DICOM-CT interface in Geant4 example

Chihiro Omachi Nagoya Proton Therapy Center

Intro

DICOM in Geant4

examples/extended/medical/DICOM and DICOM2

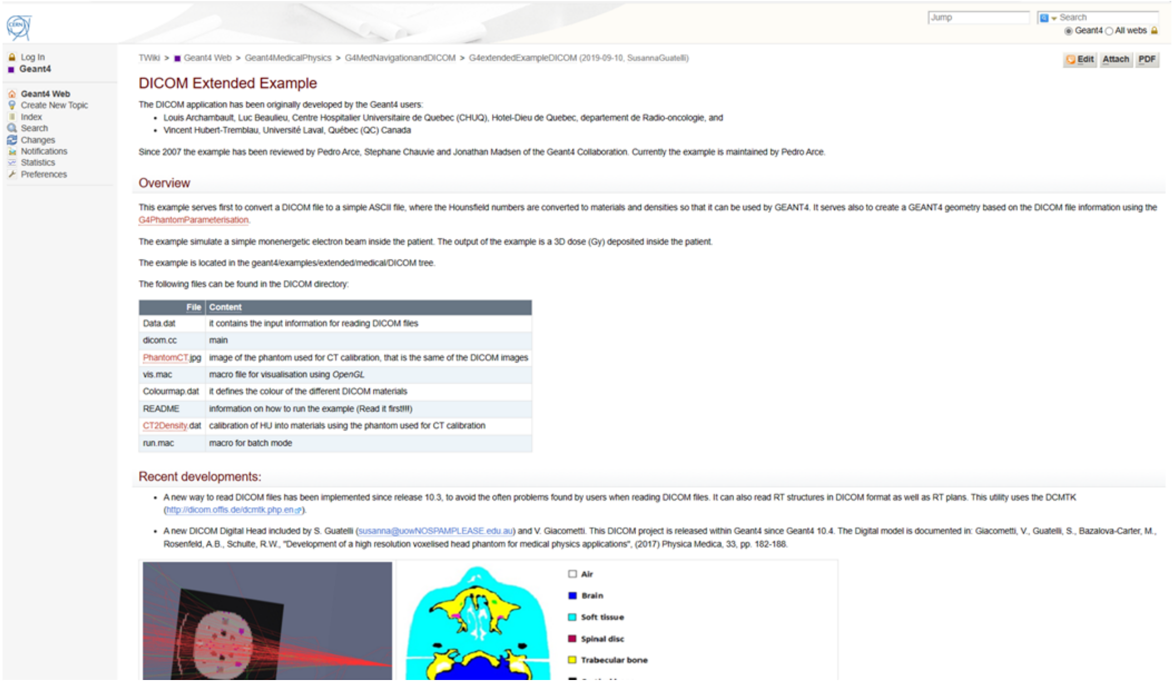
DICOM ··· Read the CT images and place in the simulation

DCMTK is used in recently release, RT-plan, structure are also read

→ reference for the people who wants to run and get used to.

