The contribution of STIR to GATE simulation studies

Performance Evaluation of radionuclide imaging systems

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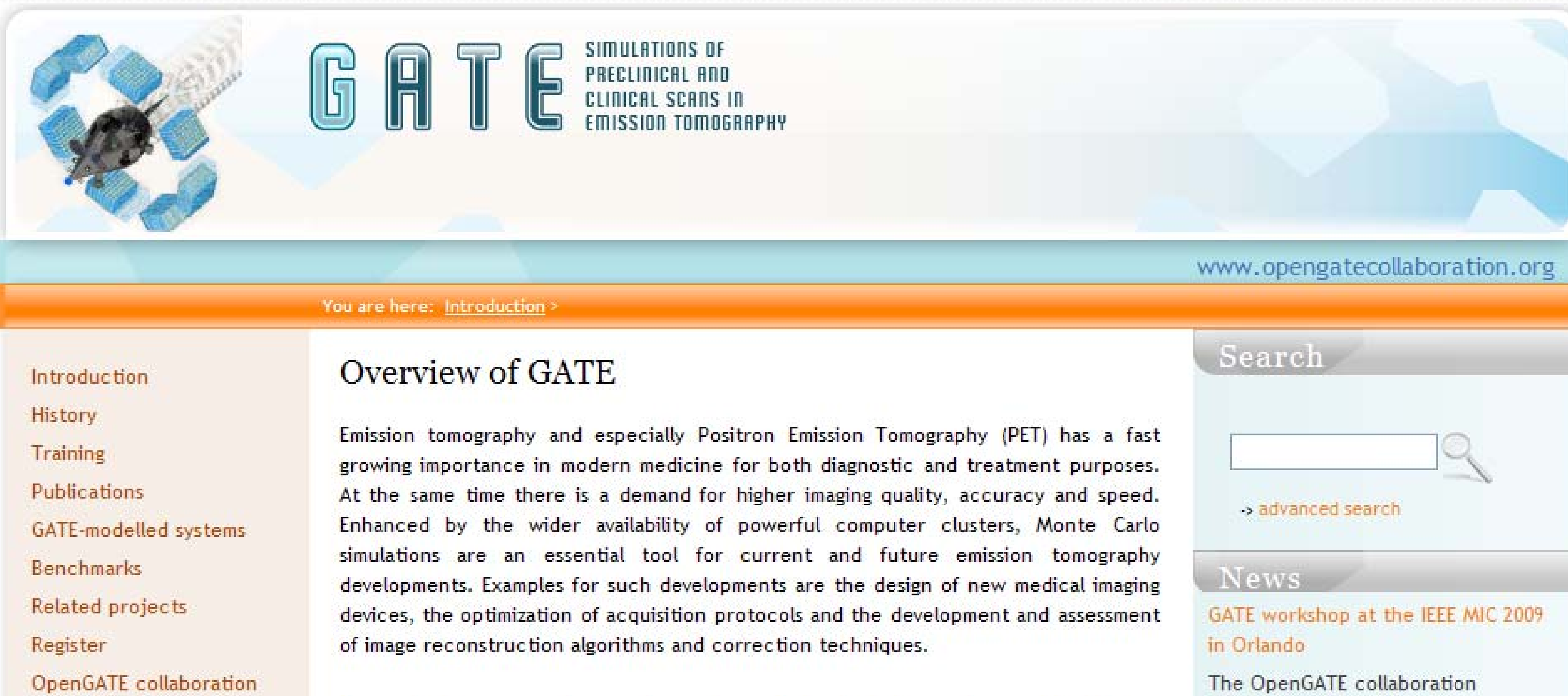
Geant4 Application for Tomography Emission and Radiotherapy (GATE)

- Based on GEANT 4
- Written in C++
- User-friendly: simulations can be designed and controlled using macros, without any knowledge in C++
- Appropriate for SPECT and PET simulations
- Flexible enough to model almost any detector design, including prototypes
- Explicit modeling of time (hence detector motion, patient motion, radioactive decay, dead time, time of flight, tracer kinetics)
- Can handle voxelized and analytical phantoms

GATE: practical features

- Can be freely downloaded, including the source codes
- Can be run on many platforms (Linux, Unix, MacOs)
- On-line documentation, including FAQ and archives of all questions (and often answers) about GATE that have been asked so far
- Help about the use of GATE can be obtained through the gate-user mailing list
- Many commercial tomographs and prototypes have already been modeled (including validation of the model)

