A Demonstration of STIR-GATE-Connection

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Abstract—We present the first open-source version of STIR-GATE-Connection, a project that aims to provide an easy-to-use pipeline to simulate realistic PET data using GATE, followed by quantitative reconstruction using STIR. Monte Carlo simulations and image reconstruction are powerful research tools for emission tomography that can assist with the design of new medical imaging devices as well as the evaluation of novel image reconstruction algorithms and various correction techniques. STIR-GATE-Connection is a collection of scripts that aid with the: (i) setup of a realistic GATE simulation of a voxelised phantom using a user selected scanner configuration, (ii) conversion of the output list mode data into STIR compatible sinograms, and (iii) computation of additive and multiplicative data corrections for Poisson image reconstruction using STIR. In this work, we demonstrate example usage of these steps. A public release of STIR-GATE-Connection, licensed under the Apache 2.0 License, can be downloaded at: http://www.github.com/UCL/STIR-GATE-Connection.

Index Terms—Monte Carlo simulation, data-correction, image reconstruction

I. INTRODUCTION

Monte Carlo simulations and image reconstruction are powerful tools for the development of: new scanner designs, algorithms for image reconstruction, intrinsic resolution modelling, and partial volume modelling. However, the development of Monte Carlo simulation and reconstruction libraries are often separate, resulting in different standards and conventions. Thus, it is paramount to link these efforts for easier usage.

STIR-GATE-Connection aims to provide a simplified pipeline to progress from Monte Carlo simulation using Geant4 Application for Tomographic Emission (GATE) [1], to quantitative image reconstruction of a known true tracer distribution using Software for Tomographic Image Reconstruction (STIR) [2]. Similar efforts to this work exist, e.g. CaSTOR [3], reconstruction software capable of processing GATE data and SIMPET [4], which uses SimSET [5] as the Monte Carlo software and STIR to reconstruct the data.

In this work, we present a summary of STIR-GATE-Connection, including: GATE setup and simulation, processing output list mode files into STIR compatible sinograms, and the computation of data corrections for image reconstruction.

II. GATE SIMULATIONS

GATE simulations are configured via macro text files. STIR-GATE-Connection incorporates a modular approach with these files, which allows different scanners to be substituted into the GATE configuration. Currently there are two example scanner configurations for simulation of a Positron Emission Tomography (PET) acquisition, the GE Discovery 690 [6] (PET scanner configuration) and the Siemens mMR [7], with an additional crystal in place of the virtual crystal. However, additional scanner configurations can easily be incorporated.

STIR-GATE-Connection provides an example GATE simulation script `ExampleSTIR-GATE.sh`. This script can either create voxelised phantoms from parameter files or a STIR compatible voxelised phantom may be provided. The GATE simulation is set up using `SetupSimulation.sh`, which loads the desired scanner geometry and runs the GATE utility to create a density map from the attenuation file. The `GATE` executable is called and a number of GATE macro variables are computed from the voxelised phantom's header files, e.g. the origin position, voxel size, and number of voxels. STIR-GATE-Connection also supports the running of GATE in batch array cluster jobs. `SetupSimulation.sh` must be run prior to launching jobs and each job will perform a GATE simulation on an independent node. Example scripts are provided for Sun Grid Engine.

III. UNLISTING

The GATE simulations output two list mode ROOT [8] files per simulation, one containing coincidence events and the other containing delayed coincidence events. `UnlistROOT.sh` may be used to process these files into STIR compatible interfile sinograms for the relevant scanner. A demonstration of the alignment between STIR and GATE data can be observed in Fig.1 with the alignment visualised in sinogram space.