DICOM2 ··· inherit the DICOM example and expand the functionality

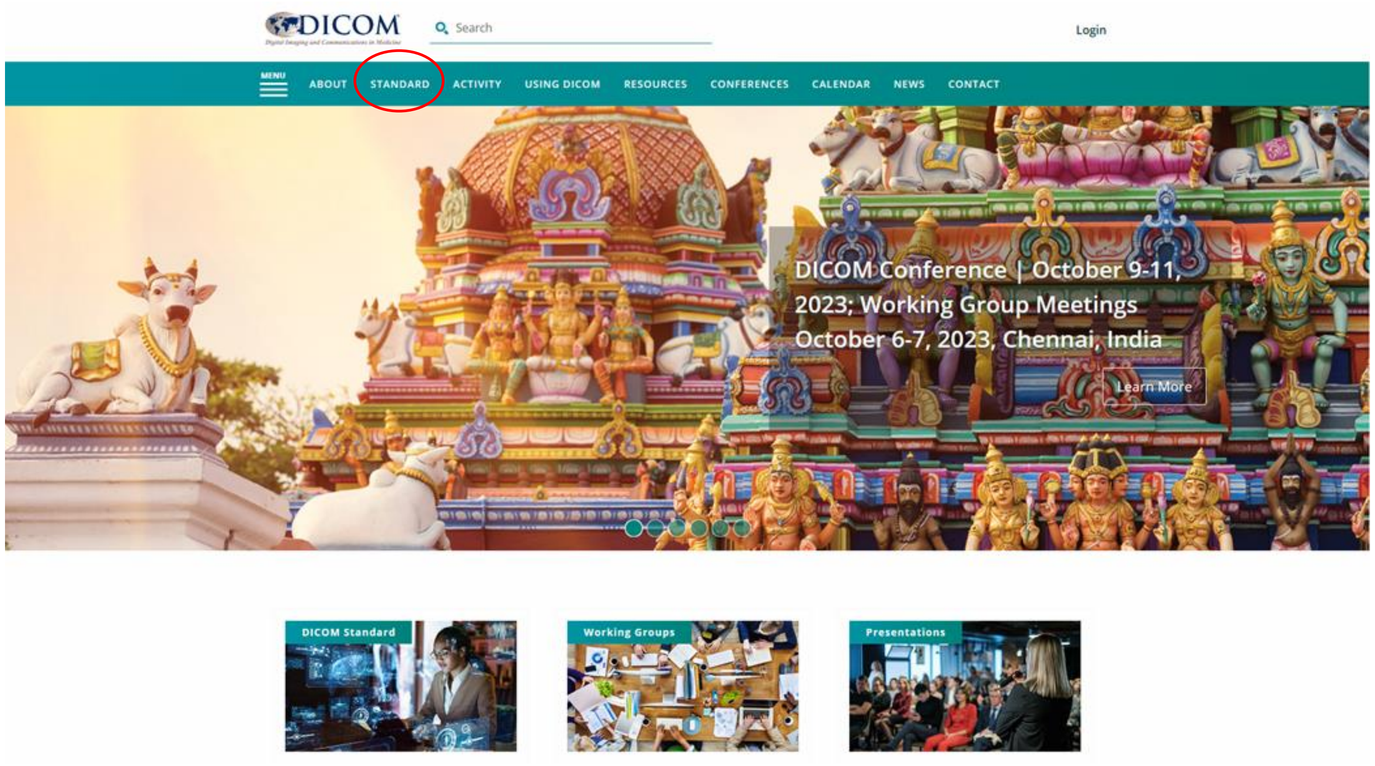
→ reference for the people who wants to make in-house DICOM simulation

