

EduGATE – basic examples for educative purpose using the GATE simulation platform

Uwe Pietrzyk^{1,2,*}, Abdelhamid Zakhnini^{2,3}, Markus Axer^{1,2}, Sophie Sauerzapf^{2,4}, Didier Benoit⁵, Michaela Gaens¹

¹ Institute of Neurosciences and Medicine (INM), Research Center Juelich, Germany

² Department of Mathematics and Natural Sciences, University of Wuppertal, Germany

³ HZDR - Resource Ecology, Research Site Leipzig, Germany

⁴ Department of Nuclear Medicine, University Hospital Freiburg, Freiburg, Germany

⁵ Imagerie et Modélisation en Neurobiologie et Cancérologie (IMNC), Orsay, France

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Abstract

EduGATE is a collection of basic examples to introduce students to the fundamental physical aspects of medical imaging devices. It is based on the GATE platform, which has received a wide acceptance in the field of simulating medical imaging devices including SPECT, PET, CT and also applications in radiation therapy. GATE can be configured by commands, which are, for the sake of simplicity, listed in a collection of one or more macro files to set up phantoms, multiple types of sources, detection device, and acquisition parameters. The aim of the EduGATE is to use all these helpful features of GATE to provide insights into the physics of medical imaging by means of a collection of very basic and simple GATE macros in connection with analysis programs based on ROOT, a framework for data processing. A graphical user interface to define a configuration is also included.

Keywords: Monte Carlo Simulation, GATE, PET, SPECT, Education, Imaging

EduGATE – einfache lehrreiche Beispiele zum Zweck der Ausbildung basierend auf der GATE Simulationsplattform

Zusammenfassung

EduGATE ist eine Sammlung einfacher basaler Beispiele für Studenten zur Einführung in die fundamentalen Aspekte der bildgebenden Systeme in der Medizin. Sie baut auf der GATE-Plattform auf, die im Feld der Simulation bildgebender Systeme besonders SPECT, PET, CT, ebenso auch Strahlentherapie eine weite Verbreitung gefunden hat. GATE wird gewöhnlich durch Kommandos gesteuert, die zur Vereinfachung in eine Reihe von Dateien (Makros) zusammengefasst sind und Phantome, verschiedene Typen an Quellen, Nachweisdetektor und Akquisitionsparameter beschreiben. Das Ziel, EduGATE zu entwickeln, war, diese vielfältigen, sehr nützlichen Eigenschaften zu nutzen, um mithilfe sehr einfacher GATE-Makros dem interessierten Nutzer Zugang zur Physik der medizinischen Bildgebung zu ermöglichen, verbunden mit einem Analyseprogramm basierend auf ROOT, einem Softwarepaket für Datenanalyse. Eine graphische Benutzerschnittstelle zur Definition der gewünschten Konfiguration ist eingeschlossen.

Schlüsselwörter: Monte-Carlo-Simulation, GATE, PET, SPECT, Bildgebung, Ausbildung

* Corresponding author: Prof. Dr. Uwe Pietrzyk, Institute of Neuroscience and Medicine, Research Center Juelich, 52425, Jülich, Germany.
E-mail: u.pietrzyk@fz-juelich.de (U. Pietrzyk).

- Long is the way of theory, short and effective by examples -

(Lucius Annaeus Seneca (the Younger), Epistulae morales)

Introduction

GATE (Geant4 Application for Emission Tomography) is a widely used Monte Carlo Simulation platform, which is being developed by the OpenGATE collaboration [1] since 2001. Following the first public release of GATE in 2004 [2] a major enhancement, referred to as GATE V6, was recently published in 2010 [3]. Besides the introduction of simulating CT (X-ray Computerized Tomography) and radiotherapy, the recent version allows the selection of various physical models for a specific process, but also the simulation of optical and hadronic processes, and options for speeding up GATE simulations. GATE has proven to be a powerful and worldwide well received tool to design and study medical imaging devices owing to the flexibility to build a device based on the simple usage of macros. While such devices can be very complex, GATE also offers the option to construct very basic setups, which, in connection with simple source and phantom arrangements, allows experiencing the effect of the underlying fundamental physical processes that can in addition be selectively switched on or off, according to the users specification. It was exactly this feature of GATE that led us to use this powerful simulation package for educational purposes during basic, but also advanced lectures in medical physics and medical imaging. A preliminary version of “EduGATE”, as we named the collection of educational examples, has been successfully used for demonstrations during lectures in medical physics. This encouraged us to make our collection available and prepare a contribution for potential users interested in applying such a utility during education and also as a starting point for practical exercises. Here we provide details about the current collection of examples, describing the basic options, which come with the examples, starting with configuring very simple setups. The collection of examples is available via the official GATE web site and as such freely available as is the GATE package. The current versions of the examples are set up for GATE V6.0 and V6.1.

