Geant 4
Detector Description – advanced features

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Detector Description:
Optimisation technique & Advanced features
Detector Description
Advanced features

- The optimisation technique
- Grouping volumes
- Reflections of volumes and hierarchies
- User defined solids
- Interface to CAD systems
- Debugging tools
Smart voxels

- For each mother volume
  - a one-dimensional virtual division is performed
    - the virtual division is along a chosen axis
    - the axis is chosen by using an heuristic
  - Subdivisions (slices) containing same volumes are gathered into one
  - Subdivisions containing many volumes are refined
    - applying a virtual division again using a second Cartesian axis
    - the third axis can be used for a further refinement, in case

- Smart voxels are computed at initialisation time
  - When the detector geometry is closed
  - Do not require large memory or computing resources
  - At tracking time, searching is done in a hierarchy of virtual divisions
Detector description tuning

- Some geometry topologies may require ‘special’ tuning for ideal and efficient optimisation
  - for example: a dense nucleus of volumes included in very large mother volume
- Granularity of voxelisation can be explicitly set
  - Methods `Set/GetSmartless()` from `G4LogicalVolume`
- Critical regions for optimisation can be detected
  - Helper class `G4SmartVoxelStat` for monitoring time spent in detector geometry optimisation
    - Automatically activated if `/run/verbose` greater than 1

<table>
<thead>
<tr>
<th>Percent</th>
<th>Memory</th>
<th>Heads</th>
<th>Nodes</th>
<th>Pointers</th>
<th>Total CPU</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>91.70</td>
<td>1k</td>
<td>1</td>
<td>50</td>
<td>50</td>
<td>0.00</td>
<td>Calorimeter</td>
</tr>
<tr>
<td>8.30</td>
<td>0k</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>0.00</td>
<td>Layer</td>
</tr>
</tbody>
</table>

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Visualising voxel structure

- The computed voxel structure can be visualized with the final detector geometry
- Helper class `G4DrawVoxels`
- Visualize voxels given a logical volume
  - `G4DrawVoxels::DrawVoxels(const G4LogicalVolume*)`
- Allows setting of visualization attributes for voxels
  - `G4DrawVoxels::SetVoxelsVisAttributes(...)`
- useful for debugging purposes
- Can also be done through a visualization command at run-time:
  - `/vis/scene/add/logicalVolume <logical-volume-name> [depth]`
Customising optimisation

- Detector regions may be excluded from optimisation (ex. for debug purposes)
  - Optional argument in constructor of `G4LogicalVolume` or through provided set methods
    - `SetOptimisation`/`IsToOptimise()`
  - Optimisation is turned on by default

- Optimisation for parameterised volumes can be chosen
  - Along one single Cartesian axis
    - Specifying the axis in the constructor for `G4PVParameterised`
  - Using 3D voxelisation along the 3 Cartesian axes
    - Specifying in `kUndefined` in the constructor for `G4PVParameterised`
Grouping volumes

- To represent a regular pattern of positioned volumes, composing a more or less complex structure
  - structures which are hard to describe with simple replicas or parameterised volumes
  - structures which may consist of different shapes
- **Assembly** volume
  - acts as an *envelope* for its daughter volumes
  - its role is over once its logical volume has been placed
  - daughter physical volumes become independent copies in the final structure
G4AssemblyVolume

G4AssemblyVolume( G4LogicalVolume* volume,
    G4ThreeVector& translation,
    G4RotationMatrix* rotation);

- Helper class to combine logical volumes in arbitrary way
- Participating logical volumes are treated as triplets
  - logical volume, translation, rotation
- Imprints of the assembly volume are made inside a mother logical volume through G4AssemblyVolume::MakeImprint(...)
- Each physical volume name is generated automatically
  - Format: av_www_impr_XXX_YYY_ZZZ
    - www – assembly volume instance number
    - xxx – assembly volume imprint number
    - yyy – name of the placed logical volume in the assembly
    - zzz – index of the associated logical volume
- Generated physical volumes (and related transformations) are automatically managed (creation and destruction)
Assembly of volumes: example -1

// Define a plate
G4VSolid* PlateBox = new G4Box( "PlateBox", plateX/2., plateY/2., plateZ/2. );
G4LogicalVolume* plateLV = new G4LogicalVolume( PlateBox, Pb, "PlateLV", 0, 0, 0 );

// Define one layer as one assembly volume
G4AssemblyVolume* assemblyDetector = new G4AssemblyVolume();