The output ROOT data generally contains different event types, i.e. true (two photons detected in the coincidence window that originated from the same emission), scattered (one or more of the photons has undergone Compton scatter prior to detection), and random events (two photons detected in the coincidence window that did not originate from the same emission). This information is only directly ascertainable from simulation and can be useful for testing "correction"
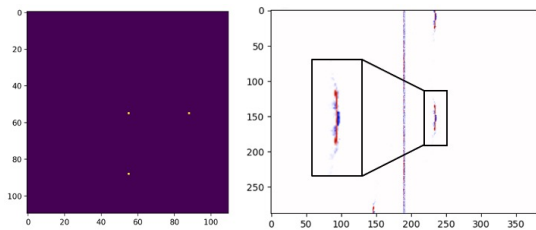
Fig. 1. Left: Three point activity source. Right: A visual comparison of a highly oblique sinogram of the three point activity computed using STIR (Red) and GATE (Blue).
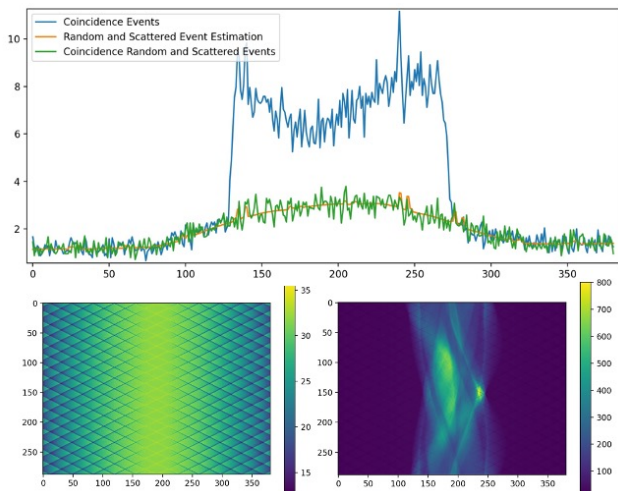

Fig. 2. Top: Line profiles through the sinograms of the coincidence events, unlisted random and scattered events, and the random and scattered event estimation. Bottom Left: Normalisation sinogram. Bottom Right: Multiplicative correction factors sinogram.

algorithms. The unlisting of each of these types of events can be toggled using STIR-GATE-Connection. Example line profiles through the unlisted sinograms, created by GATE simulation, of an XCAT torso phantom [9] are shown in Fig.2 (Top).

IV. DATA CORRECTION COMPUTATION

Iterative reconstruction methods incorporate the estimated contributions of both scattered and random events as well as physical and geometric factors of the scanner and attenuation factors into the acquisition model. STIR-GATE-Connection includes an example script of how to compute the normalisation as per component-based normalisation factors with crystal efficiencies and "geometric" effects. Symmetries are imposed on the latter to reduce noise. This is achieved by unlisting only the true coincidence events from a GATE simulation of a uniform cylindrical activity distribution as large as the scanner field-of-view and comparing the resulting sinogram to a STIR forward projection for the scanner using maximum likelihood computation [10]. An example of the normalisation sinogram for the GE Discovery 690 is depicted in Fig.2 (Bottom Left). Furthermore, attenuation correction may be modelled within the system matrix, see Fig.2 (Bottom Right) for the multiplicative correction factors of the XCAT torso.

The additive terms of the acquisition model are estimated using `ComputePoissonDataCorrections.sh`.
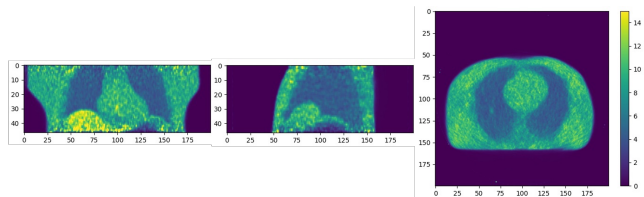

Fig. 3. An OSEM reconstruction of the measured XCAT torso phantom data, simulated in GATE, using 8 subsets and 40 sub-iterations: coronal view (Left), sagittal view (Middle), and transverse view (Right) .