Methods and Materials

EduGATE is fully integrated in the GATE environment; hence, it is operational whenever GATE and GEANT4 are correctly implemented. Besides the macros, which are required to run an experimental configuration within GATE, there are data analysis modules provided and applicable within the ROOT environment [4]. ROOT is a framework for data processing, developed at CERN for the purpose of saving, accessing, processing and visualizing large amount of data, as often happens in high-energy physics. The utilities provided by ROOT are also available within the GATE-framework. It is possible to store a history of hits, indicating the path of a particle through a detector, its interaction, including all

Table 1

A collection of possible parameters or options is stored in Coin_chan.txt. This file can be edited to include additional parameters that can be selected within the menu.

File: Coin_Chan.txt

```
ViewPointThetaPhi: 0 90; 90 0; 89 90; 30 30;
VisuOnOff: novisu; visu;
SourceActivity: 100. Bq; 1000. Bq; 10000 Bq; 100000. Bq;
Nb_Detectors: 2; 64;
CrystalMaterial: LSO; BGO; NaI;
PhantomMaterial: Water; Air; Vacuum; Lead; PVC; Plexiglass;
PhanRmax: 18 mm; 20 mm; 25 mm;
PhanRmin: 13 mm; 15 mm; 17 mm;
Phan_Source_Pos: 0.0 0.0 0.0 mm;
SourceVolMaterial: Water; Air; Vacuum; PVC; Plexiglass;
SourceEnergy: 511 keV; 100 keV;
RootFileName: Coin_Chan_{Nb_Detectors}_{PhantomMaterial};
```

major coordinates and parameters, essential for later analysis like energy, volumes of interaction, starting position (x,y,z) within a source volume and position (x,y,z) of the final interaction within a scintillator crystal. In general, the output generated by GATE is stored as binary data (“Root-File”) readable by the accompanying ROOT macro, written in C++. Such ROOT macros provide with basic histogram options, which can easily be extended and modified by the user. The GATE macros (text-files containing commands interpreted by GATE) are subdivided into major parts, describing the phantom(s), the selection of sources, the imaging device/camera, the digitizer, the selection of physics models and finally visualization options. This general structure has been maintained throughout all examples provided within the EduGATE project. To simplify the selection of parameters like source activity, phantom materials or type of source, a single configuration macro has been created, which lets the user control the simulation by setting the respective values, that are replacing aliases in the other macro files. In order to avoid editing files during demonstration, a ROOT-based graphical user interface has been created to allow the user selecting parameters from a list, which can be prepared by the user beforehand to cover the examples he wants to show to the audience. An example of the interface is given in Figure 1. Table 1 gives an example of an initial configuration that the user can edit for his preferences.

The initial collection of examples comprises two different basic imaging setups, namely: coincidence channel (Coin_Chan) and gamma camera. The basic setups are shown in Figure 2 for the coincidence channel and in Figure 4 for the gamma camera, respectively.