OpenGATE collaboration



http://www.opengatecollaboration.org/

GATE modeled PET systems

Scanner type	Studied FOM	Agreement	References
ECAT EXACT HR+, CPS	Spatial resolution Sensitivity Count rates Scatter fraction	 about 3 % < 7 % good at activity concentrations < 20 kBq/ml about 3 %	Jan *et al* 2005
ECAT HRRT, Siemens	Spatial resolution Scatter fraction Scattered coinc profiles Count rates	excellent (<0.2 mm) < 1 % very good (visual) good (about 10%)	Bataille *et al* 2004
Hi-Rez, Siemens	Scatter fraction Count rates NEC curves	about 1 % good at activity concentrations < 40 Bq/ml good at activity concentrations < 40 Bq/ml	Michel *et al* 2006

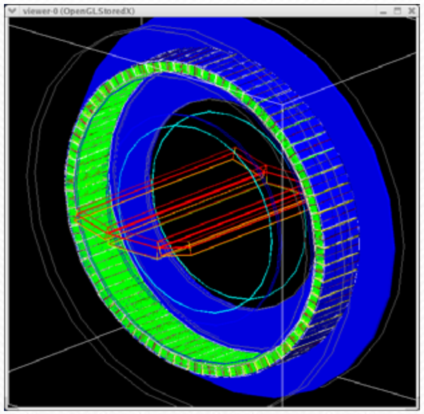
GATE modeled PET systems

Scanner type	Studied FOM	Agreement	References
Allegro, Philips	Count rate Scatter fraction	< 8 % 8 %	Lamare *et al* 2006
GE Advance, GEMS	Energy spectra Scatter fraction	not reported < 1 %	Schmidtlein *et al* 2006
MicroPET P4, Concorde	Spatial resolution Sensitivity Miniature Derenzo phantom	about 7 % < 4 % visual assessment	Jan *et al* 2003
MicroPET Focus 220, Siemens	Spatial resolution Sensitivity Count rates for mouse phantom	about 5 % about 3 % prompt coinc: < 5.5 % delayed coinc: < 13 %	Jan *et al* 2005
Mosaic, Philips	Scatter fraction Count rates	about 5 % 4-15 %	Merheb *et al* 2005

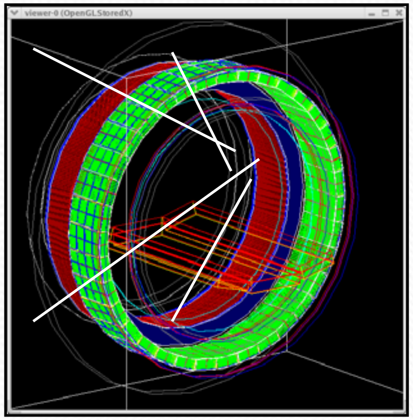
GATE: time-dependent processes

- SPECT and PET intrinsically involves time:
  - Change of tracer distribution over time (tracer biokinetic)
  - Detector motions during acquisition
  - Patient motion
  - Radioactive decay
  - Dead time of the detector
  - Time-of-flight PET

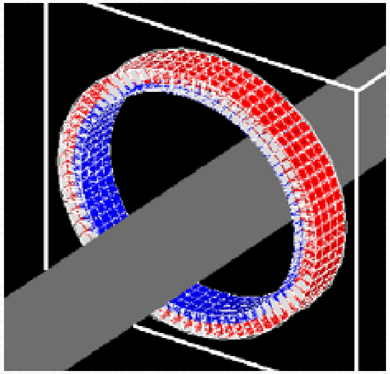
GATE examples



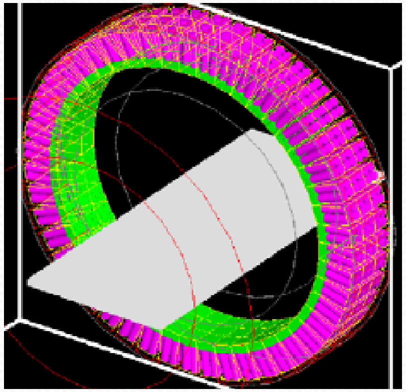
GE Advance/Discovery LS PET scanner
Schmidtlein et al, Med Phys 2006



