Monte Carlo simulations in emission tomography and GATE: an overview

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Outline

- Evolution of the use of MC simulations in ET since 1995
- Evolution of the codes used for MC simulations in ET since 1995
- New features in MC simulators in ET
- New applications for MC simulations
- Upcoming developments in MC simulations
- Conclusion
Evolution of the use of MC simulations in ET since 1995

Important role in SPECT and PET, for optimizing detector design, designing and assessing acquisition and processing protocols.


• Buvat and Castiglioni, Monte Carlo simulations in SPET and PET. *Q J Nucl Med* 46 (2002) 48-61
Evolution of the use of MC simulations in ET since 1995

- 666 entries since 1995 at the date of the search (July 1995)
- Use of MC simulations to produce SPECT and PET images: 130 entries

Number of full papers

Year


86% SPECT 14% PET
0 small animal

65% SPECT 35% PET
5 small animal

28 labs
33 labs
Evolution of the codes used for MC simulations in ET since 1995

1995-1999

• 14 different codes:
  - 10 « home-made »
  - 4 publicly released or available from authors

No « standard » code for Monte Carlo simulations in SPECT and PET

Most frequently used

- SimSET
- SIMIND

2000-2004

• 15 different codes:
  - 8 « home-made »
  - 7 publicly released or available from authors

And recently

- Geant 4
- Penelope
- GATE
Most recent code: GATE

- Motivation in 2001: provide a public code
  - based on a standard code to ensure reliability
  - enabling SPECT and PET simulations (possibly even more)
  - accommodating almost any detector design (including prototypes)
  - modeling time-dependent processes
  - user-friendly
- Developed by the OpenGATE collaboration (21 labs)
- Based on GEANT4
- Publicly released May 2004:  http://www.opengatecollaboration.org

- More than 400 subscribers to the Gate users mailing list
- IEEE MIC 2004: 61 proceedings involving MC simulations in SPECT and PET
  - 11 used GATE, 9 used GEANT4, 8 used SimSET, 4 used SIMIND
Monte Carlo simulations today
Modeling time dependent processes

Possible using SORTEO, SimSET and GATE

Reilhac et al, IEEE TNS 2005

Harrison et al, IEEE MIC Conf Rec 2004

Santin et al, IEEE TNS 2003

Groiselle et al, IEEE MIC Conf Rec 2004

$$^{15}\text{O} (2 \text{ min})$$

$$^{11}\text{C} (20 \text{ min})$$

No TOF

700 ps

500 ps

300 ps
Increasing the throughput of the simulations

Using acceleration methods

• Variance reduction techniques such as importance sampling (e.g. in SimSET)

  speed-up factors between 2 and 15

• Fictitious cross-section (or delta scattering)

Combining MC and non MC modeling

Full MC  ARF
Song et al, Phys Med Biol 2005

increase in efficiency > 100

Parallel execution of the code

Thomason et al, Comp Methods Programs Biomed 2004
Modeling original detector designs

Non-conventional geometries

Spherical geometry of the Hi-Rez PET scanner

Lazaro et al, SNM 2005

Prototypes

IASA CsI(Tl) gamma camera

Energy spectrum

Lazaro et al, Phys Med Biol 2004

<table>
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<th>Number of counts</th>
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Experiment

GATE

shielding
collimator
PSPMT
crystal
New applications for Monte Carlo simulations

1995-1999
- Design and assessment of correction and reconstruction methods
- Study of an imaging system response
- Use in the very imaging process
- Data production for evaluation purpose
- Description and validation of a code

2000-2004
- Design and assessment of correction and reconstruction methods
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- Use in the very imaging process
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- Description and validation of a code
Using Monte Carlo simulations for calculating the system matrix

\[ p = R f \]

"Object" f

Projection p

\( R(i,j) \): probability that a photon emitted in voxel j be detected in pixel i

Calculating \( R \) using Monte Carlo simulations:
- for non conventional imaging design (small animal)
- to account for fully 3D and patient-specific phenomena difficult to model analytically (mostly scatter)

Using Monte Carlo for feeding database

### The MC-ET database

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<th>No.</th>
<th>Description of study</th>
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Reilhac et al, IEEE TNS 2005
What next?
Bridging the gap between MC modelling in imaging and dosimetry

Accurate dosimetry in 131I radionuclide therapy using patient-specific, 3-dimensional methods for SPECT reconstruction and absorbed dose calculation

Dewaraja et al, J Nucl Med 2005
Modeling hybrid machines (PET/CT, SPECT/CT, OPET)

Integrating Monte Carlo modeling tools for:
- common coordinate system
- common object description
- consistent sampling
- convenient assessment of multimodality imaging

Brasse et al, IEEE MIC Conf Rec 2004
Alexandrakis et al, Phys Med Biol 2005
Designing realistic phantoms

Interfacing realistic phantoms with simulator input

Segars et al, **IEEE TNS 2001**

MOBY


Making it easier to model a wide range of body habitus and physiological motions
Conclusion

- Monte Carlo simulation is a more and more accurate modelling tool in SPECT and PET
- They will be more and more present in (nuclear) medical imaging in the future:
  - as an invaluable guide for designing imaging protocols and interpreting SPECT and PET scans,
  - in the very imaging process of a patient
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