// Rotation and translation of a plate inside the assembly
G4RotationMatrix Ra; G4ThreeVector Ta;

// Rotation of the assembly inside the world
G4RotationMatrix Rm;

// Fill the assembly by the plates
Ta.setX( caloX/4. ); Ta.setY( caloY/4. ); Ta.setZ( 0. );
assemblyDetector->AddPlacedVolume( plateLV, G4Transform3D(Ta,Ra) );
Ta.setX( -1*caloX/4. ); Ta.setY( caloY/4. ); Ta.setZ( 0. );
assemblyDetector->AddPlacedVolume( plateLV, G4Transform3D(Ta,Ra) );
Ta.setX( -1*caloX/4. ); Ta.setY( -1*caloY/4. ); Ta.setZ( 0. );
assemblyDetector->AddPlacedVolume( plateLV, G4Transform3D(Ta,Ra) );
Ta.setX( caloX/4. ); Ta.setY( -1*caloY/4. ); Ta.setZ( 0. );
assemblyDetector->AddPlacedVolume( plateLV, G4Transform3D(Ta,Ra) );

// Now instantiate the layers
for( unsigned int i = 0; i < layers; i++ ) {
    // Translation of the assembly inside the world
    G4ThreeVector Tm( 0,0,i*(caloZ + caloCaloOffset) - firstCaloPos );
    assemblyDetector->MakeImprint( worldLV, G4Transform3D(Tm,Rm) );
}
Assembly of volumes: example -2
Reflecting solids

- G4ReflectedSolid
  - utility class representing a solid shifted from its original reference frame to a new reflected one
  - the reflection (G4Reflect[X/Y/Z]3D) is applied as a decomposition into rotation and translation
- G4ReflectionFactory
  - Singleton object using G4ReflectedSolid for generating placements of reflected volumes
- Reflections can be applied to CSG and specific solids
Reflecting hierarchies of volumes - 1

G4ReflectionFactory::Place(…)

- Used for normal placements:
  i. Performs the transformation decomposition
  ii. Generates a new reflected solid and logical volume
      - Retrieves it from a map if the reflected object is already created
  iii. Transforms any daughter and places them in the given mother
  iv. Returns a pair of physical volumes, the second being a placement in the reflected mother

G4PhysicalVolumesPair

Place(const G4Transform3D& transform3D, // the transformation
      const G4String& name,        // the actual name
      G4LogicalVolume* LV,          // the logical volume
      G4LogicalVolume* motherLV,    // the mother volume
      G4bool noBool,                // currently unused
      G4int copyNo)                 // optional copy number
Reflecting hierarchies of volumes - 2

G4ReflectionFactory::Replicate(...)  
- Creates replicas in the given mother volume  
- Returns a pair of physical volumes, the second being a replica in the reflected mother

G4PhysicalVolumesPair
Replicate(const G4String& name,  // the actual name  
          G4LogicalVolume* LV,  // the logical volume  
          G4LogicalVolume* motherLV,  // the mother volume  
          Eaxis axis,  // axis of replication  
          G4int replicaNo,  // number of replicas  
          G4int width,  // width of single replica  
          G4int offset=0)  // optional mother offset
**User defined solids**

- All solids should derive from **G4VSolid** and implement its abstract interface
  - will guarantee the solid is treated as any other solid predefined in the kernel
- Basic functionalities required for a solid
  - Compute distances to/from the shape
  - Detect if a point is inside the shape
  - Compute the surface normal to the shape at a given point
  - Compute the extent of the shape
  - Provide few visualization/graphics utilities
What a solid should reply to...

1. \textbf{EInside Inside} (const G4ThreeVector& p) const;

   \textbf{Should return, considering a predefined tolerance:}
   - kOutside – \textit{if the point at offset} p \textit{is outside the shapes boundaries}
   - kSurface – \textit{if the point is close less than} Tolerance/2 \textit{from the surface}
   - kInside – \textit{if the point is inside the shape boundaries}

2. \textbf{G4ThreeVector SurfaceNormal} (const G4ThreeVector& p) const;

   \textbf{Should return the outwards pointing unit normal of the shape for the surface closest to the point at offset} p.

3. \textbf{G4double DistanceToIn} (const G4ThreeVector& p, const G4ThreeVector& v) const;

   \textbf{Should return the distance along the normalized vector} v \textbf{to the shape from the point at offset} p. \textbf{If there is no intersection, returns} kInfinity. \textbf{The first intersection resulting from 'leaving' a surface/volume is discarded. Hence, it is tolerant of points on the surface of the shape}
What a solid should reply to...