GE Advance/Discovery ST PET, 3D mode
Schmidtlein et al. MSKCC

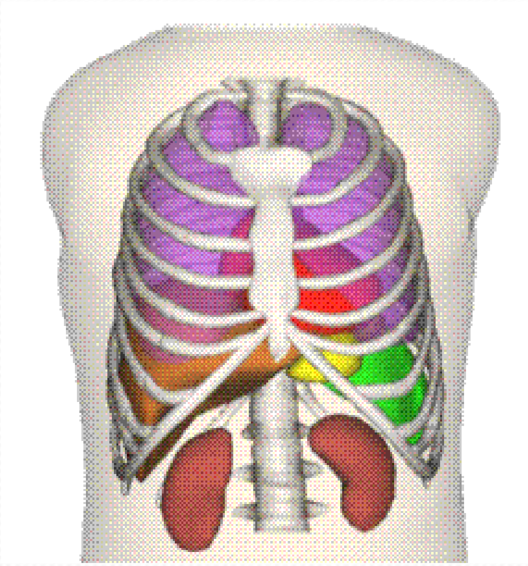


HR+ECAT EXACT PET scanner
Karakatsanis et al, NIM A, 2006

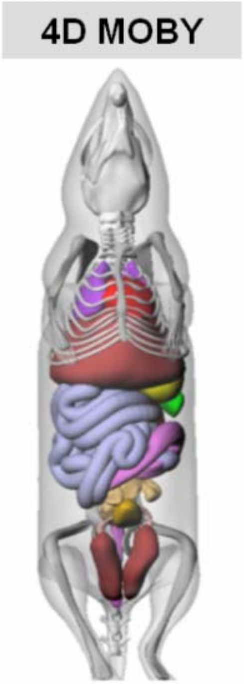


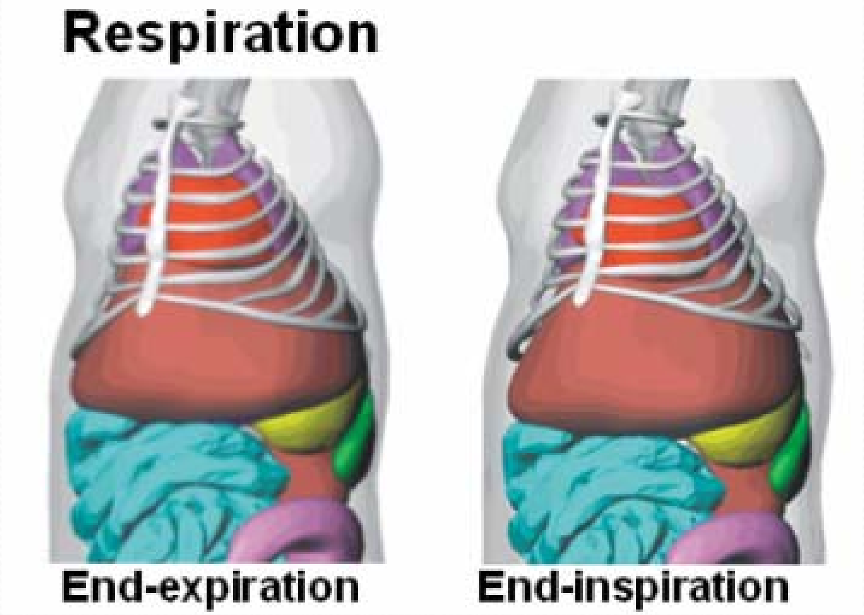
Siemens Biograh PET scanner
Karakatsanis et al, NIM A, 2006

Modeling realistic phantoms



Segars et al, IEEE TNS 2001





Segars et al, Molecular Imaging and Biology 2004

Descourt et al, IEEE MIC Conf Records 2006

Software for Tomographic Image Reconstruction (STIR)

- Open Source software for use in tomographic imaging.
- Provides a Multi-Platform Object-Oriented framework for all data manipulations in tomographic imaging.
- Currently implemented for (iterative) image reconstruction in PET
- STIR consists of 2 parts
  - A library providing building blocks for image and projection data manipulation and image reconstruction.
  - Applications using this library including basic image manipulations, file format conversions and of course image reconstructions.

