe the geometry
  - **construct** and **place volumes** of your detector geometry
  - define **sensitive detectors** and identify detector volumes to associate them to
  - associate **magnetic field** to detector regions
  - define **visualisation** attributes for the detector elements

How to define materials

Different kinds of materials can be defined

- Isotopes
- Elements
- Molecules
- Compounds and mixtures

```
PVPhysicalVolume*  MyDetectorConstruction::Construct()
 {
   …
   a = 207.19*g/mole;
   density = 11.35*g/cm3;
   G4Material* lead = new G4Material(name="Pb", z=82., a, density);

   density = 5.458*mg/cm3;
   pressure = 1*atmosphere;
   temperature = 293.15*kelvin;
   G4Material* xenon = new G4Material(name="XenonGas", z=54.,
                                      a=131.29*g/mole, density,
                                      kStateGas, temperature, pressure);
   ...
 }
```

Lead

Xenon gas

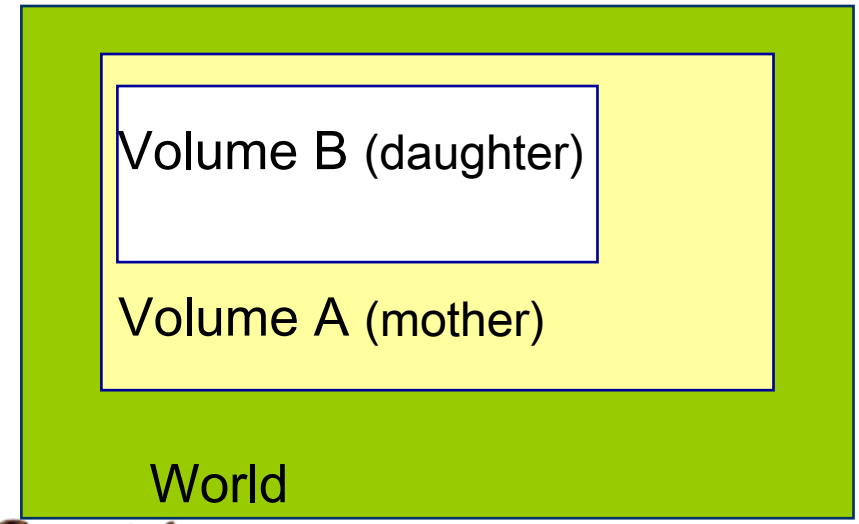
How to define a compound material

For example, a **scintillator** consisting of Hydrogen and Carbon:

```
G4double a = 1.01*g/mole;
G4Element* H  = new G4Element(name="Hydrogen", symbol="H", z=1., a);

a = 12.01*g/mole;
G4Element* C  = new G4Element(name="Carbon", symbol="C", z=6., a);

G4double density = 1.032*g/cm3;
G4Material* scintillator = new G4Material(name = "Scintillator", density,
numberOfComponents = 2);

scintillator -> AddElement(C, numberOfAtoms = 9);
scintillator -> AddElement(H, numberOfAtoms = 10);
```

Define detector geometry

- Three conceptual layers
  - G4VSolid — shape, size
  - G4LogicalVolume — material, sensitivity, magnetic field, etc.
  - G4VPhysicalVolume — position, rotation
- A unique physical volume (the world volume), which represents the experimental area, must exist and fully contain all other components



e.g.: Volume A is mother of Volume B

The mother must contain the daughter volume entirely

How to build the World

```
solidWorld = new G4Box(“World", halfWorldLength, halfWorldLength, halfWorldLength);
logicWorld = new G4LogicalVolume(solidWorld, air, "World", 0, 0, 0);
physicalWorld = new G4PVPlacement(0,                    //no rotation
                                  G4ThreeVector(),      // at (0,0,0)
                                  logicWorld,           // its logical volume
                                  "World",              // its name
                                  0,                    // its mother  volume
                                  false,                // no boolean operations
                                  0);                   // no magnetic field
```

