Customizable and Advanced Software for Tomographic Reconstruction
What is CASToR?

- Open source toolkit for 4D emission (PET/SPECT) and transmission (CT) tomographic reconstruction

- Focus on generic, modular and extensible

- High performance computing (parallel CPU computing, GPU)

- Dedicated to both specialists in the reconstruction field and “standard” users
## CASToR background

<table>
<thead>
<tr>
<th>INSERM UMR1101 Latim, Brest, France</th>
<th>UIMIV U1023 – SHFJ, Orsay, France</th>
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<tbody>
<tr>
<td>• Julien BERT</td>
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### Research fields:
- List-mode/Sinogram based reconstruction algorithms
- Statistical iterative reconstruction

- **Stute et al. 2011** Image properties of various ML-based reconstructions of very noisy HRRT data, *IEEE MIC*


- **Merlin T., Visvikis D., Fernandez P, Lamare F 2015** A novel partial volume effects correction technique integrating deconvolution associated with denoising within an iterative PET image reconstruction process, *Medical Physics, 2015, 42(2), 804-849, O,M,GB*
CASToR background

**Research fields:**
- List-mode/Sinogram based reconstruction algorithms
- Statistical iterative reconstruction
- Advanced projector modeling, TOF-PET
- GPU PET/SPECT and CT reconstruction

**Autret A, Bert J, Strauss O, Visvikis D 2013** Fully 3D PET List-Mode reconstruction including an accurate detector modeling on GPU architecture, *Fully3D Image Reconstruction in Radiology and Nuclear Medicine*

**Gaens M, Bert J, Pietrzyk U, Jon Shah N and Visvikis D 2013** GPU-accelerated Monte Carlo Based Scatter Correction in Brain PET/MR, *IEEE NSS-MIC*

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**Research fields:**
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- Advanced projector modeling, TOF-PET
- GPU PET/SPECT and CT reconstruction
- Dynamic imaging

**Lamare et al. 2007** List-mode based image reconstruction for respiratory motion correction in PET using non-rigid body transformations, *Phys. Med. Biol.* **52** 5187-5204

**Merlin et al. 2013** Dynamic PET image reconstruction integrating temporal regularization associated with respiratory motion correction for applications in oncology, *Annual meeting of the Society of Nuclear Medicine*
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- SPECT collimators

**Benoit D, Maîtrejean S, Mathy F, Montemont G, Buvat I, 2013**: Impact of the depth of interaction in reconstruction of small-animal SPECT data acquired with a space-variable-focusing collimator, *IEEE NSS-MIC*
Why building a new platform from scratch?

- Methodologies spread out in distinct code/libraries
- Different programming languages
- Difficult to merge/combine code
  - Time-consuming incorporation of new techniques
  - Requires a more flexible approach
  - Extend the platform for other users
CASToR objectives

What are we aiming for?

Customizable and Advanced Software for Tomographic Reconstruction

Customizable:
- Generic C++ core structure
- Modular architecture
- Straightforward plug-in integration
- Running on GPU or CPU
- Multi-platform (Linux, windows, mac)

Advanced methodologies:
- Forefront methods at various levels of tomographic reconstruction
- Multidimensional (2D, 3D, 4D) reconstruction
- Multimodality (PET, SPECT, CT)
- Regular updates with introduction of new methodologies

Toolkit dedicated to both users and experienced developers
CASToR objectives

What will we propose ?

For users

• Access to basic and advanced methodologies
• Support for most PET/SPECT/CT geometry
• Command-line options as a first step (user interface as a second step)
• Full support of GATE datasets (data output, corrections)
• Various utilities (analytical simulation, datafile converter, etc.)

For developers

• User-friendly plug-in integration (Projector, optimizer, image convolver, kinetic model, new system, etc.)
• Multi-level documentation (user-friendly doc and Doxygen/LXR)
Customizable and Advanced Software for Tomographic Reconstruction

Architecture overview
Practical implementation

• Programming performed in standard C++

• Message Passing Interface (MPI) Clustering for the high-level splitting

• Parallelism at the event level is implemented through OpenMP

• No use of any external libraries as much as possible (ITK/VTK, Boost, etc..)

