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ASSESSING HARDWARE-DRIVEN VARIATIONS FROM WORKSTATIONS TO PERSONAL COMPUTERS IN GATE SIMULATION TIME FOR RADIOEMBOLIZATION STUDIES

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ABSTRACT
Monte Carlo GATE (Geant4 Application for Tomographic Emission) is widely used in medical physics for tomographic emission simulations, particularly in nuclear medicine procedures like radioembolization for liver cancer treatment. Despite its user-friendly interface, GATE simulations are often criticized for their slow computational speed, which poses challenges for students and researchers. Factors such as computer hardware (RAM, CPU, GPU, storage type), simulation settings, and the complexity of physics modeling significantly influence simulation times. This study investigates how hardware configurations impact GATE simulation performance by simulating a Yttrium-90 (Y-90) radioembolization procedure using a cylindrical phantom and tumor inserts. Simulations were conducted on three computers: an HP workstation, a DELL, and an HP Envy, with varying hardware specifications. Results revealed that the workstation, equipped with higher RAM, CPU, and GPU capabilities, demonstrated significantly faster simulation times compared to the personal computers. This highlights the critical role of advanced hardware in reducing computational time for GATE simulations. The study provides valuable insights for young researchers, emphasizing the importance of hardware optimization to achieve efficient and timely results in Monte Carlo-based medical physics research.

Keywords: Radioembolization, Yttrium-90, Hardware Optimization, GATE simulation, SPECT, Computational Time

INTRODUCTION
Monte Carlo GATE (geant4 application of tomographic emission) is a popular geant4 code used in tomographic emission simulations in medical physics (Kochebina et al., 2024; Talebi & Rajabi, 2022). It is quite user-friendly and many young researchers and students tend to get along with it. However, students have constantly complained about its slowness to generate results. They find it disturbing to watch the simulations run for a very long time without producing needed results. They also worry about the inability of their personal computers to simulate GATE successfully without breaking down along the way. Several factors contribute to the length of time a simulation takes(Badal & Badano, 2009; Souris et al., 2016a), they include the capacity of the computer, a detailed physics modelling, set time of simulation, activity, detector geometry configurations, nature of image (or phantom) simulated, and several other GATE settings. While students who are new to GATE simulations often wonder why the set acquisition time usually differs from the real study time, research is continuously on to bridge the time gap, even though, Monte Carlo simulations are typically known to be time consuming and computationally intensive.

Radioembolization is a semi-invasive nuclear medicine technique used in the treatment of inoperable liver cancers and metastasis. Yttrium-90 (Y-90) is a popular radionuclide used in such procedures while single photon electron computed tomography (SPECT) imaging is employed in the pre- and post-treatment imaging aspects of the procedure. Y-90 produces over 99% bremsstrahlung radiation which can be very challenging for imaging cameras (especially SPECT) to produce clinically acceptable high-quality imaging with high contrast and signal to noise ratio. Modelling this Y-90 characteristics including that of the scanner add to computational time of a simulation (Elschot et al., 2011; Walrand et al., 2014). The complexities of scatter and attenuation is known to equally add to the computational time just as various techniques employed to reduce this effect also end up adding to the computational time (Beekman et al., 2002; Zaidi, 2001), thereby widening the gap between set time and true study time. This can be quite challenging to comprehend especially for young researchers and students who would rather love to see the results of their work in good time.

From literature, various studies have been carried out in an effort to reduce computational time. Variance reduction techniques like ARF have been proposed in different studies (Descourt et al., 2010; Sarrut et al., 2021). This involves alteration tracking or detection to reduce the variance in simulation and hence speeding up the process. Similar to this is the forced detection techniques (Cajgfinger et al., 2018; Sohlberg et al., 2008) as well as other techniques like parallelization, clusters and cloud services, all suggested in several studies (Anil et al., 2022; Liu et al., 2017; Rowedder, 2014; Yu et al., 2018). Also, studies have shown the effect of computer hardware resources and configurations on simulation time (Badal & Badano, 2009; Souris et al., 2016b; Ziegenhein et al., 2015).

It is well known that random access memory (RAM) size influences multitasking and a computer's ability to handle large amounts of data, while central processing unit (CPU) speed tells how fast a computer can process information/instructions. Also, graphics processing unit (GPU) influences quick rendering of graphics and parallelization. Factors like storage type (solid state drives-SSDs or hard disk drives- HDDs), software optimization and cooling systems also influence the overall speed of computers. In this study, we seek to demonstrate and enlighten the young researcher or student, for better clarity, how hardware resources of various computers (among other factors) influence the simulation time of GATE experiments. The effects of factors like, the processor type and speed, including memory and storage were discussed after simulating a radioembolization procedure.