STIR supported file formats

- An extension of the Interfile standard (http://www.HammersmithImanet.com/~kris/)
- GE Advance native sinogram format, but for reading only (with very limited support for the header).
- ECAT 6 matrix format by using conversion utilities to and from Interfile.Single frame/gate/bed images can be directly read or written.
- ECAT 7 matrix format for reading only (currently, an Interfile header has to be created using a utility). Single frame/gate/bed images can be directly read or written. Single frame/gate/bed sinograms can be directly read.
- In addition, a separate set of classes is available to read list-mode data. Only a few scanners are currently supported (such as the ECAT HR+ and HR++)

Finally routines will be provided by the OpenGate collaboration for reading output of GATE Monte Carlo simulator.

3-D sinogram description

- Image slice: Geometrically associated to a cylindrical volume defined by a slice of the FOV. By convention, a slice is half the width of a ring. For a scanner of n detector rings, there are 2n–1 image slices.
- Direct plane Image slice centred on a ring. For a scanner of n detector rings, there are n direct planes. The axial FOV is ended by two direct planes centred on the first and last rings.
- Cross plane Image slice in between two consecutive direct planes. Direct planes are adjacent to cross planes. For a scanner of n detector rings, there are 2n–1 cross planes.
- Sinogram: Set of bins corresponding to 1 segment and 1 axial position. Before axial compression, this corresponds to LORs in a detector ring (direct sinogram) or between two different detector rings (oblique sinogram).
  - For a scanner of n detector rings, there are
    - n direct sinograms and
    - n*n–n oblique sinograms for a total of n*n sinograms

3-D sinogram description

- Ring difference: Distance between two rings associated to a sinogram. If ringA and ringB are the ring index numbers, the ring difference is given by: ringB – ringA
- The ring difference of a direct sinogram is zero.
- Segment: Set of sinograms with a common ring difference
- Bin: A single element in a sinogram, completely specified by its segment, axial position, view and tangential position.

Michelogram representation

- Michelogram (3-D sinogram): Representation of 2-D sinograms on a square grid as shown below