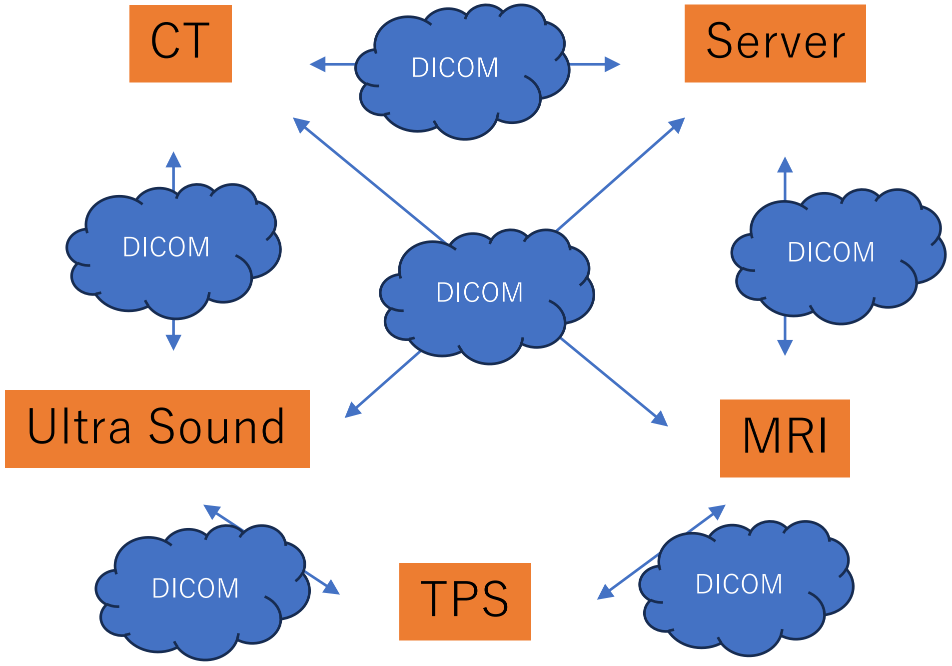


https://twiki.cern.ch/twiki/bin/view/Geant4/G4extendedExampleDICOM

Intro

DICOM (Digital Imaging and Communication in Medicine)
Reconstruction of CT images in the simulation is popular in medical application of Geant4
Communication standards for images and accompanying information between medical devices
(ex. Connection between TPS and irradiation machine, CT and MRI)





https://www.dicomstandard.org/

DICOM

What is in DICOM file?

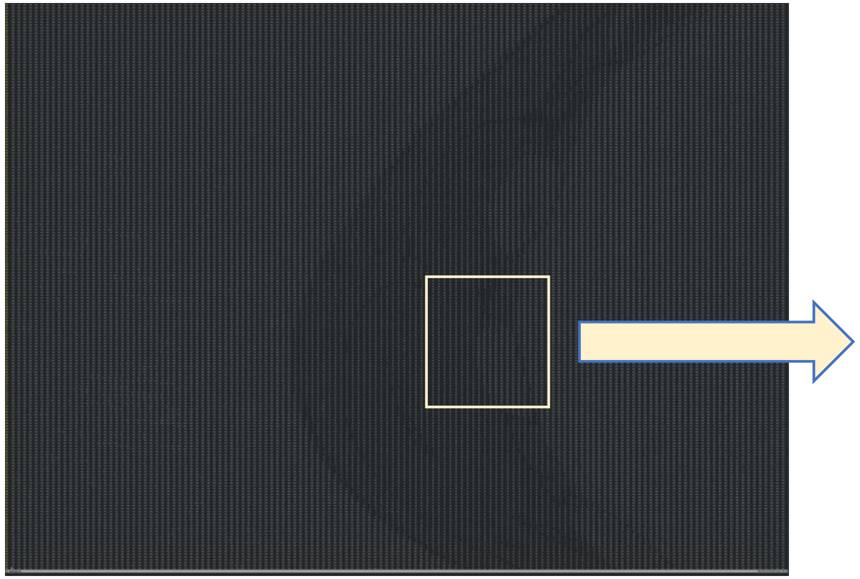
```
0002 0000(-4) UL     4(-4) (00020000 func) 206
0002 0001(-4) OB     2(-8) (00020001 func) 256
0002 0002(-4) UI    26(-4) (00020002 func) 1.2.840.10008.5.1.4.1.1.2
0002 0003(-4) UI    62(-4) (00020003 func) 1.2.826.0.1.3680043.2.135.733680.62000737.7.1257165367.578.28
0002 0010(-4) UI    18(-4) (00020010 func) 1.2.840.10008.1.2
0002 0012(-4) UI    34(-4) (00020012 func) 1.2.826.0.1.3680043.2.135.1066.101
0002 0013(-4) SH    12(-4) (00020013 func) 1.4.14/WIN32
0008 0000(-4) --     4(-4) (00080000 func) 534
0008 0005(-4) --    10(-4) (00080005 func) ISO_IR 100
0008 0008(-4) --    28(-4) (00080008 func) ORIGINAL¥PRIMARY¥AXIAL¥HELIX
0008 0012(-4) --     8(-4) (00080012 func) 20080523
0008 0013(-4) --     6(-4) (00080013 func) 174133
0008 0016(-4) --    26(-4) (00080016 func) 1.2.840.10008.5.1.4.1.1.2
0008 0018(-4) --    62(-4) (00080018 func) 1.2.826.0.1.3680043.2.135.733680.62000737.7.1257165367.578.28
0008 0020(-4) --     8(-4) (00080020 func) 20080523
0008 0022(-4) --     8(-4) (00080022 func) 20080523
0008 0023(-4) --     8(-4) (00080023 func) 20080523
0008 0030(-4) --     6(-4) (00080030 func) 173739
0008 0032(-4) --     6(-4) (00080032 func) 174107
0008 0033(-4) --    14(-4) (00080033 func) 174107.739000
0008 0050(-4) --     8(-4) (00080050 func) 4765471
0008 0060(-4) --     2(-4) (00080060 func) CT
0008 0070(-4) --     8(-4) (00080070 func) Philips
0008 0080(-4) --    18(-4) (00080080 func) OSP S.CROCE CUNEO
0008 0081(-4) --     6(-4) (00080081 func) CUNEO
0008 0090(-4) --     0(-4) (00080090 func)
0008 1010(-4) --    16(-4) (00081010 func) philips-48a88a1
0008 1030(-4) --    36(-4) (00081030 func) TAC ADDOME COMPLETO SENZA E CON MDC
0008 103e(-4) --     0(-4) (0008103e func)
0008 1040(-4) --    10(-4) (00081040 func) RADIOLOGIA
0008 1070(-4) --     2(-4) (00081070 func) 61
0008 1090(-4) --    14(-4) (00081090 func) Brilliance 64
.
.
.
```