METHODOLOGY

A simulation employing the GATE platform was conducted using a cylindrical phantom with a volume of 6400 cm^3, incorporating six spherical inserts simulating tumors, with volumes ranging from 1 cm^3 to 29 cm^3. The gamma camera was modeled based on the specifications of Symbia SPECT T2 scanner (Table 1), and simulations were performed using Y90 across various activity levels and simulation durations as detailed in Table 2. Applying, a sphere-to-background activity ratio of 10:1 (Shahmari & Taherparvar, 2019), a total activity of 11, 55, 510, and 550Bq/mL was simulated as shown in Table 2. Firstly, the above parameters were applied to the HP workstation with 64 GB RAM, 500GB HDD, 2.8GHz CPU frequency, 32 CPU cores and a GPU with CUDA core of 1280. (Table 3). CUDA means Compute Unified Device Architecture; it is a platform for parallel computing and application programming interface (API). The set simulation time for the different activities ranged from 600s to 3600s and the real study time at the end of the simulation on the HP workstation was recorded. Same parameters above were tested while simulating via DELL and HP Envy personal computers too. Their real study times were equally recorded for each activity tested. A total of 6 studies (with same parameters) were carried out on each computer (Table 3).

Geometry of Scanner

The Symbia T2 SPECT scanner, produced by Siemens (USA), features 59 photomultiplier tubes (PMT) and NaI(Tl) scintillating crystals. It is equipped with lead collimators of varying types: LEHR, LEAP, HE, and MEGP, with respective hole sizes of 24.05 mm, 24.05 mm, 40.64 mm, and 59.7 mm, as referenced in (Dong et al., 2018). For this study, the medium energy collimator was simulated. Key specifications of the Symbia T2 gamma head are summarized in Table 1 (Siemens USA, 2025).

Physical Component of GATE

GATE, or Geant4 Application for Tomographic Emission, is an extension of the Geant4 simulation toolkit, primarily coded in C++. Its architecture consists of three layers: the core, the application, and the user layers. The user layer facilitates experimental simulations through the use of Geant4 scripting language. For this research, GATE version 8.2 was utilized to study the influence of computer hardware resources on simulation time. The simulation included a medium energy collimator made of lead, with characteristics as outlined in Table 2.

All relevant physics processes, including Compton scattering, the Photoelectric effect, and Rayleigh scattering, were incorporated into the model. The simulations were conducted over a broad energy window of 60-400 keV (Pirayesh Islamian et al., 2012) to account for the wide spectrum of Y-90 emissions, which lack a distinct peak energy. The cylindrical phantom, embedded with spheres, was positioned centrally within the field of view, encircled by four gamma heads. Both the spheres and the background were designated as "water," with the external environment defined as "air." The simulation involved 60 and 120 projections, each lasting 30 seconds. Details of these parameters are presented in Table 2. The resulting output were 2D projections which were analyzed for further study (Figure1).

Table1: Specifications of SPECT T2 scanner

Characteristics	Value
Detector material	NaI (Tl)
Crystal dimension	59.1 x 44.5 cm
Field of view (FOV)	53.3 X 38.7 cm
No. of photomultiplier tubes	59
Detector shielding (back and sides)	9.5 mm and 12.7 mm
Collimator	Medium Energy
No. of Holes	14000
Hole length	40.64 mm
Septal thickness	1.14 mm
Geometric resolution at 10 cm	10.8 mm
System resolution at 10 cm	12.5 mm
Sensitivity at 10 cm	275 cpm/µCi
Source: https://www.siemens-healthineers.com/en-us/molecular-imaging/spect-and-spect-ct/symbia-t	

Table 2: Simulation parameters

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Study	Total Activity (Bq)	Energy Window (keV)	Simulation Time (s)
1	11	60-400	3600
2	11	60-400	1800
3	55	60-400	1800
4	55	60-400	3600
5	510	60-400	600
6	550	60-400	1800

