The contribution of STIR to GATE simulation studies

Performance Evaluation of radionuclide imaging systems

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Geant4 Application for Tomography Emission and Radiotherapy (GATE)

- Based on GEANT 4
- Written in C++
- User-friendly: simulations can be designed and controlled using macros, without any knowledge in C++
- Appropriate for SPECT and PET simulations
- Flexible enough to model almost any detector design, including prototypes
- Explicit modeling of time (hence detector motion, patient motion, radioactive decay, dead time, time of flight, tracer kinetics)
- Can handle voxelized and analytical phantoms
GATE: practical features

- Can be freely downloaded, including the source codes
- Can be run on many platforms (Linux, Unix, MacOs)
- On-line documentation, including FAQ and archives of all questions (and often answers) about GATE that have been asked so far
- Help about the use of GATE can be obtained through the gate-user mailing list
- Many commercial tomographs and prototypes have already been modeled (including validation of the model)
Overview of GATE

Emission tomography and especially Positron Emission Tomography (PET) has a fast growing importance in modern medicine for both diagnostic and treatment purposes. At the same time there is a demand for higher imaging quality, accuracy and speed. Enhanced by the wider availability of powerful computer clusters, Monte Carlo simulations are an essential tool for current and future emission tomography developments. Examples for such developments are the design of new medical imaging devices, the optimization of acquisition protocols and the development and assessment of image reconstruction algorithms and correction techniques.

http://www.opengatecollaboration.org/
# GATE modeled PET systems

<table>
<thead>
<tr>
<th>Scanner type</th>
<th>Studied FOM</th>
<th>Agreement</th>
<th>References</th>
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</table>
| ECAT EXACT HR+, CPS   | Spatial resolution  
Sensitivity  
Count rates  
Scatter fraction | about 3 %  
< 7 % good at activity concentrations < 20 kBq/ml about 3 % | Jan *et al* 2005 |
| ECAT HRRT, Siemens    | Spatial resolution  
Scatter fraction  
Scattered coinc profiles  
Count rates | excellent (<0.2 mm)  
< 1 % very good (visual) good (about 10%) | Bataille *et al* 2004 |
| Hi-Rez, Siemens       | Scatter fraction  
Count rates  
NEC curves | about 1 % good at activity concentrations < 40 Bq/ml good at activity concentrations < 40 Bq/ml | Michel *et al* 2006 |
## GATE modeled PET systems

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<tbody>
<tr>
<td>Allegro, Philips</td>
<td>Count rate&lt;br&gt;Scatter fraction</td>
<td>&lt; 8 %&lt;br&gt;8 %</td>
<td>Lamare <em>et al</em> 2006</td>
</tr>
<tr>
<td>GE Advance, GEMS</td>
<td>Energy spectra&lt;br&gt;Scatter fraction</td>
<td>not reported&lt;br&gt;&lt; 1 %</td>
<td>Schmidtlein <em>et al</em> 2006</td>
</tr>
<tr>
<td>MicroPET P4, Concorde</td>
<td>Spatial resolution&lt;br&gt;Sensitivity&lt;br&gt;Miniature Derenzo phantom</td>
<td>about 7 %&lt;br&gt;&lt; 4 % visual assessment</td>
<td>Jan <em>et al</em> 2003</td>
</tr>
<tr>
<td>MicroPET Focus 220, Siemens</td>
<td>Spatial resolution&lt;br&gt;Sensitivity&lt;br&gt;Count rates for mouse phantom</td>
<td>about 5 %&lt;br&gt;about 3 %&lt;br&gt;prompt coinc: &lt; 5.5 %&lt;br&gt;delayed coinc: &lt; 13 %</td>
<td>Jan <em>et al</em> 2005</td>
</tr>
<tr>
<td>Mosaic, Philips</td>
<td>Scatter fraction&lt;br&gt;Count rates</td>
<td>about 5 %&lt;br&gt;4-15 %</td>
<td>Merheb <em>et al</em> 2005</td>
</tr>
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</table>
GATE: time-dependent processes

- SPECT and PET intrinsically involves time:
  - Change of tracer distribution over time (tracer biokinetic)
  - Detector motions during acquisition
  - Patient motion
  - Radioactive decay
  - Dead time of the detector
  - Time-of-flight PET
GATE examples

GE Advance/Discovery LS PET scanner
Schmidtlein et al, Med Phys 2006

GE Advance/Discovery ST PET, 3D mode
Schmidtlein et al. MSKCC

HR+ECAT EXACT PET scanner
Karakatsanis et al, NIM A, 2006

Siemens Biograph PET scanner
Karakatsanis et al, NIM A, 2006
Modeling realistic phantoms

Segars et al, IEEE TNS 2001

Segars et al, Molecular Imaging and Biology 2004

Descourt et al, IEEE MIC Conf Records 2006
Software for Tomographic Image Reconstruction (STIR)