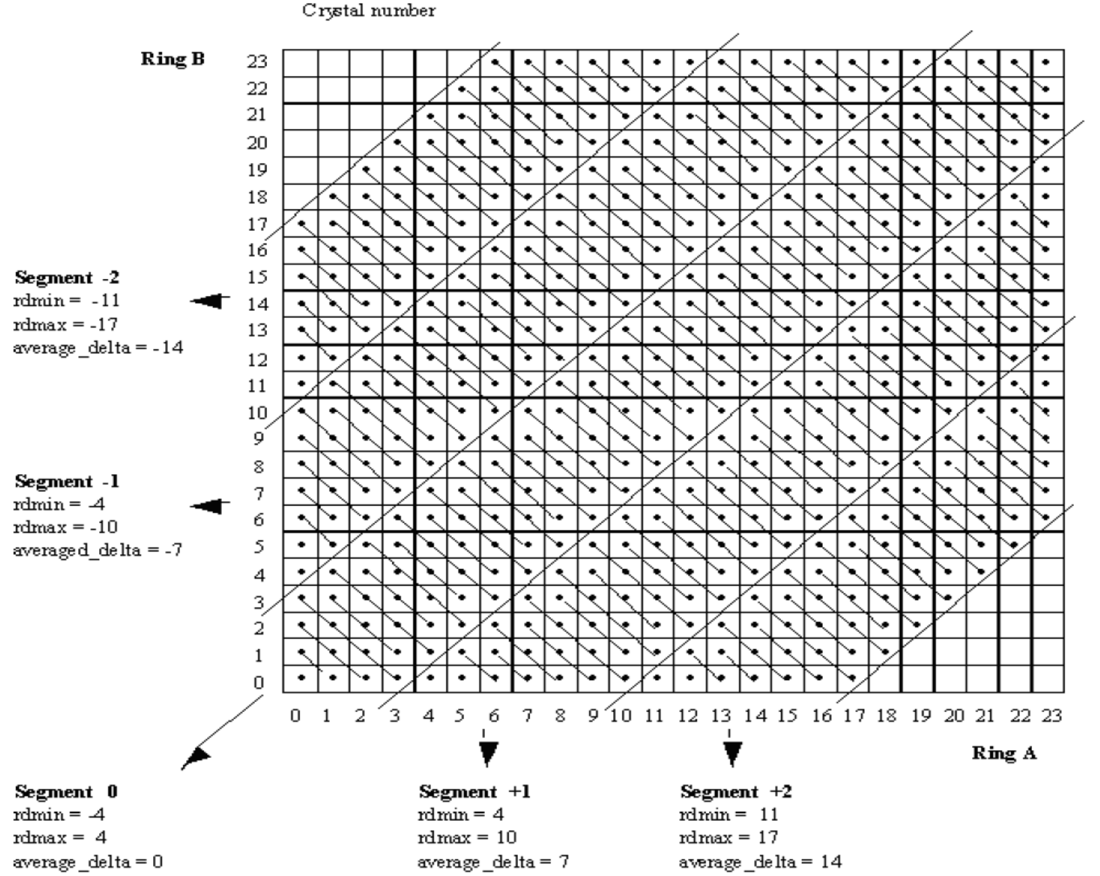


Figure 1: Michelogram with span=7

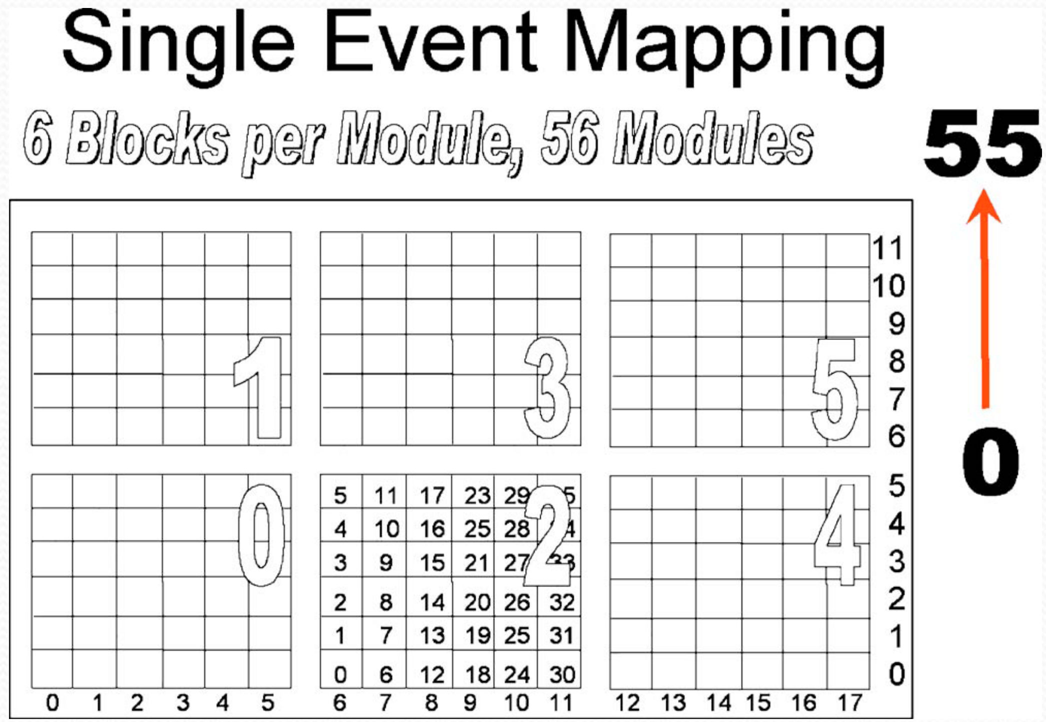
Sinogram binning method [GATE-STIR connection]

- ROOT C++ routine implemented
  - bin GATE projection data to form a 3-D sinogram (interfile format) suitable for STIR

Gate uses the Crystal, Block and Module identification numbers (IDs) to store detection events in ROOT