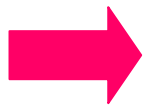
How to build a volume inside the World

```
solidTarget = new G4Box(“Target", targetSize, targetSize, targetSize);
logicTarget = new G4LogicalVolume(solidTarget, targetMaterial, "Target",0,0,0);
physicalTarget = new G4PVPlacement(0,                   // no rotation
                                   positionTarget,      // at (x,y,z)
                                   logicTarget,         // its logical volume
                                   "Target",            // its name
                                   logicWorld,          // its mother  volume
                                   false,               // no boolean operations
                                   0);                  // no particular field
```

Select physics processes

- Geant4 does not have any default particles or processes
- Derive your own concrete class from the ***G4VUserPhysicsList*** abstract base class
  - define all necessary particles
  - define all necessary processes and assign them to proper particles
  - define production thresholds (in terms of range)
- Pure virtual methods of G4VUserPhysicsList

ConstructParticles()
ConstructProcesses()
SetCuts()



to be implemented by the user in his/her concrete derived class

PhysicsList: particles and cuts

```
MyPhysicsList :: MyPhysicsList():  G4VUserPhysicsList()
{
    defaultCutValue = 1.0*cm;
}
```

⟸ Define **production thresholds** (the same for all particles)

```
void MyPhysicsList :: ConstructParticles()
{
    G4Electron::ElectronDefinition();
    G4Positron::PositronDefinition();
    G4Gamma::GammaDefinition();
}
```

⟸ Define the **particles** involved in the simulation

```
void MyPhysicsList :: SetCuts()
{
    SetCutsWithDefault();
}
```

⟸ Set the **production threshold**

PhysicsList: more about cuts

```
MyPhysicsList :: MyPhysicsList():  G4VUserPhysicsList()
{
    // Define production thresholds
    cutForGamma  = 1.0*cm;
    cutForElectron = 1.*mm;
    cutForPositron = 0.1*mm;
} ;
```

```
void MyPhysicsList :: SetCuts()
{
    // Assign production thresholds
    SetCutValue(cutForGamma, "gamma");
    SetCutValue(cutForElectron, "e-");
    SetCutValue(cutForPositron, "e+");
}
```

The user can define different cuts for different particles or different regions

Physics List: processes

```
void MyPhysicsList :: ConstructParticles()
 {
   if (particleName == "gamma")
     {
          pManager->AddDiscreteProcess(new G4PhotoElectricEffect());
          pManager->AddDiscreteProcess(new G4ComptonScattering());
          pManager->AddDiscreteProcess(new G4GammaConversion());
     }
   else if (particleName == "e-")
     {
          pManager->AddProcess(new G4MultipleScattering(), -1, 1,1);
          pManager->AddProcess(new G4eIonisation(), -1, 2,2);
          pManager->AddProcess(new G4eBremsstrahlung(), -1,-1,3);
     }
   else if (particleName == "e+")
     {
          pManager->AddProcess(new G4MultipleScattering(), -1, 1,1);
          pManager->AddProcess(new G4eIonisation(), -1, 2,2);
          pManager->AddProcess(new G4eBremsstrahlung(), -1,-1,3);
          pManager->AddProcess(new G4eplusAnnihilation(),  0,-1,4);
     }
}
```

Select physics processes to be activated for each particle type

The Geant4 *Standard* electromagnetic processes are selected in this example

Primary events

- Derive your own concrete class from the *G4VUserPrimaryGeneratorAction* abstract base class
- Define primary particles providing:
  - Particle type
  - Initial position
  - Initial direction
  - Initial energy
- Implement the virtual member function **GeneratePrimaries()**