- **Open Source** software for use in tomographic imaging.
- Provides a Multi-Platform **Object-Oriented** framework for all data manipulations in tomographic imaging.
- Currently implemented for (iterative) image reconstruction in **PET**
- STIR consists of 2 parts
  - A library providing building blocks for image and projection data manipulation and image reconstruction.
  - Applications using this library including basic image manipulations, file format conversions and of course image reconstructions.
STIR supported file formats

- GE Advance native sinogram format, but for reading only (with very limited support for the header).
- ECAT 6 matrix format by using conversion utilities to and from Interfile. Single frame/gate/bed images can be directly read or written.
- ECAT 7 matrix format for reading only (currently, an Interfile header has to be created using a utility). Single frame/gate/bed images can be directly read or written. Single frame/gate/bed sinograms can be directly read.
- In addition, a separate set of classes is available to read list-mode data. Only a few scanners are currently supported (such as the ECAT HR+ and HR++)

Finally routines will be provided by the OpenGate collaboration for reading output of GATE Monte Carlo simulator.
3-D sinogram description

- **Image slice**: Geometrically associated to a cylindrical volume defined by a slice of the FOV. By convention, a slice is half the width of a ring. For a scanner of n detector rings, there are 2n–1 image slices.
- **Direct plane Image slice** centred on a ring. For a scanner of n detector rings, there are n direct planes. The axial FOV is ended by two direct planes centred on the first and last rings.
- **Cross plane Image slice** in between two consecutive direct planes. Direct planes are adjacent to cross planes. For a scanner of n detector rings, there are 2n–1 cross planes.
- **Sinogram**: Set of bins corresponding to 1 segment and 1 axial position. Before axial compression, this corresponds to LORs in a detector ring (direct sinogram) or between two different detector rings (oblique sinogram).
  - For a scanner of n detector rings, there are
    - n direct sinograms and
    - n*n–n oblique sinograms for a total of n*n sinograms
3-D sinogram description

- **Ring difference:** Distance between two rings associated to a sinogram. If ringA and ringB are the ring index numbers, the ring difference is given by:  \( \text{ringB} - \text{ringA} \)
- The ring difference of a direct sinogram is zero.
- **Segment:** Set of sinograms with a common ring difference
- **Bin:** A single element in a sinogram, completely specified by its segment, axial position, view and tangential position.
Michelogram representation

- Michelogram (3-D sinogram): Representation of 2-D sinograms on a square grid as shown below

Figure 1: Michelogram with span=7
Sinogram binning method
[GATE-STIR connection]

- ROOT C++ routine implemented
  - bin GATE projection data to form a 3-D sinogram (interfile format) suitable for STIR

Gate uses the Crystal, Block and Module identification numbers (IDs) to store detection events in ROOT

Sinogram binning method uses these IDs of detected events to organize sinograms

ROOT ID’s for each coincidence pair are converted into crystal-ring pairs through INT and MOD calculations

Schmidtlein et al, Medical Physics, 2006
LORs are binned into a block matrix with index dimensions in the $\phi$ (azimuthal), $r$ (radial) and $\theta$ (ring difference) directions.

**Azimuthal binning**
For each projection plane the sum of the crystal numbers ($C#$) for a coincidence pair will always sum to one of the two numbers that are unique to a particular projection plane

$$i = [(\text{Crystal}_1 + \text{Crystal}_2) + \text{Const}]$$

where const is an arbitrary constant which satisfies the boundary condition $\phi=0$

**Radial binning**
The radial distance from the center of the scanner is related to the index difference of the crystals in the pair. In terms of indexing, the index $j$ for $r$ can be expressed as

$$\text{abs}(j) = N/2 - \text{abs}((\text{Crystal}_1 - \text{Crystal}_2))$$

with $j$ in the time space of $[0,N/2)$ for the case of interlacing
GATE – STIR study: Zubal phantom

GATE simulated Zubal data reconstructed with STIR (OSMAPOSL)

Original activity map
A single central slice

1sec acquisition time
single activity slice

10sec acquisition time
single activity slice

10sec acquisition time
4 neighboring activity slides included
Modeling realistic phantoms

Simulation configuration in GATE

PET bone reconstructed data
STIR OSMAPSOL (6 iterations)

Sagittal slice.

Transverse slice

Sakellios et al, IEEE MIC Conf Records 2006
**Minimum Detectable Activity [GATE- STIR]**

**Results:** Performance analysis of Biograph 6 in terms of MDA

Reconstructed image data for the LSO-based Biograph 6 GATE model

The simulated projection data were histogrammed into time frames of 15min, 10min, 5min and 1min respectively.

Each frame was later reconstructed using FBP-3DRPJ algorithm of STIR package.

It consists of four different signal to background ratio regions, beginning at left with the highest ratio (region A) and ending to the right with the lowest ratio region (region D).
Thank you!

We would like to thank the OpenGATE collaboration and the STIR developers community for allowing us to use the open source software for the presented radionuclide imaging studies.