Sinogram binning method uses these IDs of detected events to organize sinograms

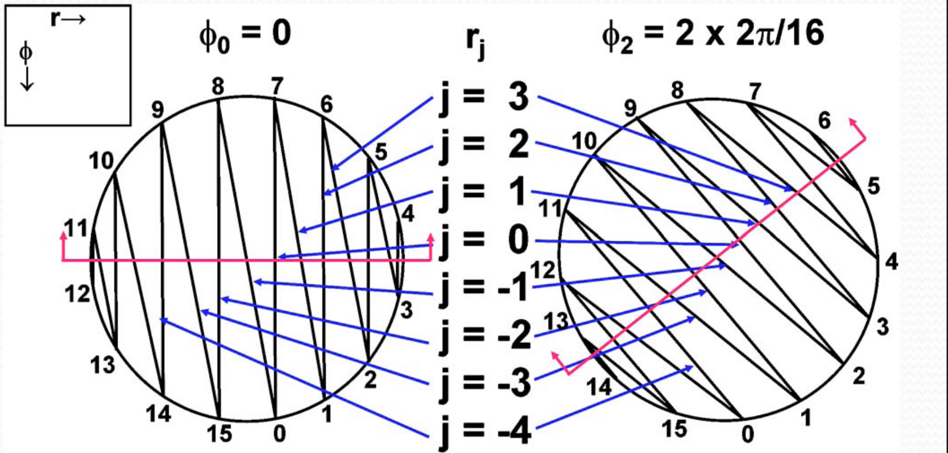
ROOT ID's for each coincidence pair are converted into crystal-ring pairs through INT and MOD calculations



Schmidtlein et al, Medical Physics, 2006

Sinogram binning method [GATE-STIR connection]

Schmidtlein et al, Medical Physics, 2006



- LORs are binned into a block matrix with index dimensions in the ϕ (azimuthal), r (radial) and θ (ring difference) directions.

Azimuthal binning

For each projection plane the sum of the crystal numbers (C#) for a coincidence pair will always sum to one of the two numbers that are unique to a particular projection plane

i= [(Crystal1+Crystal2) + Const]

where const is an arbitrary constant which satisfies the boundary condition ϕ=0

Radial binning

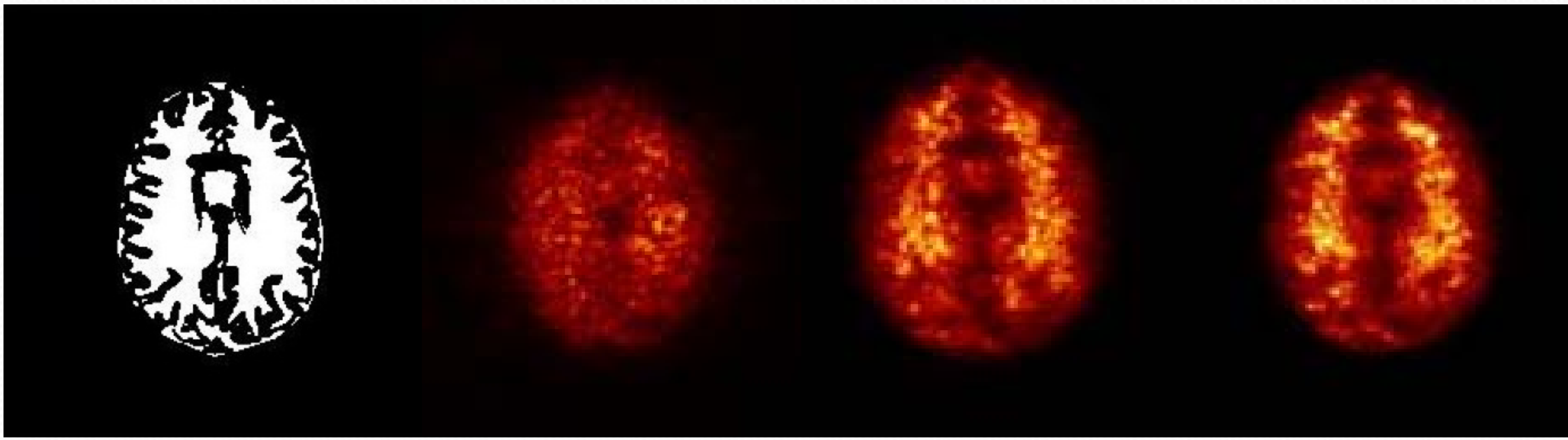
The radial distance from the center of the scanner is related to the index difference of the crystals in the pair.In terms of indexing, the index j for r can be expressed as

abs(j) = N/2 – abs(Crystal1-Crystal2)

with j in the time space of [0,N/2) for the case of interlacing

GATE – STIR study: Zubal phantom

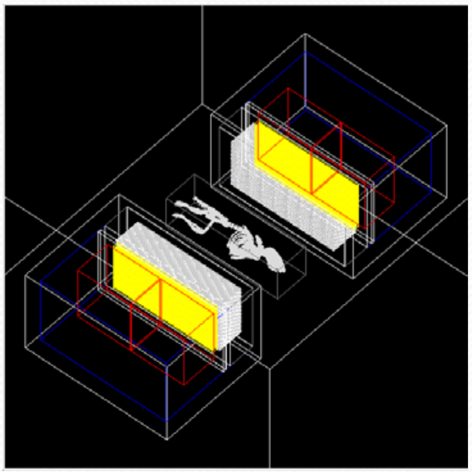
GATE simulated Zubal data reconstructed with STIR (OSMAPOSL)