Generate primary particles

```
MyPrimaryGeneratorAction:: My PrimaryGeneratorAction()
{
  G4int numberOfParticles = 1;
  particleGun = new G4ParticleGun (numberOfParticles);
  G4ParticleTable* particleTable = G4ParticleTable::GetParticleTable();
  G4ParticleDefinition* particle = particleTable->FindParticle("e-");
  particleGun->SetParticleDefinition(particle);
  particleGun->SetParticlePosition(G4ThreeVector(x,y,z));
  particleGun->SetParticleMomentumDirection(G4ThreeVector(x,y,z));
  particleGun->SetParticleEnergy(energy);
}

void MyPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
  particleGun->GeneratePrimaryVertex(anEvent);
}
```

Optional User Action classes

- Five concrete base classes whose virtual member functions the user may override to gain control of the simulation at various stages
  - G4User**Run**Action
  - G4User**Event**Action
  - G4User**Tracking**Action
  - G4User**Stacking**Action
  - G4User**Stepping**Action

- Each member function of the base classes has a dummy implementation
  - Empty implementation: does nothing
- The user may implement the member functions he desires in his/her derived classes

- Objects of user action classes must be registered with G4RunManager

Optional User Action classes

G4UserRunAction

- BeginOfRunAction(const G4Run*)
  - For example: book histograms
- EndOfRunAction(const G4Run*)
  - For example: store histograms

G4UserEventAction

- BeginOfEventAction(const G4Event*)
  - For example: perform and event selection
- EndOfEventAction(const G4Event*)
  - For example: analyse the event

G4UserTrackingAction

- PreUserTrackingAction(const G4Track*)
  - For example: decide whether a trajectory should be stored or not
- PostUserTrackingAction(const G4Track*)

Optional User Action classes

G4UserSteppingAction

- UserSteppingAction(const G4Step*)
  - For example: kill, suspend, postpone the track
  - For example: draw the step

G4UserStackingAction

- PrepareNewEvent()
  - For example: reset priority control
- ClassifyNewTrack(const G4Track*)
  - Invoked every time a new track is pushed
  - For example: classify a new track (priority control)
    - Urgent, Waiting, PostponeToNextEvent, Kill
- NewStage()
  - Invoked when the Urgent stack becomes empty
  - For example: change the classification criteria
  - For example: event filtering (event abortion)

Select (G)UI and visualisation

- In your **main()**, taking into account your computer environment, instantiate a **G4UIsession** concrete class provided by Geant4 and invoke its **sessionStart()** method

- Geant4 provides:
  - G4UIterminal
  - csh or tcsh like character terminal
  - G4GAG
  - tcl/tk or Java PVM based GUI
  - G4Wo
  - Opacs
  - G4UIBatch
  - batch job with macro file
  - …

- In your **main()**, taking into account your computer environment, instantiate a **G4VisExecutive** and invoke its **initialize()** method