DICOM/1.dcm

many information(modality, hospital, patient, …)
Image and its information(CT values, direction, bits, …)

DICOM

What is the image in DICOM?



Numbers stored in tag(7fe0 0010)

108	172	215	207	175	189	222	58	-288
114	191	241	224	180	175	218	122	-218
118	201	252	235	184	156	179	127	-164
124	214	270	256	199	154	144	93	-137
138	232	288	267	203	162	141	74	-124
148	244	304	277	207	169	151	77	-116
140	245	310	278	200	152	145	87	-106
132	243	313	278	185	121	125	92	-92
128	235	318	295	192	116	124	105	-70
120	222	321	309	208	132	133	118	-44
107	207	317	315	218	137	130	125	-23
97	197	313	325	224	133	125	132	-3
93	187	310	342	237	129	115	135	23
89	170	304	362	262	140	115	142	59
80	151	296	381	298	166	125	158	100
71	129	269	385	333	197	140	175	130
61	103	226	367	353	225	166	196	150
62	94	191	336	358	251	193	211	170
62	81	148	294	362	277	202	206	184
52	59	103	240	345	295	208	186	173
49	47	70	176	299	300	218	170	152
51	43	49	121	249	302	245	183	152
45	43	45	82	190	283	268	209	163
43	46	43	53	123	238	265	213	163
43	39	37	30	54	169	244	220	176
47	37	39	21	10	82	189	213	184

The numbers are the value of absorption rate of X-ray
Air is set to -1000, and Water is set to 0 in general.

CT → Geometry
CT → Material

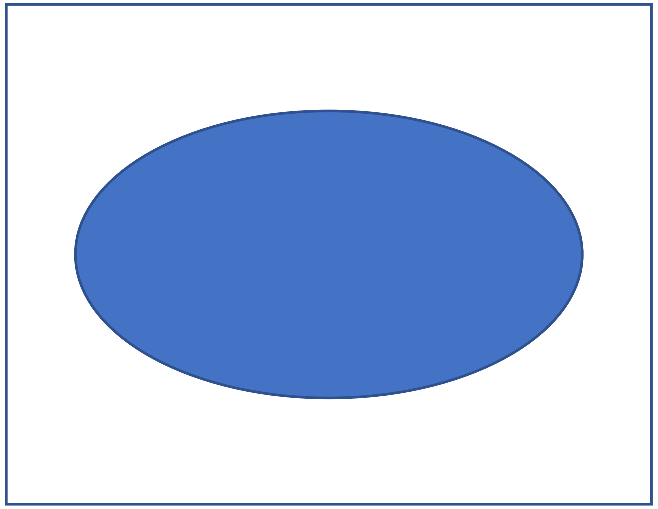
CT → Geometry

The CT image is build as the aggregation of voxel on Geant4.
The shape is cube and the size is based on the grid size stored in CT data.
The density of the voxel is calculated from CT value.