The random events contribution is estimated from the delayed coincidence window. The delayed coincidence data was modified to reduce the number of events by 10% due to an over representation from GATE. The script configures and utilises STIR's `estimate_scatter` utility to estimate the contribution due to scatter. The contribution due to scattered and random coincidence events in the measured coincidence data is demonstrated in Fig.2 (Top) along with the corresponding estimated contribution, computed using STIR-GATE-Connection.

An OSEM reconstruction of the measured GATE data was performed with the aforementioned computed data corrections, see Fig.3

V. CONCLUSIONS AND FUTURE WORK

The presented platform is an open source research tool that allows researchers to progress from GATE simulations to quantitative PET reconstruction. In future, we aim to add: additional scanners, the ability to estimate the random events contribution from single events, and the ability to process SPECT data.

REFERENCES

[1] S. Jan, D. Benoit, E. Becheva, *et al.*, "GATE V6: A major enhancement of the GATE simulation platform enabling modelling of CT and radiotherapy," *Physics in Medicine and Biology*, vol. 56, no. 4, pp. 881–901, 2011. DOI: 10.1088/0031-9155/56/4/001.

[2] K. Thielemans, C. Tsoumpas, S. Mustafovic, *et al.*, "STIR: software for tomographic image reconstruction release 2," *Physics in Medicine and Biology*, vol. 57, no. 4, pp. 867–883, Feb. 2012. DOI: 10.1088/0031-9155/57/4/867.

[3] T. Merlin, S. Stute, D. Benoit, *et al.*, "CASToR: a generic data organization and processing code framework for multi-modal and multi-dimensional tomographic reconstruction," *Physics in Medicine & Biology*, vol. 63, no. 18, p. 185 005, Sep. 2018. DOI: 10.1088/1361-6560/aadac1.

[4] J. Paredes-Pacheco, F. J. López-González, J. Silva-Rodríguez, *et al.*, "SimPET—An open online platform for the Monte Carlo simulation of realistic brain PET data. Validation for 18 F-FDG scans," *Medical Physics*, mp.14838, Mar. 2021. DOI: 10.1002/mp.14838.

[5] K. G. Baum and M. Helguera, "Execution of the SimSET Monte Carlo PET/SPECT Simulator in the Condor Distributed Computing Environment," *Journal of Digital Imaging*, vol. 20, no. S1, pp. 72–82, Nov. 2007. DOI: 10.1007/s10278-007-9058-z.

[6] V. Bettinardi, L. Presotto, E. Rapisarda, *et al.*, "Physical Performance of the new hybrid PET/CT Discovery-690," *Medical Physics*, vol. 38, no. 10, pp. 5394–5411, Sep. 2011. DOI: 10.1118/1.3635220.

[7] G. Delso, S. Furst, B. Jakoby, *et al.*, "Performance Measurements of the Siemens mMR Integrated Whole-Body PET/MR Scanner," *Journal of Nuclear Medicine*, vol. 52, no. 12, pp. 1914–1922, Dec. 2011. DOI: 10.2967/jnumed.111.092726.

[8] R. Brun and F. Rademakers, "ROOT - An object oriented data analysis framework," *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 389, no. 1-2, pp. 81–86, Apr. 1997. DOI: 10.1016/S0168-9002(97)00048-X.

[9] W. P. Segars, G. Sturgeon, S. Mendonca, *et al.*, "4D XCAT phantom for multimodality imaging research," *Medical Physics*, vol. 37, no. 9, pp. 4902–4915, Aug. 2010. DOI: 10.1118/1.3480985.

[10] T. Niknejad, S. Tavernier, J. Varela, *et al.*, "Validation of 3D model-based maximum-likelihood estimation of normalisation factors for partial ring positron emission tomography," in *2016 IEEE Nuclear Science Symposium, Medical Imaging Conference and Room-Temperature Semiconductor Detector Workshop (NSS/MIC/RTSD)*, vol. 2017-Janua, IEEE, Oct. 2016, pp. 1–5. DOI: 10.1109/NSSMIC.2016.8069577.