

A Flexible and Precise Batch-mode Technique for Multi-threaded GATE Simulation

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Abstract—*In order to reduce the long computational time, parallel or multi-threaded computing techniques are widely considered for GATE simulations. In this research, the GATE simulations are accelerated via the GATE built-in batch-mode simulation. Different to GATE built-in multi-threaded programs, this new method required only minor modification for macro files and have higher precision for simulation parameters input. Moreover, this method is flexible for splitting jobs that makes the simulation achieve higher efficiency. This method is also easy to extend to other applications such as time separating or combining with built-in multi-threaded programs.*

Keywords: GATE, multi-threaded, batch-mode, flexible

1. Introduction

Geant4 Application for Emission Tomography (GATE) is a powerful Monte-Carlo simulation toolkit for emission tomography [1]–[3]. Since the geant4 could model the interaction mechanism of photons and materials, this toolkit has been greatly extended to the x-ray computed tomography (CT) [4], optical imaging [1], and radiotherapy experiments [4]. The GATE simulation has become an essential toolkit for modern medical image researches.

The major challenge for GATE simulation is the time consuming [1], [5]. It takes huge time to complete a simulation especially for a complex imaging system. In order to solve the time consuming problem, parallel computing techniques are included into GATE software [6]. Use multi-threaded simulation, the simulation time could decreased by several times. The down times are almost proportional to the thread numbers. This built-in technique consists of two extra programs, job splitter and file merger.

There are two steps to do the job splitting [7]. The macro file required to be modified to suitable for using job splitting or multi-threaded simulation. The second step is to use the built-in program to do several copies of the macro files. The job splitter program also created a ".split" file to record the

splitting information. This file can help file merger to merge file correctly. Moreover, the job splitter program can split files into similar computational loading automatically.

Although the built-in multi-threaded simulation tool is automatic splitter and worked well [7], this multi-threaded simulation method still have several limitations in dynamic imaging system. First, the method is not efficient for all imaging system. The method can split scan time or source activity into different threads, but it is hard to split different scan angle into different thread in dynamic imaging system, such as single photon emission computed tomography (SPECT) or tomosynthesis. Second, the multi-threaded simulation method is not flexible. If there are little mechanical fluctuation, the automatic splitting is also hard to split files into similar computational loading.

In this research, we focused on tomosynthesis imaging system and consider that how to achieve high performance and efficient multi-threaded GATE simulations. We used the batch-mode [7] to execute GATE simulation. Although the batch-mode was not designed for multi-threaded computation to accelerate the simulations in original, we collocate the batch-mode and background process techniques to accelerate the simulation by multi-threaded computing. An additional program was used to control and make the multi-threaded simulation splitting jobs based on different projection angle possible. No extra file will be created for recording split information because the merging process is already inside the program. Moreover, we use the same program to calculating the x-ray source precise position and set this precise position as alias values into GATE simulation. At last, the modification of macro files is much easier than job-splitter. The minor modification is to set an alias name and replace the actual number in original macro file by this alias name. We will also introduce how to extend this method to different simulation schemes.

2. Materials and Methods

2.1 Batch-mode multi-threaded simulation

In this research, there are three alias variables required for a batch-mode parallel GATE simulation. The most important part of the macro file modification is the filename for simulation output. The output filename should contain different information to distinguish to avoid the later result overwrite the un-processed old one. Therefore, we make the output filename contain 2 sets of information, the projection angle and the simulation ID.

The second part need to be modified is the x-ray source position. Since each projection is independent to each other in tomosynthesis, one projection angle should assign one thread to perform its simulation. The trajectory of source is an arc with radius 650mm source-image distance(SID), we manage these coordinates of x-ray source as variables.

The alias control program was coded using C language. There are three variables required by batch-mode GATE simulation. Since the x-ray source is rotated along y -axis, the x and z coordinates of x-ray source are two independent variables. These two variables can be type by hand after calculation. In this research, we used the SID and projection angular information to calculate the x-ray position by program and transfer the precise position coordinates into the batch-mode GATE simulation directly. This method can avoid typing error and have higher precision. On the other hand, the program can also use the random number generator to simulate the small fluctuation for rotating imaging system.

In this research, all simulations were executing on a dual Intel(R) Xeon(R) E5-2670 v3 CPUs workstation with 64GB RAM. Each of E5-2670 v3 CPU contains 12 cores and 24 threads. Therefore, the entire workstation can support 24 cores and 48 threads. A 48 threads workstation can decrease about 48 times of original single thread simulation time. The schematic diagrams of built-in multi-threaded simulation and batch-mode multi-threaded simulation are shown in Fig. 1 (a) and (b), respectively.

2.2 Simulated Hardware Parameters

A 3D tomosynthesis imaging system was used to evaluate the performance for batch-mode parallel simulation. The distance from x-ray source to detector center is 650mm. There are 61 equally spaced projection angles from 60° to 120° . The detector number is 1440×1080 and the size of each detector is $0.25\text{mm} \times 0.25\text{mm}$.

