The OpenGATE Collaboration

GATE developments and future releases

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Outline

✓ Theranostics modeling
✓ Radiobiology
✓ Optics
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✓ Theranostics modeling
✓ Radiobiology
✓ Optics
Theranostics concept

- Therapeutic strategy (e.g. chemotherapy, hyperthermia, photodynamic, radiation therapy) combined with one or more in-vivo imaging modalities (e.g. PET, SPECT, CT, MRI)
- This concept is a current trend towards achieving personalized medicine (use of imaging to guide and monitor response to therapy)

Main issue

- There is currently no integrated software platform allowing for the in-silico simulation of a broad variety of theranostic scenarios that could help in designing, optimizing, testing and validating such protocols targeting different clinical applications

Consortium 2014-2018

- Inserm LATIM – Brest (PI)
- CNRS Creatis – Lyon
- CNRS / CEA / Inserm – Orsay
- Inserm – Toulouse

Funding: French National Research Agency
T-GATE: platform for theranostics modeling

New approaches to define a virtual patient with GATE

► Generic voxelised volume (patient / phantom): multi-scale description, mixing high and low resolution

► Combining voxelised and analytical phantom description – Merging Mesh volume within a voxelised volume

Patient CT image

Artificial implants

Anatomical details
New approaches to define a virtual patient with GATE

Combining voxelised and analytical phantom description

► H**Y**brid Voxelized A**N**alytical primitive (YVAN)
  ► Generic approach with a main navigator
  ► Analytical objects are inside a voxelized phantom (medical applications)
  ► Any type of analytical objects
  ► Any type of particles

New YVAN primitive
Geant4 YVAN solid

Geant4 tessellated solid

Geant4 navigator

voxelized solid
Combining voxelised and analytical phantom description

Demonstrator: accurate seed simulation in brachytherapy application
T-GATE: platform for theranostics modeling

Multi Resolution Issues

- Simulation and modeling at the microscopic scale:
  - Physical processes
  - Introducing ‘tissue’ properties

- Management of nano-object nanoparticles as theranostic agents

- Multi-physics: hybrid MC and analytical description
  - Light and heat propagation by solving the diffusion equation
Thermal Therapy modeling with GATE

Hybrid approach
1. MC for photon/NanoObjet interactions
2. Analytical for heat diffusion

Optical photons

Monte-Carlo simulation

Analytical simulation

\[
\frac{\partial T(x, y, z, t)}{\partial t} = \nabla \cdot [k \nabla T(x, y, z, t)] + \sigma (T_{\text{Blood}} - T)
\]

Conduction

Heat loss to blood (advection)
Development of a **hybrid MC-analytical** simulation module

- Investigate algorithms combining Monte-Carlo and deterministic methods to speed-up computation in specific situations (radiotherapy - dosimetry)
- Group all those algorithms into an “**hybrid module**”

**Speed-up computing**

- Computation of absorbed dose distribution for low energy photon beam (<1 MeV)
- Based on TLE (Track Length Estimator) combined with low statistic Monte-Carlo and splitting
- 10^5 time faster than analog Monte-Carlo.
- **Available since 7.1**

**Split exponential track length estimator for Monte-Carlo simulations of small-animal radiation therapy**

F Smekens, J M Létang, C Noblet, S Chiavassa, G Delpon, N Freud, S Rit, and D Sarrut

- Université de Lyon, CREATIS CNRS UMR5220, Inserm U1044, INSA-Lyon, Université Lyon 1, Centre Léon Bérard, France
- Inserm UMR 892, IRT UN, F-44007 Nantes, France
- Institut de Cancérologie de l’Ouest, Centre René Gauducheau, Saint-Herblain, France

**Monte Carlo simulation of prompt γ-ray emission in proton therapy using a specific track length estimator**

W El Kanawati, J M Létang, D Dauvergne, M Pinto, D Sarrut, E Testa, and N Freud

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Outline

✓ Theranostics modeling
✓ Radiobiology
✓ Optics
Developments of tools for radiobiology
- 2D & 3D cell models
- Cell population modeling
- Cell irradiation
- Survival fraction
- Interactions with DNA
- Evaluation of DNA damage

Cell population modeling
- Definition of cell properties
  - Shape, size, components
  - Cellular phase, number
- Spatial positioning optimization
  - Grid, forces
- Realistic cell population
  - Integration into GATE simulations

CPOP library for the geometrical representation of 2D and 3D cell populations. C++ based, open-source and cross-platform, compatible with GATE
Developments of tools for radiobiology

► DNA geometry: atomic representation of DNA based on PDB files (Protein Data Bank)

PDBlib C++ library:

► Load the geometry into memory
► Algorithm to build a 3D architecture into continuous water medium
► Geant4 geometry (spheres) for visualization purpose only

Available Geant4 release 10.1

Random assembly of nucleosomes

► At the moment
  ► Nucleosome

► On going
  ► Expand the nucleosome geometry
✓ Theranostics modeling
✓ Radiobiology
✓ Optics
Optics

Implementation of a scintillator surface model in GATE using measured surface properties

An approach based on 3D measurements of crystal surfaces
- 3D topography obtained by Atomic Force Microscopy
- No analytical description of the surface
- Computing reflectance and angular distribution of reflected rays at various angles of incidence
- Storing in look-up-table (LUT)

3D view and line profiles of 90 µm x 90 µm LSO crystal surfaces scanned with AFM

Creating inherited GATE classes from G4OpticalSurface and G4OpBoundaryProcess to implement a “LUT optical” model
Bug Fixes

► **Compatibility with Geant4 version 10.1.p01** (Mojca Miklavec, following suggestions from Andrea Dotti (Geant4 collaboration))

► Bug in **voxelized dose calculations** for a phantom. Wrong material handler in voxel value to material translator (using both range and Hounsfield converters), giving wrong density values and therefore erroneous dose calculations (Alex Vergara Gil)

► Changes, cleaning and other stuffs: unobtrusive in sequential Gate, but necessary in order to move to MT (Alex Vergara Gil)

► Required changes to make **Gate C++11 compatible** (Alex Vergara Gil)

► Major cleanup of floating point constants and random number usage (Gergely Patay)

► Bug causing string buffer overflow for certain time slices (Gergely Patay)

► Fix the use of IAEA phase space files (Germano Russo)
Many contributions to GATE source code during the last months have been provided by people external to the OpenGATE collaboration.

GitHub made this possible in a relatively simple way.

GATE is now publicly available on GitHub at https://github.com/OpenGATE/Gate
GitHub

https://github.com/OpenGATE/Gate

- A web-based Git repository hosting service
- Offering all of the distributed revision control and source code management functionality of Git
- Adding its own features
  - Online browsing tool for accessing the source code
  - Access control
  - Several collaboration features: bug tracking, feature requests, task management, and wikis

- The stable version is branch 'master' (or tag '7.1')
  http://github.com/OpenGATE/Gate/tree/V7.1
- The current development version is branch 'develop' (default)
  http://github.com/OpenGATE/Gate/tree/develop
Once merged, pull-requests, commits and corresponding source code changes can be visualized using GitWeb

http://git.opengatecollaboration.org/gitweb/?p=opengate.git;a=shortlog;h=refs/heads/develop
To conclude

Release V7.2 – Spring 2016
- DICOM reader
- New hybrid algorithm (split & exponential-TLE → 10 to 15 times faster than TLE)
- New “source” to speed-up the $^{90}$Y bremsstrahlung photon production – PET imaging applications
- New image reader classes for activity distribution (many types, float …)

Potential V8 – End 2016
- New optical module
- Developments provided by the T-GATE project
- Developments for radiobiology applications
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