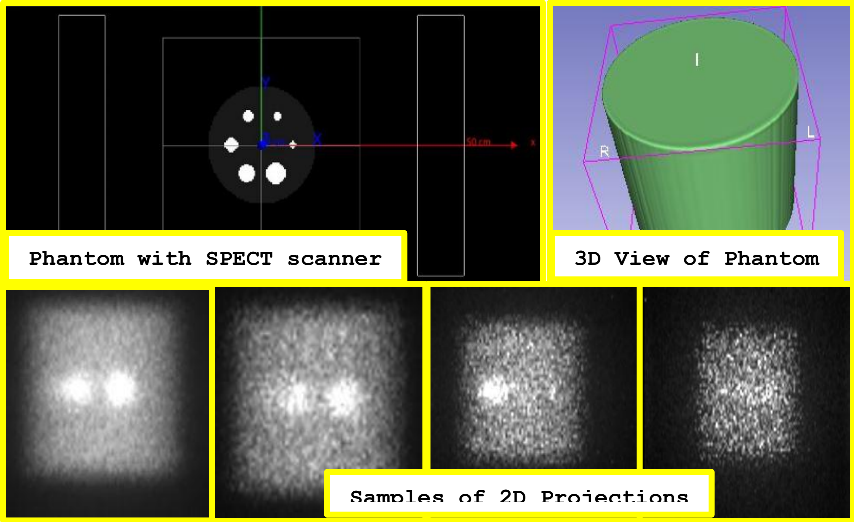

Figure 1 Showing Phantom with inserts and 2D projections output

Table 3: Computer Hardware specifications considered

Computer	Model	Operating System (OS)	OS Type (bit)	Random Access Memory (GB)	HDD/ SSD (GB)	CPU Type	CPU Freq. (GHz)	No. of CPU Core	Logical Cores	CUDA Cores
Hewlett Packard (HP)	HP Z8-G4 Worksta-tion	Ubuntu	64	64	500	Intel Xeon Gold	2.8	32	32	1280
Hewlett Packard (HP)	HP ENVY TS 17 Notebook PC	Ubuntu	64	16	1000	Intel Core i7	2.4	4	8	0
Dell	Latitude 5590	Ubuntu	64	16	256	Intel Core i5	1.9	4	8	0

RESULTS

At the end of each simulation on various computers, the simulation starting and stopping time was recorded and the study period calculated as shown in Table 4. For study 1, the set simulation time was 3600s (1 hr.) but the real study time was 2.45, 20.42 and 23.5 hrs. for workstation, HP Envy and Dell latitude computers respectively. Study 2 had a simulation time of half an hour with a corresponding real study time of 1.22, 10.17 and 11.7 hrs. respectively for the three tested computers. Similarly, study 3 – 6 had varying simulation time from 0.17 – 1 hr. and a range of real study time from 4.75 to 38.02 hrs. (workstation), 39.58 to 316.83 hrs. (HP Envy), and 45.56 to 364.7 hrs. (DELL Latitude) as shown in Table 4.

Table 4: Simulation time Vs Real Study Time

Study	Set Simulation Time (hr.)	Real Study Time-WkStn (hr.)	Real Study Time-HP Envy (hr.)	Real Study Time- DELL Latitude (hr.)	% Time Increase-WKSTN	% Time Increase-HP ENVY	% Time Increase-DELL LAT
1	1	2.45	20.42	23.5	145	1942	2250
2	0.5	1.22	10.17	11.7	144	1934	2240
3	0.5	5.62	46.83	53.91	1024	9266	10682
4	1	12.08	100.67	115.88	1108	9967	11488
5	0.17	4.75	39.58	45.56	2694	23182	26700
6	0.5	38.02	316.83	364.7	7504	63266	72840

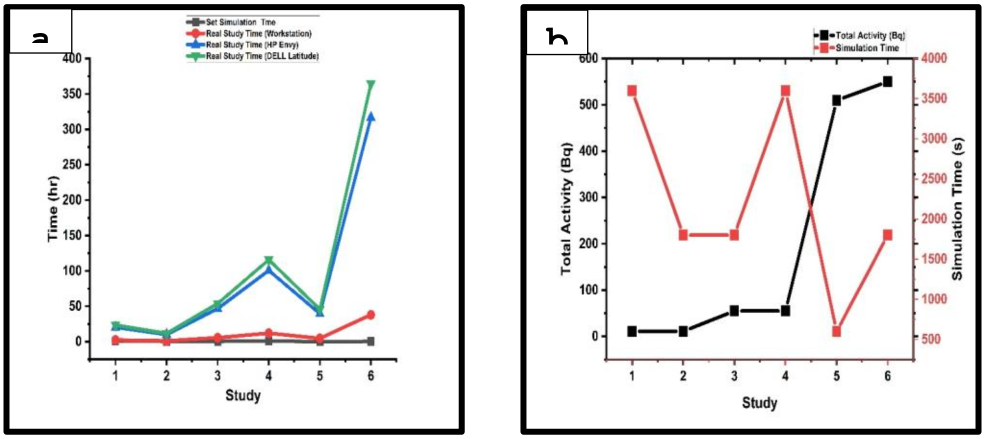

Figure 2 a. Simulation time vs real study time **b**. Activity vs simulation time