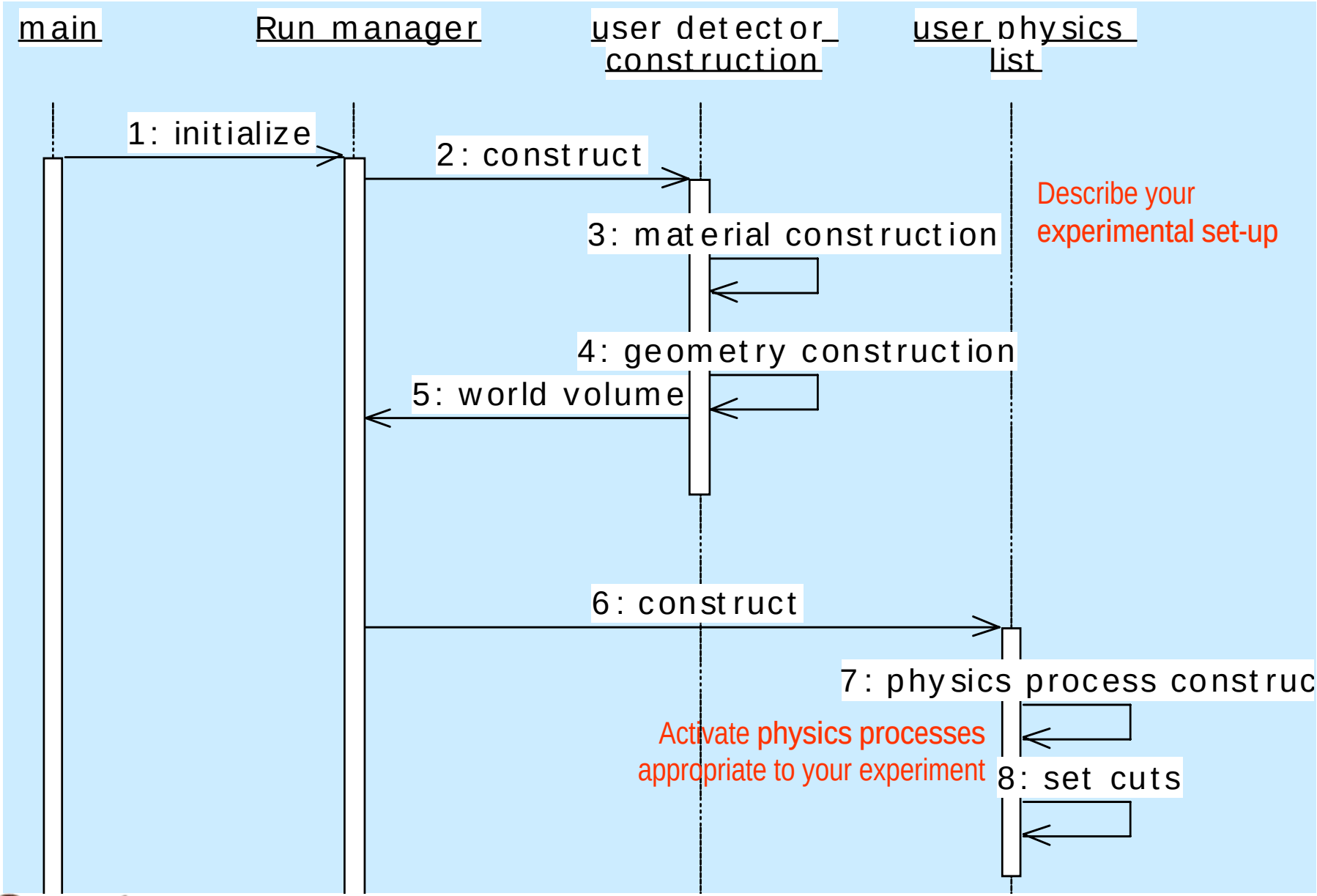
- Geant4 provides interfaces to various graphics drivers:
  - DAWN *(Fukui renderer)*
  - WIRED
  - RayTracer *(ray tracing by Geant4 tracking)*
  - OPACS
  - OpenGL
  - OpenInventor
  - VRML
  - …