Coincidence Channel

The general setup of this “Coincidence Channel” (Fig. 2a) is taken from the Cylindrical PET example, which comes with the GATE distribution, but has been simplified for the purpose of EduGATE. To start with, the type of source has been chosen

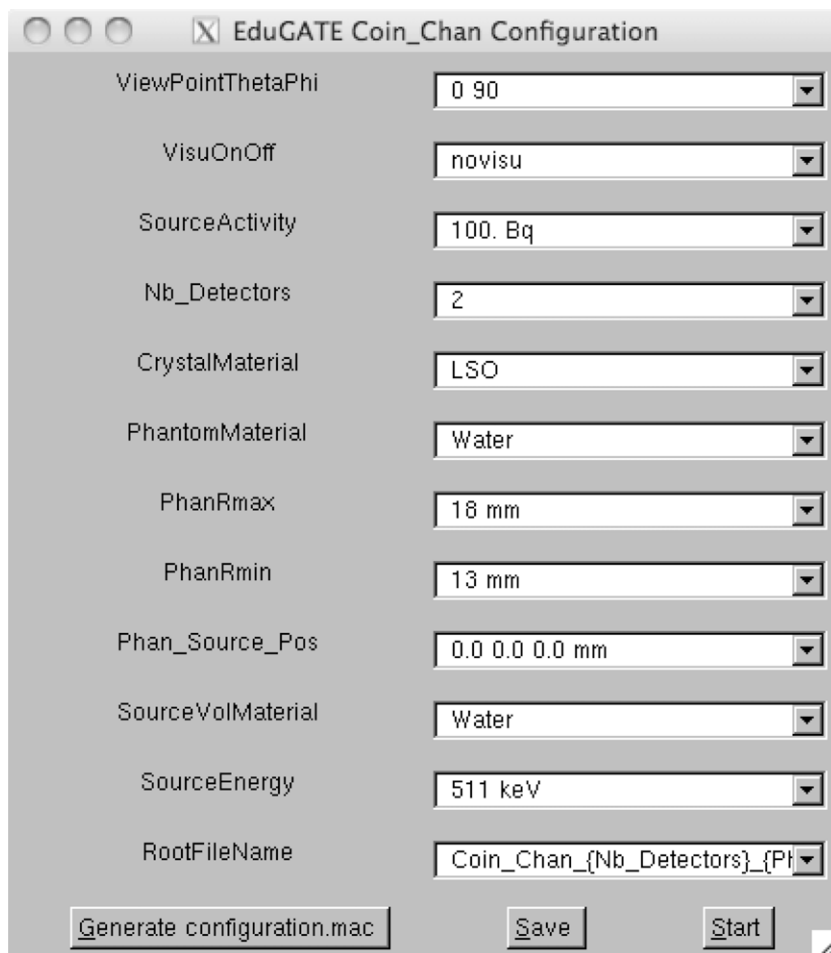


Figure 1. Interactive selection of a configuration. Click the “Save”-button to store the current settings as default in file “Coin_Chan.txt” for the future. Click “Generate configuration.mac” to save the current setting in configuration.mac, which after clicking “Start” will be used for the next run.

as two gammas (shown as green lines in Figure 2a and b) emitted back-to-back from an annihilation event. There is no explicit generation of a positron emitted from a nucleus and a subsequent annihilation with an electron. However, the interested user, following the rules for GATE to define sources, can easily introduce this. Also, to speed up the demonstration, the emission of the two co-linear gammas is artificially limited in the angular range. This results in a much faster generation of a large number of detected events, sufficient to show meaningful distributions of for instance the system response function. The material of the volume surrounding the source (named source_vol, cylinder of 30 mm radius) shown in white can be selected in the configuration file. The needle-like source has a size of 0.1 mm radius and length of 30 mm. The phantom (i.e attenuating volume) is shown in blue. Here, the thickness can/should be adjusted by varying the respective radii of the cylindrical phantom aliased to PhanRmax/PhanRmin in order to study the effect of attenuating or scattering material on gammas at different energies. The coincidence channel is the basic

setup, consisting of two detector modules shown as red boxes. The users, however, can extend this system by setting the number of detectors to a higher number like 8, 16, 32, or even 64, ending up with a fully equipped PET system (see Figure 2b). The green lines shown in Figure 2b again represent gammas, unscattered and scattered, whereas the red line represents an electron (Colors predefined in GEANT/GATE as green for neutral, red for negative and blue for positive particles). The material of the crystal used for detecting the gammas can be varied among various types.

