Overview of Geant4 Use and Issues in Imaging:

Emission Tomography (PET and SPECT)

Assen S. Kirov
Department of Medical Physics
Memorial Sloan-Kettering Cancer Center
New York
Why simulate imaging systems and scans?

• Better understand and model phenomena affecting image quality and accuracy

• Optimize scan imaging and processing parameters

• Calculate parameters needed for improved image reconstruction
**Basis of this talk**

Membership in the  
**OpenGATE collaboration**  
(www.opengatecollaboration.org)

Whose goal is

- the creation of an elaborate and flexible Monte Carlo program that allows realistic simulation of the physical processes, detector geometry and all factors affecting emission tomography applications

- realistic modeling of patient and small animal anatomy

- based on GEANT4
Basis of this talk

• Product of OpenGATE: GATE (GEANT4 Application for Tomographic Emission)

• Widely used for
  – PET
  – SPECT

• Potential for CT (why not?)

• Potential for Radioimmunotherapy and Nuclide Therapy dosimetry

Jan et al, PMB 49 (2004) 4543
Use of GEANT4 prior to GATE for imaging

• GEANT3 and GEANT4 based codes
  – example Jan S (Thesis) : GePETos

• Summary of other codes:
  – Buvat and Castiglioni (Q J Nuc Med, 46, p 48-61, 2002)
GATE architecture

User Layer

Application Layer

Core Layer

GEANT 4

Jan et al, PMB 49 (2004) 4543
User Layer

- Verbosity and visualization
- Geometry
- Digitizer
- Physics
- Sources
- Outputs
- Experiment

...
GATE systems

- Geometry organization: Hierarchical structures
  - For realistic signal processing organization
  - Simplifies geometry input

GATE system:

\{Hierarchically organized geometry + corresponding LMF output\}

5 GATE systems

SPECT - 1
PET – 3 (2 block based, 1 pixelated)
Generic -1

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GATE time and movements

Needed for:
- Patient and organ motion
- Scanner rotation
- Activity distribution changes

GEANT4 limitations:
- geometry: static during simulation
- no source movements

Solutions in GATE:
- Geometry updated between simulation time steps
- The source is confined to a smaller volume moving inside a larger emission volume


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GATE physics

- **Sources**
  - Particle type, position (volume), direction (solid angle), energy (spectrum), activity
  - Modified GEANT4’s RDM – *virtual clock* defines absolute time used to initialize GEANT4’s internal tracking time
  - Multiple, **voxelized** sources
  - e⁺ emission (Jan 2002):
    - β⁺ spectra parametrization - faster
    - annihilation photon noncolinearity

- **GEANT4’s interaction processes and cuts**

*Jan et al*, PMB 49 (2004) 4543
- Resolution blurring, spatial blurring, crosstalk
- Parallelizable and non-parallelizable dead times
- Coincidence processing
- Post simulation processing of output files stored before digitization
GATE validation

- **PET** at least 5 patient and microPET scanners
  - energy spectra, sensitivity, resolution, scatter fraction, count rates, image quality, contrast recovery

- **SPECT** at least 5 systems
  - energy spectra, sensitivity, resolution,…

- **Prototype** at least 4 systems
  - energy spectra, sensitivity, resolution…

GE Advance/ DLS PET scanner
MC based coincidence count rates for IQ phantom

See Schmidtlein et al, SU-EE-A4-03  Mod. Poster at this meeting
Other issues

• **CT simulations** – GATE could handle the geometry, not tested yet

• **Optical imaging** – very promising field for GEANT4: small animal; 3D dosimetry (see Kirov et al, SU-FF-T-229 at this meeting), etc.

• **Worst GATE/GEANT4 problem for imaging**
  
  » Very time consuming simulations

  **35 CPU days** on 2 GHz !!
Conclusions

• GEANT4 with GATE - powerful, flexible, convenient for use and accurate tool for nuclear medicine imaging applications

• GEANT4 without GATE: worth pursuing only if a new approach can drastically improve performance

• Efficiency: work needed