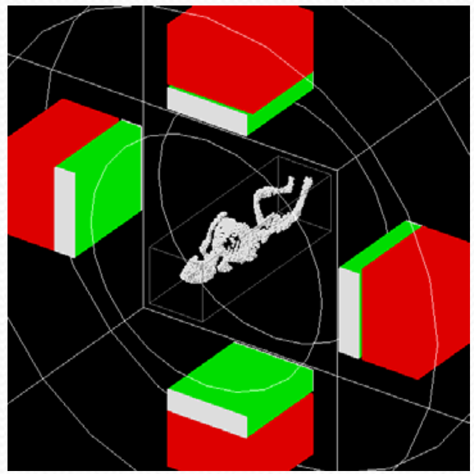
Original activity map A single central slice	1sec acquisition time single activity slice	10sec acquisition time single activity slice	10sec acquisition time 4 neighboring activity slides included

Modeling realistic phantoms

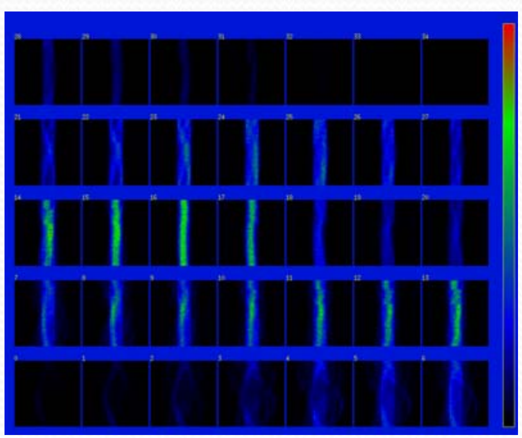
Simulation configuration in GATE



SPECT bone scan

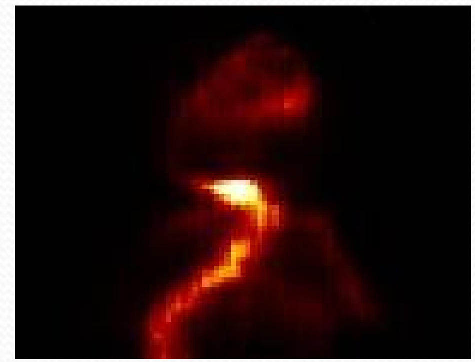


PET bone scan.

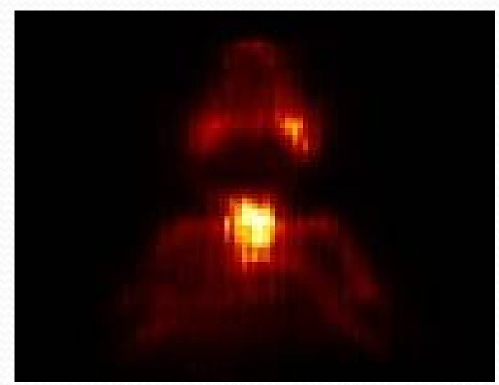


GATE - PET projection data

PET bone reconstructed data
STIR OSMAPSOL (6 iterations)



Sagittal slice.