- **G4double** `DistanceToIn(const G4ThreeVector& p) const;`
  - Calculates the distance to the nearest surface of a shape from an outside point `p`. The distance can be an underestimate.

- **G4double** `DistanceToOut(const G4ThreeVector& p, const G4ThreeVector& v, const G4bool calcNorm=false, G4bool* validNorm=0, G4ThreeVector* n=0) const;`
  - Returns the distance along the normalised vector `v` to the shape, from a point at an offset `p` inside or on the surface of the shape. Intersections with surfaces, when the point is less than `Tolerance/2` from a surface must be ignored. If `calcNorm` is true, then it must also set `validNorm` to either:
    - True - if the solid lies entirely behind or on the exiting surface. Then it must set `n` to the outwards normal vector (the Magnitude of the vector is not defined)
    - False - if the solid does not lie entirely behind or on the exiting surface

- **G4double** `DistanceToOut(const G4ThreeVector& p) const;`
  - Calculates the distance to the nearest surface of a shape from an inside point `p`. The distance can be an underestimate.
Solid: more functions...

G4bool CalculateExtent(const EAxis pAxis,
                       const G4VoxelLimits& pVoxelLimit,
                       const G4AffineTransform& pTransform,
                       G4double& pMin, G4double& pMax) const;

- Calculates the minimum and maximum extent of the solid, when under the specified transform, and within the specified limits. If the solid is not intersected by the region, return false, else return true

Member functions for the purpose of visualization:

void DescribeYourselfTo (G4VGraphicsScene& scene) const;

- "double dispatch" function which identifies the solid to the graphics scene

G4VisExtent GetExtent () const;

- Provides extent (bounding box) as possible hint to the graphics view
Interface to CAD systems

- Models imported from CAD systems can describe the solid geometry of detectors made by large number of elements with the greatest accuracy and detail
  - A solid model contains the purely geometrical data representing the solids and their position in a given reference frame
- Solid descriptions of detector models can be imported from CAD systems
  - e.g. Katia & Pro/Engineer
    - using STEP AP203 compliant protocol
- Tracking in BREP solids created through CAD systems is supported
How to import CAD geometries

- Detector geometry description should be modularized
  - By sub-detector and sub-detector components
  - Each component in a separate STEP file
- `G4AssemblyCreator` and `G4Assembly` classes from the `STEPInterface` module should be used to read a STEP file generated by a CAD system and create the assembled geometry in Geant4
  - Geometry is generated and described through BREP shapes
  - Geometry modules for each component are assembled in the user code
Importing STEP models: example -1

G4AssemblyCreator MyAC("tracker.stp");
    // Associate a creator to a given STEP file.
MyAC.ReadStepFile();
    // Reads the STEP file.
STEPentity* ent=0;
    // No predefined STEP entity in this example.
    // A dummy pointer is used.
MyAC.CreateG4Geometry(*ent);
    // Generates GEANT4 geometry objects.

void *pl = MyAC.GetCreatedObject();
    // Retrieve vector of placed entities.
G4Assembly* assembly = new G4Assembly();
    // An assembly is an aggregation of placed entities.
assembly->SetPlacedVector(*(G4PlacedVector*)pl);
    // Initialise the assembly.
G4int solids = assembly->GetNumberOfSolids();
    // Get the total number of solids among all entities.
for(G4int c=0; c<solids; c++)
    // Generate logical volumes and placements for each solid.
{
    ps = assembly->GetPlacedSolid(c);
    G4LogicalVolume* lv =
        new G4LogicalVolume(ps->GetSolid(), Lead, "STEPlog");
    G4RotationMatrix* hr = ps->GetRotation();
    G4ThreeVector* tr = ps->GetTranslation();
    G4VPhysicalVolume* pv =
        new G4PVPlacement(hr, *tr, ps->GetSolid()->GetName(),
            lv, experimentalHall_phys, false, c);
GGE (Graphical Geometry Editor)

- Implemented in JAVA, GGE is a graphical geometry editor compliant to Geant4. It allows to:
  - Describe a detector geometry including:
    - materials, solids, logical volumes, placements
  - Graphically visualize the detector geometry using a Geant4 supported visualization system, e.g. DAWN
  - Store persistently the detector description
  - Generate the C++ code according to the Geant4 specifications