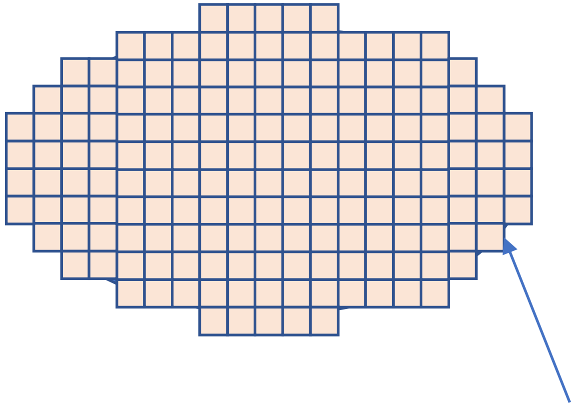
CT → Material

Every CT values are convert to the density, and materials are choose based on that density.

CT



Geometry on Geant4



example/extended/medical/DICOM

How to install and run is written in README.

This example has three DetectorConstruction

DicomNestedParamDetectorConstruction ⟷ G4PVNestedParameterisation fast, light
DicomRegularDetectorConstruction ⟷ G4PVParameterised
DicomPartialDetectorConstruction ⟷ G4PVParameterised cut the image

↑ inherit

DicomDetectorConstruction

Use can switch through environment parameters

```
if( !bPartial ){
                    ...
    // Initialisation of physics, geometry, primary particles ...
    char* nest = std::getenv( "DICOM_NESTED_PARAM" );
    if( nest && G4String(nest) == "1" )
      theGeometry = new DicomNestedParamDetectorConstruction();
    else theGeometry = new DicomRegularDetectorConstruction();
}
else  theGeometry = new DicomPartialDetectorConstruction();

runManager->SetUserInitialization(theGeometry);
```

Priority
Partial is judged at first, and next is Nested.

example/extended/medical/DICOM

CT image (DICOM) → text file → Geometry (Nested)Parameterised Volume

DCMTK

1.dcm
2.dcm
3.dcm

test2.g4dcm

DicomNestedParamDetectorConstruction

runManager->Initialize();

→DicomDetectorConstruction::Construct()

→DicomNestedParamDetectorConstruction::ConstructPhantom()

```
void DicomNestedParamDetectorConstruction::ConstructPhantom()
{
                                        ...
  //----- Replication of Water Phantom Volume.
  //--- Y Slice
  G4String yRepName("RepY");
  G4VSolid* solYRep = new G4Box(yRepName,
                                fNoVoxelsX*fVoxelHalfDimX,
                                fVoxelHalfDimY,
                                fNoVoxelsZ*fVoxelHalfDimZ);
  G4LogicalVolume* logYRep = new G4LogicalVolume(solYRep,fAir,yRepName);
  new G4PVReplica(yRepName, logYRep, fContainer_logic, kYAxis, fNoVoxelsY, fVoxelHalfDimY*2.);

  logYRep->SetVisAttributes(new G4VisAttributes(G4VisAttributes::GetInvisible()));

  //--- X Slice
  G4String xRepName("RepX");
  G4VSolid* solXRep = new G4Box(xRepName,
                                fVoxelHalfDimX,
                                fVoxelHalfDimY,
                                fNoVoxelsZ*fVoxelHalfDimZ);
  G4LogicalVolume* logXRep = new G4LogicalVolume(solXRep,fAir,xRepName);
  new G4PVReplica(xRepName,logXRep,logYRep,kXAxis,fNoVoxelsX,fVoxelHalfDimX*2.);

  logXRep->SetVisAttributes(new G4VisAttributes(G4VisAttributes::GetInvisible()));
                                        ...
```