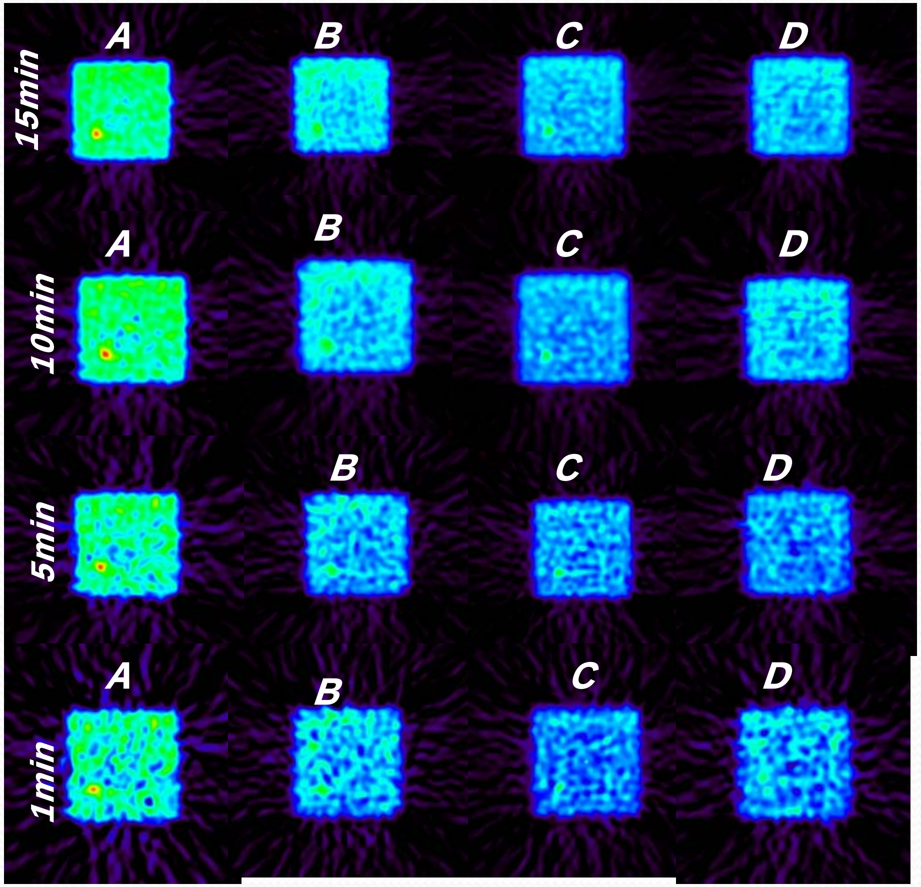
Transverse slice

Sakellios et al, IEEE MIC Conf Records 2006

Minimum Detectable Activity [GATE- STIR]

Results: Performance analysis of Biograph 6 in terms of MDA

Reconstructed image data for the LSO-based Biograph 6 GATE model

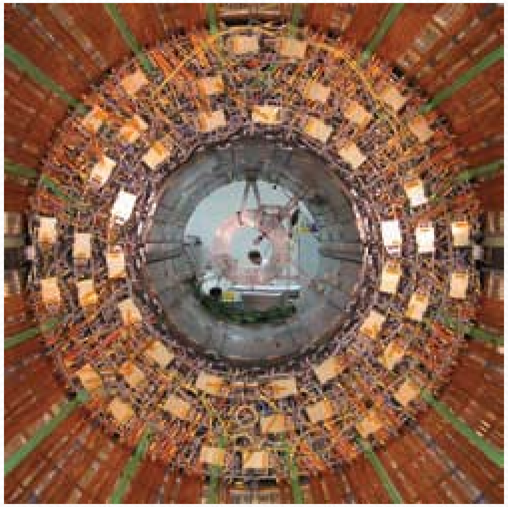


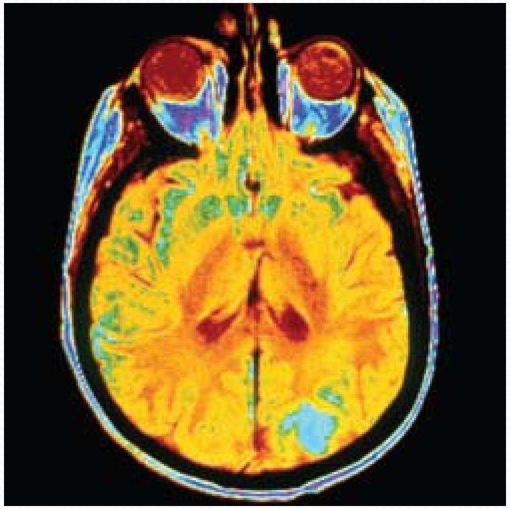
The simulated projection data were histogrammed into time frames of 15min, 10min, 5min and 1min respectively

Each frame was later reconstructed using FBP-3DRPJ algorithm of STIR package.

It consists of four different signal to background ratio regions, beginning at left with the highest ratio (region A) and ending to the right with the lowest ratio region (region D)

Thank you!





We would like to thank
the OpenGATE collaboration and
the STIR developers community
for allowing us to use the open source software for the presented radionuclide imaging studies
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