- GGE can be downloaded from Web as a separate tool:
  - [http://erpc1.naruto-u.ac.jp/~geant4/](http://erpc1.naruto-u.ac.jp/~geant4/)
Visualizing detector geometry tree

- Built-in commands defined to display the hierarchical geometry tree
  - As simple ASCII text structure
  - Graphical through GUI (combined with GAG)
  - As XML exportable format
- Implemented in the visualization module
  - As an additional graphics driver
- G3 DTREE capabilities provided and more
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[Image of a computer screen with a window displaying a tree structure and commands related to a detector description.]
Debugging geometries

- An overlapping volume is a contained volume which actually protrudes from its mother volume.
  - Volumes are also often positioned in a same volume with the intent of not provoking intersections between themselves. When volumes in a common mother actually intersect themselves are defined as overlapping.

- Geant4 does not allow for malformed geometries.

- The problem of detecting overlaps between volumes is bounded by the complexity of the solid models description.

- Utilities are provided for detecting wrong positioning:
  - Graphical tools
  - Kernel run-time commands
Debugging tools: DAVID

- DAVID is a graphical debugging tool for detecting potential intersections of volumes.
- Accuracy of the graphical representation can be tuned to the exact geometrical description.
  - Physical-volume surfaces are automatically decomposed into 3D polygons.
  - Intersections of the generated polygons are parsed.
  - If a polygon intersects with another one, the physical volumes associated to these polygons are highlighted in color (red is the default).
- DAVID can be downloaded from the Web as an external tool for Geant4.
Debugging run-time commands

- Built-in run-time commands to activate verification tests for the user geometry are defined

  geometry/test/run  or  geometry/test/grid_test

  - to start verification of geometry for overlapping regions based on a standard grid setup, limited to the first depth level

  geometry/test/recursive_test

  - applies the grid test to all depth levels (may require CPU time!)

  geometry/test/cylinder_test

  - shoots lines according to a cylindrical pattern

  geometry/test/line_test

  - to shoot a line along a specified direction and position

  geometry/test/position

  - to specify position for the line_test

  geometry/test/direction

  - to specify direction for the line_test
Example layout:

GeomTest: no daughter volume extending outside mother detected.
GeomTest Error: Overlapping daughter volumes

The volumes Tracker[0] and Overlap[0], both daughters of volume World[0], appear to overlap at the following points in global coordinates: (list truncated)

<table>
<thead>
<tr>
<th>length (cm)</th>
<th>----- start position (cm) -----</th>
<th>----- end position (cm) -----</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>-240</td>
<td>-145.5</td>
</tr>
<tr>
<td></td>
<td>-145.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-145.5</td>
<td>-145.5</td>
</tr>
</tbody>
</table>

Which in the mother coordinate system are:

<table>
<thead>
<tr>
<th>length (cm)</th>
<th>----- start position (cm) -----</th>
<th>----- end position (cm) -----</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which in the coordinate system of Tracker[0] are:

<table>
<thead>
<tr>
<th>length (cm)</th>
<th>----- start position (cm) -----</th>
<th>----- end position (cm) -----</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which in the coordinate system of Overlap[0] are:

<table>
<thead>
<tr>
<th>length (cm)</th>
<th>----- start position (cm) -----</th>
<th>----- end position (cm) -----</th>
</tr>
</thead>
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</tbody>
</table>

Debugging tools: OLAP

- Uses tracking of neutral particles to verify boundary crossing in opposite directions
- Stand-alone batch application
  - Provided as extended example
  - Can be combined with a graphical environment and GUI (ex. Qt library)
  - Integrated in the CMS Iguana Framework
Debugging tools: OLAP

Graphical indication of detected overlaps

Geant4 Macro:

```
/vis/scene/create
/vis/sceneHandler/create VRML2FILE
/vis/viewer/create
/olap/goto ECalEnd
/olap/grid 7 7 7
/olap/trigger
/vis/viewer/update
```

Output:

```
delta=59.3416
vol 1: point=(560.513,1503.21,-141.4)
vol 2: point=(560.513,1443.86,-141.4)
A -> B:
[0]: ins=[2] PVName=[NewWorld:0] Type=[N] ...
[1]: ins=[0] PVName=[EcalEndcap:0] Type=[N]
B -> A:
[0]: ins=[2] PVName=[NewWorld:0] Type=[N] ...
```

Navigation Histories of points of overlap (including: info about translation, rotation, solid specs)

Red: mother
Blue: daughters
Daughters are protruding their mother