Recipe for novice users

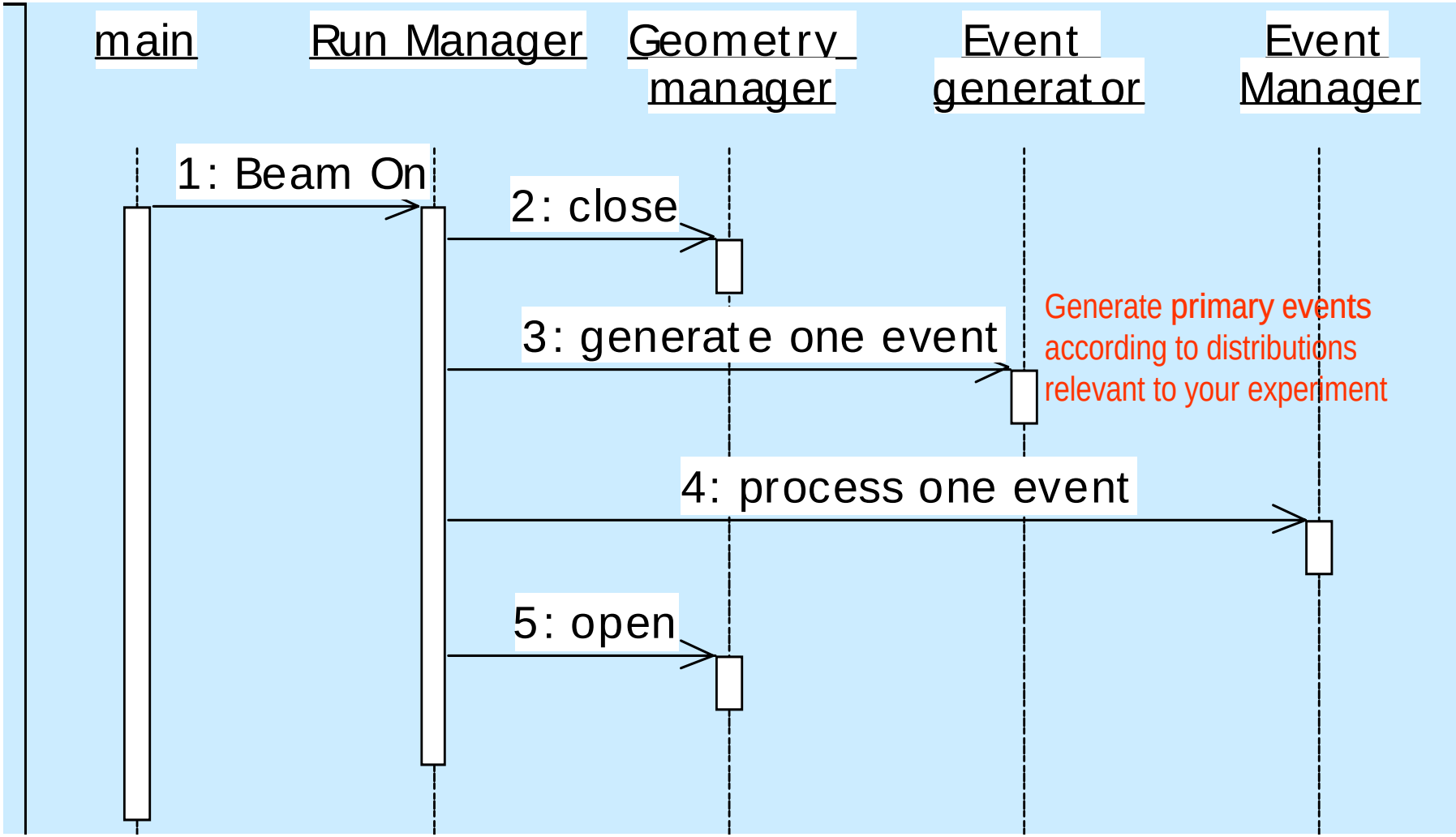
Experienced users may do much more, but the conceptual process is still the same…

- Design diagram as in generic Geant4 Advanced Example
- Create your derived mandatory user classes
  - My**DetectorConstruction**
  - My**PhysicsList**
  - My**PrimaryGeneratorAction**
- Optionally create your derived user action classes
  - MyUser**Run**Action
  - MyUser**Event**Action
  - MyUser**Tracking**Action
  - MyUser**Stacking**Action
  - MyUser**Stepping**Action
- Create your main()
  - Instantiate G4RunManager or your own derived MyRunManager
  - Notify the RunManager of your mandatory and optional user classes
  - Optionally initialize your favourite User Interface and Visualization
- That's all!

Initialisation



Beam On


main
Run Manager
Geometry_ manager
Event generator
Event Manager
1: Beam On
2: close
3: generate one event
Generate primary events according to distributions relevant to your experiment
4: process one event
5: open

Event processing