2.3 Phantom Design

The phantom design contains two parts. The first part is the breast phantom and the second one is the micro-calcification. The Breast phantom is combined by a semi-cylindrical and a cuboid. The semi-cylindrical has 120 mm in radius and 60 mm height. The side length for cuboid is $240\text{mm} \times 60\text{mm} \times 20\text{mm}$. Fig. 2(a) shows the phantom

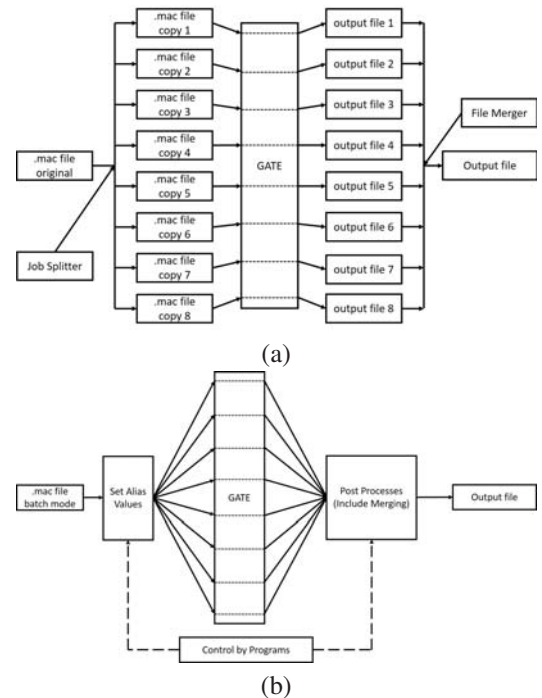


Fig. 1: The working schemes for multi-threaded GATE simulation. (a) The working scheme used the built-in job splitter and file merger in GATE software. The job splitter will do several copies of the macro files and execute GATE simulation by these copied macro files. (b) The working schemes for using batch-mode multi-threaded simulation. The macro files will not be copied. An extra program are used for the batch-mode multi-threaded simulation to set the alias value and post-process the output files.

diagram. The second part is the micro-calcification points. The micro-calcifications are located in 5 layers as shown in Fig. 2(b), and the micro-calcification distribution on each layer is shown in Fig. 2(c).

3. Result

Fig. 3 shows the simulation result for tomosynthesis, the labeled number is the different projection ID for the tomosynthesis scan. The x-ray source is moved for the top to bottom with the projection index increasing, therefore, the 3^{rd} projection contains a tail in the bottom and the 59^{th} projection also contains a tail on the top of the projection. According to the phantom design, the micro-calcification point will be overlapped in the same position but different depth when the x-ray moved to the center. The 31^{st} projection shows the overlapping projection as the phantom designs.

In this simulation work, one projection angle simulation were done by one independent thread. The batch-mode multi-threaded simulation are used to separate different projection angle to different thread for simulating. All of

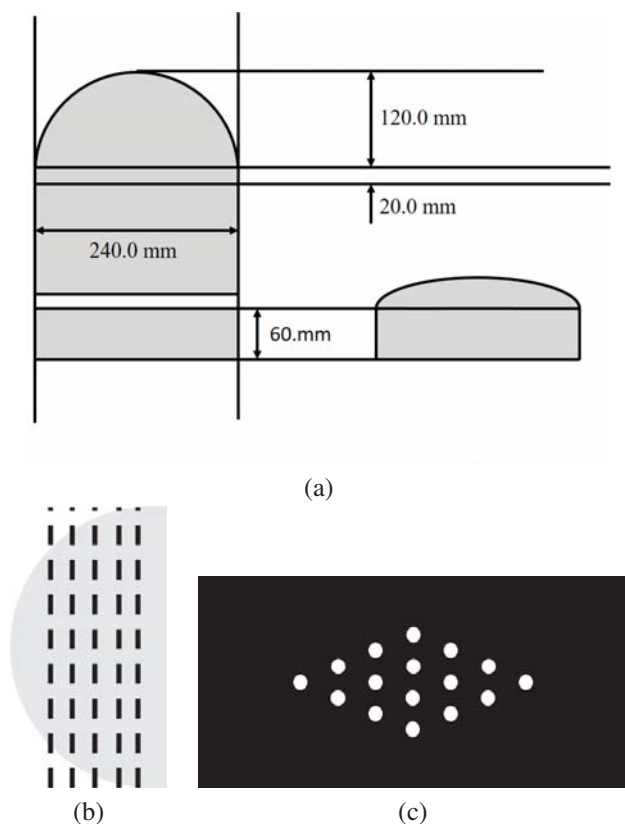


Fig. 2: The phantom design. (a) The breast phantom is a semi-cylindrical using the GATE built-in material “breast”. (b) Five layers (dash line) of micro-calcification. The radius of micro-calcification are 1.4mm, 1.6mm, 1.8mm, 2.0mm, 2.2mm from right layer to left one, respectively. (c) The distribution of micro-calcification on a layer.

the simulated projection will be put in the same directory with meaningful filename which contains two information, the projection angular ID and the simulation order. The projection angular ID is to indicate the x-ray source location. In order to simulate different x-ray quantum, we use low photon generating rate and short simulation time for one simulation so that we can select different total photon number level by merging different file number. On the other hand, use different filename can avoid the later simulation result overwriting the older one.