An analysis program based on ROOT and provided with the EduGATE-distribution yields a short statistical evaluation:

total coincidences	: 71298
true unscattered coincidences	: 69910
random coincidences	: 37
scattered coincidences	: 1351
ratio scatter/true	: 0.0193248

Two basic plots are shown in Figure 3, with the transaxial detection position in Figure 3a. Also the position of source in

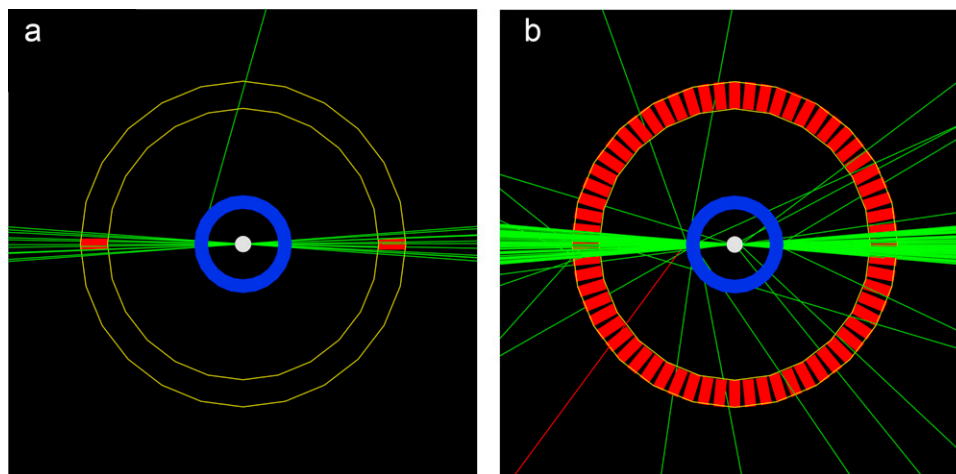


Figure 2. a: General setup of the Coincidence Channel as seen from the front, i.e., scanner axis perpendicular to the Figure. The emitted gammas are shown as green lines. See also text for details.

b: Extended setup of the Coincidence Channel with 64 modules as seen from the front, i.e., scanner axis perpendicular to the Figure. Scattered gammas now have the chance to be detected by the modules added to make up a full ring. Gammas are shown as green lines, the red line represents an electron.

the center is shown. Despite the fact that the two gammas are emitted in a narrow angular range, a number of coincidences are detected remote from the detector modules these gammas were initially directed to. It obviously is a contribution of scattered gammas. Sorted into a sinogram as plotted in Figure 3b, such events are to be understood as unscattered coincidences but are actually scattered.

Gamma camera

As another basic device the traditional gamma camera has been introduced in EduGATE. The general setup is shown in

Figure 4a and 4b for the frontal and lateral view, respectively. The Technetium-99m source has been selected to consist of three gamma-emitting spheres distributed along the z-axis, also visible on Figure 4b. Again, the angular range of the emitted gammas was restricted for practical reasons, i.e. to collect a sufficient amount of events during the demonstration. Figure 5 shows the y-z-coordinates of the detected gammas, which corresponds to the location of the detection of the gammas in the crystal. While there is no structure to be discerned in Figure 5a, in Figure 5b, the detected gammas show a clear accumulation. This difference is caused by the fact that for Figure 5a the material of the collimator was set to vacuum,