DicomNestedParamDetectorConstruction

```
                                        ...
// Parameterisation for transformation of voxels.
//  (voxel size is fixed in this example.
//    e.g. nested parameterisation handles material
//    and transfomation of voxels.)
G4ThreeVector voxelSize(fVoxelHalfDimX,fVoxelHalfDimY,fVoxelHalfDimZ);
DicomNestedPhantomParameterisation* param = new
                       DicomNestedPhantomParameterisation(voxelSize, fMaterials);

new G4PVParameterised("phantom",    // their name
              logicVoxel, // their logical volume
              logXRep,      // Mother logical volume
              kZAxis,       // Are placed along this axis
              //kUndefined,
              // Are placed along this axis
              fNoVoxelsZ,      // Number of cells
              param);       // Parameterisation.

param->SetMaterialIndices( fMateIDs );
param->SetNoVoxels( fNoVoxelsX, fNoVoxelsY, fNoVoxelsZ );

//phantom_phys->SetRegularStructureId(0);

// Z logical volume
SetScorer(logicVoxel);

}
```

```
G4Material* DicomNestedPhantomParameterisation::
ComputeMaterial(G4VPhysicalVolume* physVol, const G4int iz,
                const G4VTouchable* parentTouch){
                          ...
```

DicomRegularDetectorConstruction

```
void DicomRegularDetectorConstruction::ConstructPhantom()
{
#ifdef G4VERBOSE
  G4cout << "DicomRegularDetectorConstruction::ConstructPhantom " << G4endl;
#endif

  //----- Create parameterisation
  DicomPhantomParameterisationColour* param =
    new DicomPhantomParameterisationColour();

  //----- Set voxel dimensions
  param->SetVoxelDimensions( fVoxelHalfDimX, fVoxelHalfDimY, fVoxelHalfDimZ );

  //----- Set number of voxels
  param->SetNoVoxels( fNoVoxelsX, fNoVoxelsY, fNoVoxelsZ );

  //----- Set list of materials
  param->SetMaterials( fMaterials );

  //----- Set list of material indices: for each voxel it is a number that
  // correspond to the index of its material in the vector of materials
  // defined above
  param->SetMaterialIndices( fMateIDs );
```

```
class DicomPhantomParameterisationColour : public G4PhantomParameterisation
{
                                    ...
  virtual G4Material* ComputeMaterial(const G4int repNo,
                                      G4VPhysicalVolume *currentVol,
                                      const G4VTouchable *parentTouch=0);
                                    ...
```

DicomRegularDetectorConstruction

```
//----- Define voxel logical volume
 G4Box* voxel_solid =
  new G4Box( "Voxel", fVoxelHalfDimX, fVoxelHalfDimY, fVoxelHalfDimZ);
 G4LogicalVolume* voxel_logic =
  new G4LogicalVolume(voxel_solid,fMaterials[0],"VoxelLogical",
                      0,0,0);
 // material is not relevant, it will be changed by the
 // ComputeMaterial method of the parameterisation

  voxel_logic->SetVisAttributes(
          new G4VisAttributes(G4VisAttributes::GetInvisible()));

 //--- Assign the fContainer volume of the parameterisation
 param->BuildContainerSolid(fContainer_phys);

 //--- Assure yourself that the voxels are completely filling the
 // fContainer volume
 param->CheckVoxelsFillContainer( fContainer_solid->GetXHalfLength(),
                                  fContainer_solid->GetYHalfLength(),
                                  fContainer_solid->GetZHalfLength() );

 //----- The G4PVParameterised object that uses the created parameterisation
 // should be placed in the fContainer logical volume
 G4PVParameterised * phantom_phys =
  new G4PVParameterised("phantom",voxel_logic,fContainer_logic,
             kXAxis, fNoVoxelsX*fNoVoxelsY*fNoVoxelsZ, param);
```

DicomPartialDetectorConstruction

CT image (DICOM) → text file → Geometry (Nested)Parameterised Volume

DCMTK

1.dcm
2.dcm
3.dcm

test2.g4dcm

DicomIntersecVolume
(ex. at (0,0,0), no rotation, 10cm cube
/dicom/intersectWithUserVolume 0 0 0 0 0 0 “BOX” 10.0 10.0 10.0*cm)