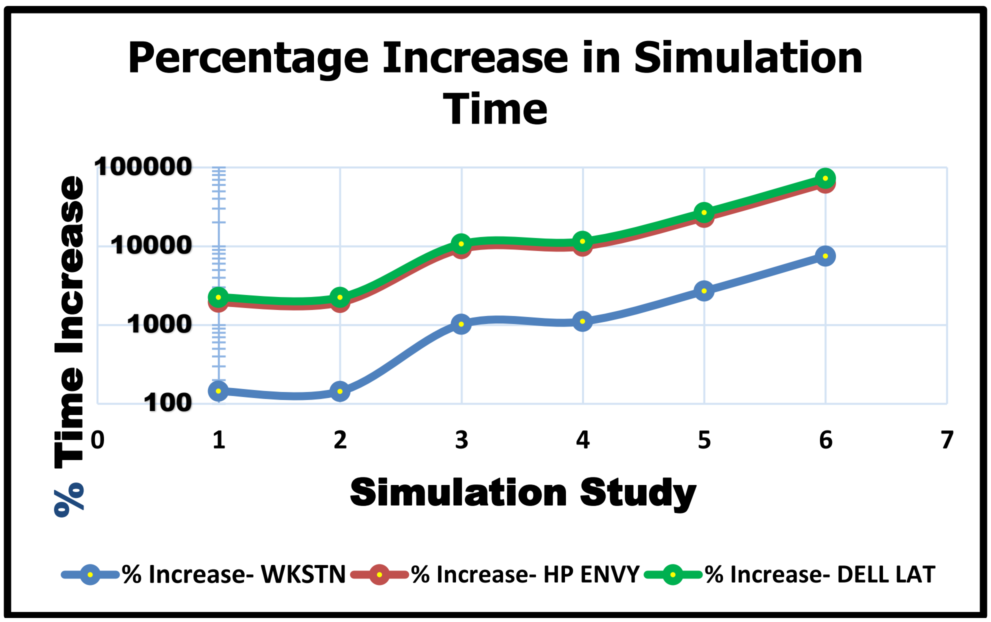

Figure 3: Percentage Increase in simulation time

DISCUSSION

From the results, study1 obviously had a small simulation time (1hr) set in GATE but the workstation took 145 % more time to run the simulation while it took 1942% and 2250% more time to run the same simulation on HP and DELL computers respectively. The simulated time is more than the set time on the software and the workstation had the smallest simulation time compared to others. This shows the impact of the hardware resources like increased RAM size and CPU/GPU capacities that the workstation has over the other two computers. This is despite its use of HDD which is slower than SSD used by the other PCs. Recall that the workstation has a 64GB ram size including 32 CPU cores, 32 logical cores and 1280 CUDA cores (for GPU). These are quite high specifications as compared to that of HP and Dell (table 3). Similarly for study 2, the percentage increase in simulation time on the computers were 144%, 1934%, and 2240% for workstation, HP and Dell. Study 3 had a percentage increase in simulation time from 1024% to 10682% while studies 4, 5 and 6 had a range of 1108% - 11488%, 2694% - 26700%, and 7504% - 72840% for workstation, Hp, and DELL respectively (figure 3). The time gap between the workstation and the other computer is very wide owing to the high capacity of RAM and CPU/GPU resources. Also, the time gap between the HP and DELL PCs is very small. This may be due to the similarities in their CPU and RAM capacities. HP and Dell both have a RAM of 16GB, but a slightly different CPU speed of 2.4GHz and 1.9GHz respectively. Even though both use SSD storage, the difference in time is largely due to the CPU speed.

Conclusion

This study was conducted to assess the hardware-driven variation in GATE simulation time via a radioembolization procedure on a workstation and two different personal computers. The study has established the fact that GATE simulations do take time and that the set simulation time varies widely with the real study time. It is obvious that despite the fact that same activity, simulation time and other settings were employed in the simulation, the resulting true simulation time was clearly different from the set simulation time on the three computers. The workstation had a smaller percentage increase in time compared to the other two computers. This is largely due to its high RAM size and high CPU and GPU frequencies. To achieve a short simulation time in GATE, a high-end computer like the workstation should be employed.

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