• I/O image file format : interfile

• Command-line options in the first version of the platform
Generic architecture

Main classes

Main
Iterative loops

« Branches »

Optimizer
Projector
Event
Datafile
Scanner

Other classes

Mother classes
Child classes

Keep the specific features in child classes
• “Specific” code is transparent in the main loop of the program
• New child class addition does not require modifications of the generic classes (one class dedicated to the auto-inclusion of new child classes)
• Allows addition of new branches in the future with minimal changes
CASToR Datafile format

Unique datafile format

+ Allow the definition of mandatory/optional fields for each modality

+ Extendable

- Require user to convert their own datafiles to CASToR format
  -> Conversion tools provided for some scanners
  -> Conversion templates

- Complete support for GATE simulated datasets
  -> Conversion and reconstruction could be merged into one operation
CASToR datafile format

- ASCII header, containing information about acquisitions

```
Data filename: ListTOTO_Frm20.Cdf
Number of events: 53906430
Data mode: 0
Data type: 0
Start time: 0
Stop time: 3600
Scanner name: PET_GE_DRX
Axial compression: 0
Azimuthal compression: 0
Max ring diff: 160
Calibration factor: 1
Isotope: unknown #(analytic projection)
TOF capability: 0
DOI capability: 0,0,0
Attenuation correction flag: 0
Normalization correction flag: 0
Scatter correction flag: 0
Random correction flag: 0
```

- Raw data file
CASToR scanner format

System geometry description

- User-friendly ASCII file
  - Mandatory/optional information
  - Geometry calculated at run-time
  - User-guide providing support for datafile conversion

```plaintext
# comments
# X
# 
# Z
# Y
# positions in millimeters
# scanner axis is Z
# use comma without space as separator in the tables.

modality : PET
scanner name : PET_GE_DRX

scanner radius : 443  # Distance between the center of the scanner and the
center of a rsector (Gate;rsector)

# rsectors are repeated on a ring
number of elements : 15120
number of rsectors : 70
rsectors first angle : 0  # optional (default is 0 deg)
rsectors angular span : 360  # optional (default is 360 deg)
rsectors ZShift : 0  # optional (default is 0mm) could be
                   # an array (example: [-10.0, 3.0]).

number of modules transaxial : 1  # optional (default is 1)
number of modules axial : 4  # optional (default is 1)
module step transaxial : 0  # optional (default is 0mm)
module step axial : 1.75  # optional (default is 0mm)
```
CASToR scanner format

System geometry description

- User-friendly ASCII file
- User-made LUT (Look-Up Table)
  - ASCII header and binary files
  - Pre-computed by the user
- Dedicated to scanner with “complex” geometry

```plaintext
scanner name:    PET_GE_DRX
modality : PET
scanner radius: 443
number of rings in scanner: 24
number of elements: 15120
number of layers: 1
number of crystals in layer: 15120
layers size depth: 30
layers size transaxial: 4.23
layers size axial: 6.35
layers material: LYSO
voxels number transaxial: 256
voxels number axial: 47
field of view transaxial: 700
field of view axial: 153.69
min angle difference: 40 #deg
mean depth of interaction: -1 # optional (default value : center of crystal )
```
CASToR scanner format

System geometry description

- User-friendly ASCII file
- User-made LUT (Look-Up Table)

Easy integration

- Scanner files located in a repository
- Geometry generated/loaded at run-time
Customizable and Advanced Software for Tomographic Reconstruction

Some illustrative results
Current implementation

CASToR reconstruction:
- Siddon line-projector
- OSEM
- GE DRX scanner model

NCAT phantom image

CASToR reconstruction

- NCAT anthropomorphic phantom
- Projection with CASToR (no noise model)
- OSEM (2 iterations, 16 subsets)

- List-mode patient [18F]-FDG dataset
- GE-DRX scanner
- OSEM (2 iterations, 16 subsets)
Current implementation

CASToR reconstruction:
- Siddon line-projector
- OSEM (2 iterations, 16 subsets)
- GE scanner model

Dynamic reconstruction:
- GATE simulation of a NCAT dynamic dataset
- Linear Temporal regularization using Gaussian basis functions

Motion-corrected image reconstruction:
- Transformation parameters estimated from optical flow registration algorithm
- Amplitude-gated, 8 bins
Multithreading: speedup factor in relation with the number of cores

- OpenMP
- dual E5-2650 2GHz
- GE DRX, 46M LORs
- 256x256x94 voxels of 2x2x2 mm
- Projection on 16 threads: ≈1 min
Customizable and Advanced Software for Tomographic Reconstruction

General information and future plans
Future plans

Planned features for the first release (Second-half 2016)

Reconstruction

• List-mode & sinogram iterative reconstruction
• Basic and advanced projectors
• Basic and advanced PET optimizers
• SPECT reconstruction supporting basic features
• MPI clustering & multithreading
• Other features

Utilities

• GATE conversion tools
• Analytical simulation tool and other utilities
• Developer documentation
Future plans

Planned features for later releases

• Advanced features for PET/SPECT :
  • Penalty (optimization)
  • Pre-computed system matrix
  • Advanced resolution modeling
  • Dynamic imaging
• GPU implementation (main loop algorithm, projectors)
• GATE : estimation of corrections (scatter, random, …) according to the input data
• Iterative CT reconstruction
• Analytical reconstruction algorithms
• Analytical simulation tools with advanced features
Information/Contribution

Distribution

• Open-source

• No use of external libraries

• Script to convert manufacturer datafiles to CASToR format distributed as binaries

Website & contact

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