→ text file → Geometry
Parameterised Volume

test.g4pdcm

Material

Material of the voxels are decided two steps based on two tables

HU→Physical density→Material

HU→Physical density

```
DICOM/CT2Density.dat
---------------
8
-5000     0.0
-1000     0.0
-400      0.602
-150      0.924
100       1.075
300       1.145
2000      1.856
4927      3.379
```

HU Physical densities

Interpolated densities are assigned to every HU in CT

Physical density→Material

Another choice is ICRU, shown in README

ICRU materials -> NIST

```
###################################
#    Density Range            Material          #
#-----------------------------------------------#
#      mg/cm3                 -                 #
#-----------------------------------------------#
#  [ 0.    , 0.207 )          Air               #
#  [ 0.207 , 0.481 )          Lungs (inhale)    #
#  [ 0.481 , 0.919 )          Lungs (exhale)    #
#  [ 0.919 , 0.979 )          Adipose           #
#  [ 0.979 , 1.004 )          Breast            #
#  [ 1.004 , 1.043 )          Phantom           #
#  [ 1.043 , 1.109 )          Liver             #
#  [ 1.109 , 1.113 )          Muscle            #
#  [ 1.113 , 1.496 )          Trabecular Bone   #
#  [ 1.496 , 1.654 ]          Dense Bone        #
###################################
```

Proper materials are assigned based on the voxel density

Material

The density pitch of the Material can be changed by environment variable
Default value is 0.01
export DICOM_CHANGE_MATERIAL_DENSITY=0.01
unset DICOM_CHANGE_MATERIAL_DENSITY

```
void DicomDetectorConstruction::ReadVoxelDensities( std::ifstream& fin )
{
  G4String stemp;
  std::map<G4int, std::pair<G4double,G4double> > densiMinMax;
  std::map<G4int, std::pair<G4double,G4double> >::iterator mpite;
  for( G4int ii = 0; ii < G4int(fPhantomMaterialsOriginal.size()); ++ii )
  {
    densiMinMax[ii] = std::pair<G4double,G4double>(DBL_MAX,-DBL_MAX);
  }

  char* part = std::getenv( "DICOM_CHANGE_MATERIAL_DENSITY" );
  G4double densityDiff = -1.;
  if( part ) densityDiff = G4UIcommand::ConvertToDouble(part);

  std::map<G4int,G4double> densityDiffs;
  for( G4int ii = 0; ii < G4int(fPhantomMaterialsOriginal.size()); ++ii )
  {
    densityDiffs[ii] = densityDiff; //currently all materials with same step
```

Material

ColourMap.dat

```
9
G4_AIR                    0.0  0.0  0.0  1.0
G4_LUNG_ICRP              0.1  0.1  0.1  1.0
G4_ADIPOSE_TISSUE_ICRP    0.2  0.2  0.2  1.0
G4_WATER                  0.3  0.3  0.3  1.0
G4_MUSCLE_WITH_SUCROSE    0.4  0.4  0.4  1.0
G4_B-100_BONE             0.5  0.5  0.5  1.0
G4_BONE_COMPACT_ICRU      0.6  0.6  0.6  1.0
G4_BONE_CORTICAL_ICRP     0.7  0.7  0.7  1.0
G4_Fe                     0.8  0.8  0.8  1.0
material                  red  green blue opacity
```

Data.dat

```
:COMPRESSION 2
:MATE G4_AIR                    -1000
:MATE G4_LUNG_ICRP              -145
:MATE G4_ADIPOSE_TISSUE_ICRP    -60
:MATE G4_WATER                  0
:MATE G4_MUSCLE_WITH_SUCROSE    60
:MATE G4_B-100_BONE             1150
:MATE G4_BONE_COMPACT_ICRU      1500
:MATE G4_BONE_CORTICAL_ICRP     2100
:MATE G4_Fe                     66000
:CT2D  -5000    0.0
:CT2D  -1000    0.01
:CT2D  -400     0.602
:CT2D  -150     0.924
:CT2D  100      1.075
:CT2D  300      1.145
:CT2D  2000     1.856
:CT2D  4927     3.379
:CT2D  66000    7.8
:FILE 1.dcm
:FILE 2.dcm
:FILE 3.dcm
:FILE_OUT test2.g4dcm
```