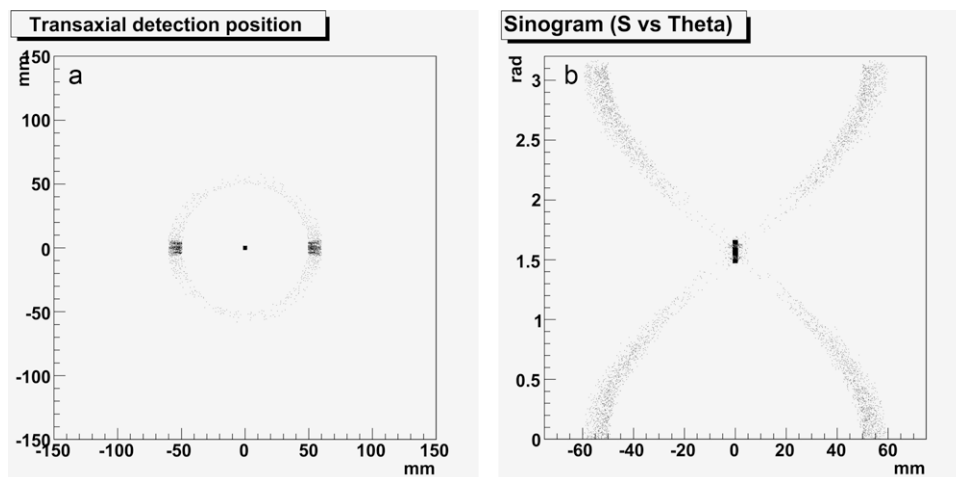


Figure 3. a: Transaxial detection position of all coincidences, with the position of the source marked in the center. The true coincidences are, as expected, visible as accumulations left and right of the source.

b: The true coincidences gather in the center, while scattered coincidences obviously accumulate at locations, which normally would be taken by other coincidences, once the radiation from the source would be isotropic.

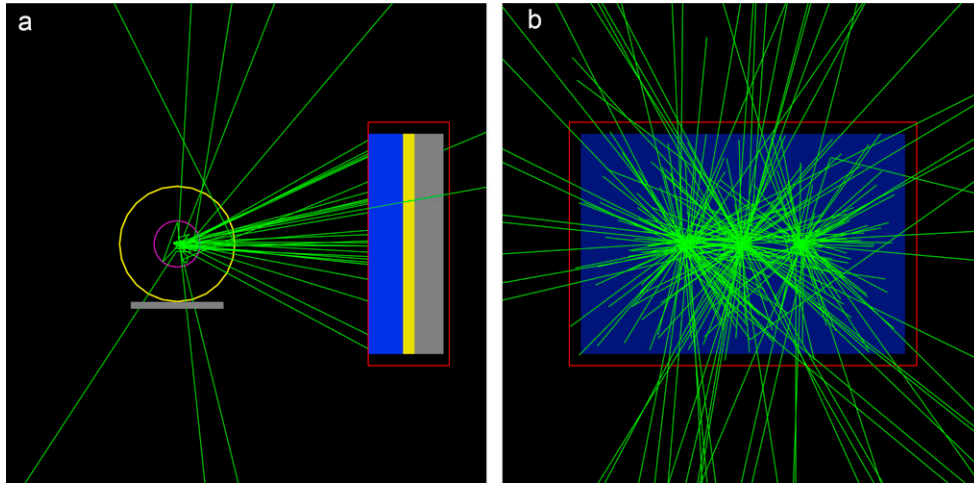


Figure 4. a: General setup of the Gamma Camera System as seen from the front, i.e., looking with the z-axis. The red box shows the outer dimensions of the detector head. It contains the collimator (blue), the crystal (yellow) and the back-compartment (grey). Also in grey supporting the phantom is the patient table.

b: Lateral view of the Gamma Camera System, showing the collimator (detailed structure not shown explicitly) and the three separate sources with the emitted gammas drawn as green lines.

