Evolution of the GATE project: new results and developments


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We present the status of the Geant4 Application for Emission Tomography (GATE) project, a Monte Carlo simulator for Single Photon Emission Computed Tomography (SPECT) and Positron annihilation Emission Tomography (PET). Its main features are reminded, including modelling of time dependent phenomena and versatile, user-friendly scripting interface. The focus of this manuscript will be on new developments introduced in the past 4 years. New results have been achieved in the fields of validation on real medical and research PET and SPECT systems, voxel geometries, digitisation, distributed computing and dosimetry.

1. INTRODUCTION

Simulations play a key role in functional imaging, with applications ranging from scanner design, to image reconstruction, scatter correction, protocol optimisation [1]. Analytical models provide rapid response and are often preferred to more complex simulation approaches when speed is required, but at the cost of approximations in the description of physics processes, geometry or system response. Monte Carlo (MC) is now widely used in parallel to analytical computations or experimental studies. Previous dedicated tools offered fast development cycle, and optimisations (with remarkable impact on computing speed) were possible by limiting the application range, or reducing the level of detail on physics and geometry models.

Research groups and clinical users share the need for new generation simulation tools offering ease of use, precision and speed, together with flexibility and support of the software implementation. GATE [2] intended to answer to the requirements from these two communities.

2. STATUS AND EVOLUTION OF THE GATE PROJECT

A number of simulators for PET and/or SPECT were developed in the nineties and early 2000’s [3], suggesting that until recently no code was considered as a standard for MC simulations in emission tomography. A new code, GATE, has recently been designed as upper layer of the GEANT4 toolkit [4] with the ambition to become the gold standard in nuclear medicine simulations.
GEANT4, an open source project with collaborative development and long-term support, was chosen as core element for the good description of physics and geometry models, and the modern software technology. Ease of use and tailoring for use in PET and SPECT are covered by GATE specific developments. The usability of GATE is greatly improved by a scripting mechanism by which users can design and control complete simulations (from geometry model to activity and detector response) using macros, without any C++ coding [5]. A number of PET and SPECT commercial and research tomographs, together with commonly used phantoms, have been modelled in GATE via the scripting mechanism [6][7][8][9].

Explicit modelling of time includes detector motion, patient motion, radioactive decay, dead time, time of flight, tracer kinetics [10]. Interfaces to voxelised models and image reconstruction packages improve the integration of GATE in the global modelling cycle.

The OpenGATE collaboration [11], counting at present 22 laboratories, shares long-term development, validation, documentation, and support of the tool. Access to the GATE software is open, offering to registered users (more than 1000, worldwide, at the time of writing) source code and support tools (e.g. documentation, mailing lists).

2.1. Recent developments

The possibility to load voxel geometry (and source) models was added to GATE. The interface includes generic internal treatment of voxel elements and dedicated developments for input of various formats [12], also with variable voxel size [13]. Besides the traditional use as input for the material description, the voxel model can also be used as a map of source activities, overlaid onto the geometry.

The relevance of the correction of movement artefacts is increasing with the improvement of the scanner resolution, and the availability of description of these movements in realistic phantoms a key feature in modern simulation tools. On top of the generic voxel models, dedicated interfaces to specific widely used phantoms were recently added to GATE: the 4D NURBS-based Cardiac-Torso (NCAT) and the 4D Digital Mouse Whole Body (MOBY) phantoms [14][15] are available (as geometry and activity maps), fully integrating the model respiratory and cardiac motions and time-dependent activities within each organ with the GATE time management [16].

Significant improvements were made to the detector response simulation (“digitizer”): new processing types are available for the assembly of the linear signal processing chain, including configurable dead time [17][7].

Other recent developments include the extension of GATE to the dosimetry application domain [18], user-friendly interfaces to the GEANT4 optical photon tracking, and a new Graphical User Interface.

A major collaboration effort aims at performance improvement through efficiency optimisation (variance reduction techniques include importance sampling and forced detection) [19] and distributed computing (with openMosix, Condor, and so on) [20]. A truly parallel version with MPI is also under construction and first results are demonstrated on worldwide computer grids.

Developments are ongoing for the integration of modelling tools for hybrid scanners (including SPECT/CT, PET/CT, OPET) [21][22][23][24][25].

Recent clinical applications of GATE include a study on contamination effects in TI-201 myocardial perfusion imaging [26].

3. CONCLUSIONS AND OUTLOOK

Simulations will be more and more present in (nuclear) medical imaging in the future: for designing imaging protocols and interpreting SPECT and PET scans, in the very imaging process of a patient. GATE has become a popular tool for Monte Carlo simulations in emission tomography, with collaborative effort in development, validation and support by the OpenGATE collaboration. Thanks to the significant results obtained by the wide user community, it is hoped by the authors that GATE, nowadays considered as tool of excellence in the domain, will become the gold standard simulator in nuclear medicine.

REFERENCES

2. S. Jan, G. Santin, D. Strul, S. Staelens et al. (OpenGATE collaboration), “GATE: a