Scoring in DICOM

Accumulated dose in every voxel are recorded and exported in “dicom.out”

dicom.out

5763	3.31902e-09
6014	1.62953e-09
6015	3.66152e-09
6016	1.64112e-09
6018	5.83092e-09
6019	1.10233e-08
6020	1.30748e-08
6021	5.10171e-09
6270	4.22088e-09
6272	3.21115e-09
6273	2.70602e-09
6274	2.50778e-08
6275	8.46614e-08
6276	4.02584e-08
6277	1.56376e-08

Scoring in DICOM

```
void DicomRunAction::EndOfRunAction(const G4Run* aRun)
{
 G4int nofEvents = aRun->GetNumberOfEvent();

 static G4double local_total_dose = 0;
 G4double total_dose = 0;
 const DicomRun* reRun = static_cast<const DicomRun*>(aRun);
 //--- Dump all scored quantities involved in DicomRun.
 for ( G4int i = 0; i < (G4int)fSDName.size(); i++ ){
  //
  //---------------------------------------------
  // Dump accumulated quantities for this RUN.
  //  (Display only central region of x-y plane)
  //      0       ConcreteSD/DoseDeposit
  //---------------------------------------------
  G4THitsMap<G4double>* DoseDeposit =
   reRun->GetHitsMap(fSDName[i]+"/DoseDeposit");

  if( DoseDeposit && DoseDeposit->GetMap()->size() != 0 ) {
   std::map<G4int,G4double*>::iterator itr =
    DoseDeposit->GetMap()->begin();
   for(; itr != DoseDeposit->GetMap()->end(); itr++) {
    if(!IsMaster()) { local_total_dose += *(itr->second); }
    total_dose += *(itr->second);
   }
  }
 }
                              ...
```

```
                              ...
if( DoseDeposit && DoseDeposit->GetMap()->size() != 0 ) {
    std::ostream *myout = &G4cout;
    PrintHeader(myout);
    std::map<G4int,G4double*>::iterator itr =
                        DoseDeposit->GetMap()->begin();
    for(; itr != DoseDeposit->GetMap()->end(); itr++) {
     fileout <<  itr->first
           << "     "  << *(itr->second)/CLHEP::gray
           << G4endl;
     //G4cout << "     " << itr->first
     //       << "     " << std::setprecision(6)
     //       << *(itr->second)/CLHEP::gray << " Gy"
     //       << G4endl;
 }
```

DICOM example の移植

We prepared the hands on lecture that implanted the DICOM to Galet

GaletDicomNestedModule
GaletDicomRegularModule
GaletDicomPartialModule

← inherit

DicomNestedParamDetectorConstruction
DicomRegularDetectorConstruction
DicomPartialDetectorConstruction

ActionInitialization.cc
DetectorConstruction.cc
EventAction.cc
GaletDICOM.cc
GaletDicomNestedParamModule.cc
GaletDicomPartialModule.cc
GaletDicomRegularModule.cc
GaletHit.cc
GaletMagneticField.cc
GaletNestedPhantomParameterisation.cc
GaletPhantom.cc
GaletSD.cc
GaletTrackInformation.cc
ParallelWorldConstruction.cc
ParticleConstruction.cc
PhysicsList.cc
PrimaryGeneratorAction.cc
RunAction.cc
SteppingAction.cc
TrackingAction.cc

```
G4LogicalVolume* GaletDICOM::ConstructPhantom(){

 G4LogicalVolume* dicomLV;

 if(bPartial){
  GaletDicomPartialModule *theModule = new GaletDicomPartialModule();
  dicomLV=theModule->ConstructAsModule(bUseDCMTK);
 }
 else if(bNest){
  GaletDicomNestedParamModule *theModule = new GaletDicomNestedParamModule();
  dicomLV=theModule->ConstructAsModule(bUseDCMTK);
 }
 else{
  GaletDicomRegularModule *theModule = new GaletDicomRegularModule();
  dicomLV=theModule->ConstructAsModule(bUseDCMTK);
 }

 new DicomIntersectVolume();

 return dicomLV;
}
```