Using GATE to understand performance of a full-torso PET scanner

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IEEE MIC 2017
The full-torso scanner will allow for **low-dose** adult imaging, **fast** pediatric imaging,
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Data courtesy of Drs. Austin Pantel and Robert Mach, University of Pennsylvania
The full-torso scanner will allow for low-dose adult imaging, fast pediatric imaging, full-torso dynamic imaging with novel tracers, and imaging of low β+ fraction isotopes.

\[
\beta^+ : 22.3 \%
\]

\[
\gamma_5, 909 \text{ KeV}
\]

\[
\gamma_1, 909 \text{ KeV}
\]

\[^{18}_F\] has a positron fraction of 96.86 %
Simulating a full-torso scanner
We modeled the 16-cm Philips Vereos scanner in GATE and extended it to 23 cm and to a 70-cm full-torso scanner.

320 ps Timing Resolution
10% energy resolution
4 x 4 x 20 mm³ crystals
NEMA Experiments

Sensitivity

Count Rate

Spatial Resolution

Image Quality

4:1
Our Computing Resources

Node 2
24 GB RAM
12 CPU cores

Node 3
24 GB RAM
12 CPU cores

Node 4
24 GB RAM
12 CPU cores

Node 5
12 GB RAM
12 CPU cores

Node 6
12 GB RAM
12 CPU cores

Node 7
32 GB RAM
16 CPU cores

Node 1

Totals
76 CPU cores
2 GATE runs per core
Up to 152 GATE runs per batch

Each node includes dual 2.3-2.8 GHz Nehalem-class Xeon CPUs
In General, GATE runtimes were linear up to root file sizes of 1 GB.

A 3-minute GATE scan required 1800 100 ms simulations.

Running the 3-minute NEMA IQ Simulation
Running the 3-minute NEMA IQ Simulation

100 ms scan took
44 min: 23-cm scanner
75 min: 70-cm scanner

Total Runtimes
8.5 hours: 23-cm scanner
15 hours: 70-cm scanner

3-min Scan

1800 GATE Simulations

1800 root files

3-min List file
Simulating a voxelized XCAT 2.0 anthropomorphic phantom
Simulation Plan

**[18F] FDG Patient Scan**

**List of Important Organs**

<table>
<thead>
<tr>
<th>Body (i.e. Fat)</th>
<th>Blood Pool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Bone</td>
<td>Uterus (F)</td>
</tr>
<tr>
<td>Lung</td>
<td>Spine Bone</td>
</tr>
<tr>
<td>Breast (F)</td>
<td>Liver</td>
</tr>
<tr>
<td>Muscle</td>
<td>Kidney</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Brain (WM)</td>
</tr>
<tr>
<td>Gut</td>
<td>Myocardium</td>
</tr>
<tr>
<td>Spleen</td>
<td>Brain (GM)</td>
</tr>
<tr>
<td>Bladder</td>
<td><strong>Total = 17 organs</strong></td>
</tr>
</tbody>
</table>

**Adult Female**

5’5” (165 cm)
165 lbs (75 kg)
Filling the XCAT anthropomorphic phantom with an $[^{18}F]$FDG distribution

#1: Atlases in literature
Filling the XCAT anthropomorphic phantom with an [18F]FDG distribution

#2: Physician input using patient data

Dr. Austin R. Pantel

[18F] FDG Patient Scan

N = 10
Filling the XCAT anthropomorphic phantom with an [18F]FDG distribution

#3: Voxelize activity

Each voxel is discrete

↓ size → ↑ RAM

↑ size → coarse dist’n

ActivityRange.dat

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 12 | 1 | 40 | Body, Other Bone
| 11 | 2 | 63 | Lung
| 10 | 3 | 79 | Breast(F)
| 9  | 4 | 119| Muscle
| 8  | 5 | 190| Pancreas
| 7  | 6 | 206| Gut
| 6  | 7 | 238| Spleen, Blood Pool, Uterus (F)
| 5  | 8 | 254| Spine Bone
| 4  | 9 | 317| Liver, Kidney, Brain (WM)
| 3  | 10| 634| Myocardium
| 2  | 11| 1268| Brain (GM)
| 1  | 12| 1585| Bladder
Filling the XCAT anthropomorphic phantom with an [18F]FDG distribution

#4: Crop the Image down to minimize RAM usage

192 x 192 x 600

↓

192 x 100 x 230

- Save as analyze
- Set datatype to 16 (floating point)
Converting the XCAT Attenuation Image for GATE

μ map w/22 organs

Index map w/17 organs

Segment

Crop
GATE simulations of the XCAT phantom on a full-torso scanner take a LOT of time
To include small lesions in our phantom, we simulated them separately and embedded them.

Lesion w/ 3:1 contrast → fill with 2x the local background activity

GATE V8.0

20 min later

1800 root files

3-min List file

AttenuationRange.dat

17
1 1 Air
2 2 Lung
3 3 Adipose
4 4 Water
5 5 Intestine
6 6 Pancreas
7 7 Brain
8 8 Muscle
9 9 Kidney
10 10 Heart
11 11 Liver
12 12 Blood
13 13 Spleen
14 14 Cartilage
15 15 SpineBone
16 16 Skull
17 17 RibBone
Merged list files and subsampled data to study the dose lowering effects of the full-torso scanner.

<table>
<thead>
<tr>
<th>Lesion List Mode data</th>
<th>FDG woman List Mode data</th>
</tr>
</thead>
<tbody>
<tr>
<td>=</td>
<td></td>
</tr>
<tr>
<td><strong>Total List Mode data</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>whole</th>
<th>1/2</th>
<th>1/4</th>
<th>1/8</th>
<th>1/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>x10</td>
<td>x10</td>
<td>x10</td>
<td>x10</td>
<td>x10</td>
</tr>
</tbody>
</table>

This was done as:

- 1 bed pos – 70-cm scanner
- 5 bed pos – 23-cm scanner

Mean (CRC) Std (CRC)

LM TOF OSEM 4 x 25 subsets
The full-torso scanner maintains measurement accuracy and precision at lower imaging doses. Patient dose can be lowered by 2x-4x.
Summary

1. How I run simulations on our cluster
   - Parallelizing GATE into many short runs

2. How I process the XCAT phantom for GATE simulations
   - Phantom was filled using data from literature and on-campus imaging studies
   - Attenuation and Activity images were segmented into 10-20 discrete organs
   - Simulations were run using analyze images

3. Future Directions
   - Planning simulations of dynamic datasets to understand how the improved sensitivity of a full-torso scanner will impact dose and temporal sampling for improved kinetic parameter estimation
Funding:
NIH R01-CA113941
NIH R01-CA196528
Philips Research Agreement