Notice that the low photon generating rate and short simulation time is totally the same as the built-in job-splitter and file-merger functions in GATE. The short simulation time is the same as to divide the time frame in job-splitter and the low photon generating rate is to divide the photon emission frame. The effect may be totally the same to use the built-in and batch-mode multi-threaded simulation for GATE. What the job-splitter difficult to do is to divide different projection angle to different thread to simulate.

In this research, the projection (simulation) number is

larger than the thread number in the workstation. Therefore, all of the threads in the workstation are full-loading. To achieve the highest performance, more threads applied for simulation are required and this is not very hard by using higher level CPU or clustering several workstations.

4. Conclusions

In this research, we used the batch-mode to execute multi-threaded GATE simulation. The batch-mode method can not only achieve the same accelerate quality to the built-in multi-threaded simulation but also be flexible for job dividing selection. Moreover, the batch-model multi-threaded simulation can use high precision alias parameters for simulation and avoid typing errors or imprecision insufficient problems for Irrational numbers. The results of research show the feasible for this method, but there are several directions can be improved. For example, this method is difficult to ensure that divided jobs have similar computational loading which the built-in job-splitter have verified. The quantized comparison for batch-mode multi-threaded and built-in simulation method is also important issue. After most of this issues are verified and improved, the batch-mode multi-threaded will become a very powerful tool for GATE simulation.

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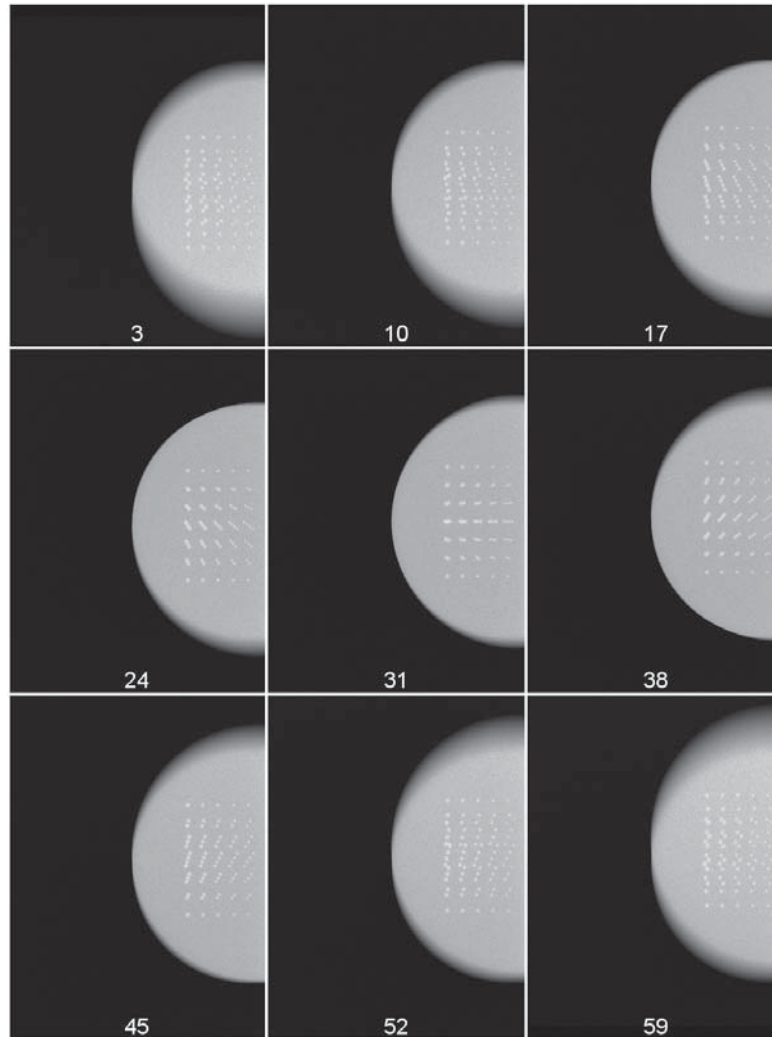


Fig. 3: The GATE simulation result. The labeled numbers are the projection angle order. The x-ray source is moved from top to bottom, therefore, the 3rd projection contains a tail in the bottom and the 59th projection also contains a tail on the top of the projection. Along the projection order, the depth effects for tomosynthesis are also shown in the simulation results. The micro-calcification point has higher displacement if the location of micro-calcification is close to the x-ray source. On contrary, if the distance for the x-ray source and micro-calcification point is longer, the projection for this micro-calcification point has smaller displacement.

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