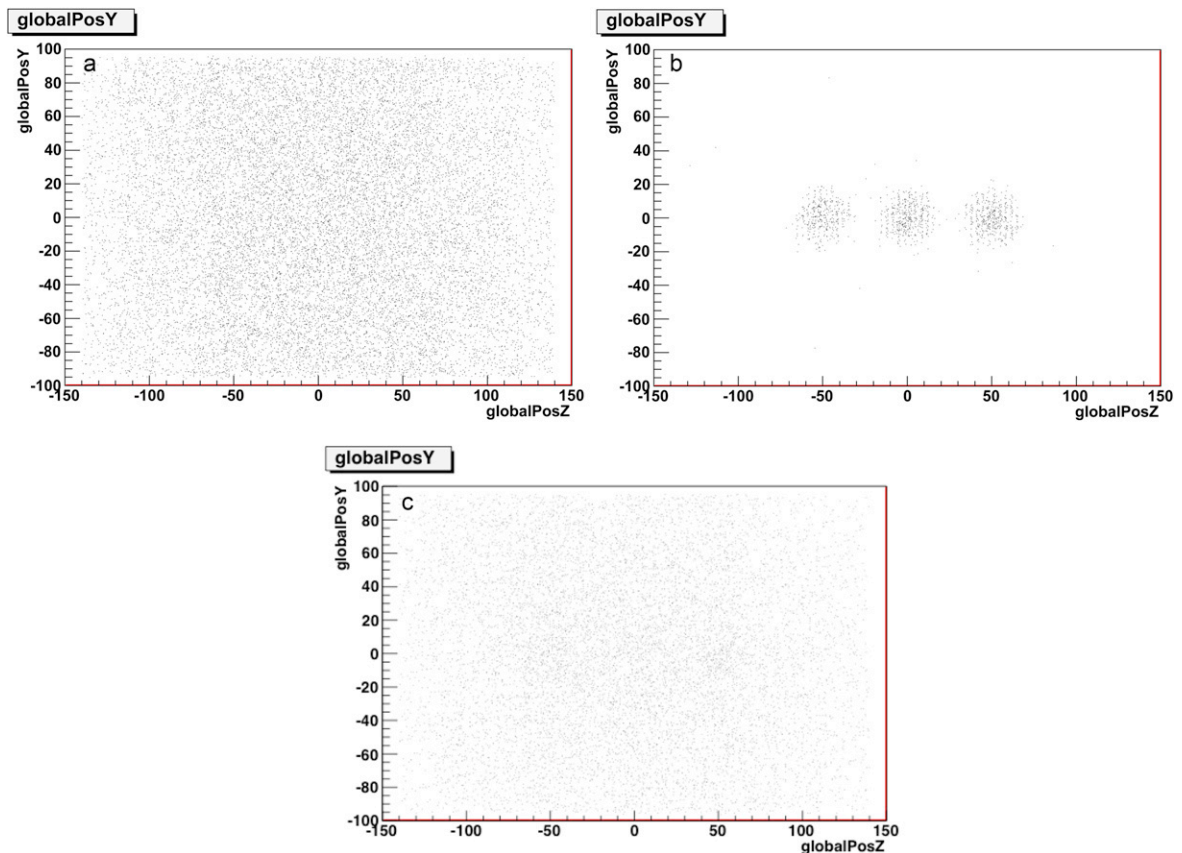


Figure 5. Distribution of the y-z-coordinates, i.e., locations where gammas were detected in the crystal.

a) Collimator material: vacuum, yielding no distinct structure, b) the three sources can be clearly discerned, since the collimator material was set to lead, c) again no clear structure visible, but this time, the energy of the gammas was selected to be 364 keV, too high for the type of collimator used for the simulation.

where it was selected to be lead for the simulation yielding the result shown in Figure 5b. Although the proper material was selected for the collimator, namely lead, Figure 5c shows no clear separation of the three sources, the reason being a much higher energy of 364 keV, the main gamma line of Iodine-364, which was selected for this simulation, while keeping the collimator type which is typical for the lower Technetium-99m gamma line of 141 keV. Figure 5c clearly shows the impact of an improper selection of a collimator not suitable for the relevant gamma energy range.

Different from the coincidence channel example, there are various types of sources provided, namely for single gamma, three gamma, electron, positron. Especially the electron sources may provide with basic insights for medical applications, where electron-emitting isotopes like Iodine-131 and Yttrium-90 are applied during therapy. High-energetic electrons, like in the case of Yttrium-90 may also produce a considerable amount of Bremsstrahlung, which can be used for imaging the distribution of the emitting isotope inside the body. However, since such Bremsstrahlung photons have a wide energy spectrum rather than a fixed energy, the selection of an appropriate collimation and window setting can be supported by simulation.

EduGATE distribution

The EduGATE-related modules (GATE macros, ROOT modules, documentation) ready to be used under MacOS, Linux and Windows (vGATE) are freely available for GATE-users via the following web-address: <http://www.opengatecollaboration.org/EduGATE>

and are distributed under the same conditions as the GATE-framework itself.

Conclusions

EduGATE opens an interesting opportunity for lecturers as well as students to use powerful tools, while becoming acquainted with the world of medical imaging through basic examples. It also provides an easy start into the fundamental physics involved in the principles of imaging devices. Relying solely on Open Source software, which is freely available, it can be used on any platform where GATE and ROOT are operating.

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