CASToR

Customizable and **A**dvanced

Software for **To**mographic

Reconstruction

CASToR

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

INSERM UMR1101 Latim, Brest, France

- Julien BERT
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- Didier BENOIT
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UIMIV U1023 – SHFJ, Orsay, France

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CNRS UMR5287 INCIA, Bordeaux, France

- Frédéric LAMARE

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*
- **Stute S and Comtat C 2013** Practical considerations for image-based PSF and blobs reconstruction in PET, *Phys. Med. Biol.* **58** 3849-3870
- **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*

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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*
- **Bert J and Visvikis D 2011** A Fast CPU/GPU Ray Projector for Fully 3D List-Mode PET Reconstruction, *IEEE NSS-MIC*

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- 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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- Statistical iterative reconstruction
- Advanced projector modeling, TOF-PET
- GPU PET/SPECT and CT reconstruction
- Dynamic imaging
- 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*

CASToR background

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

➢ *Require 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)

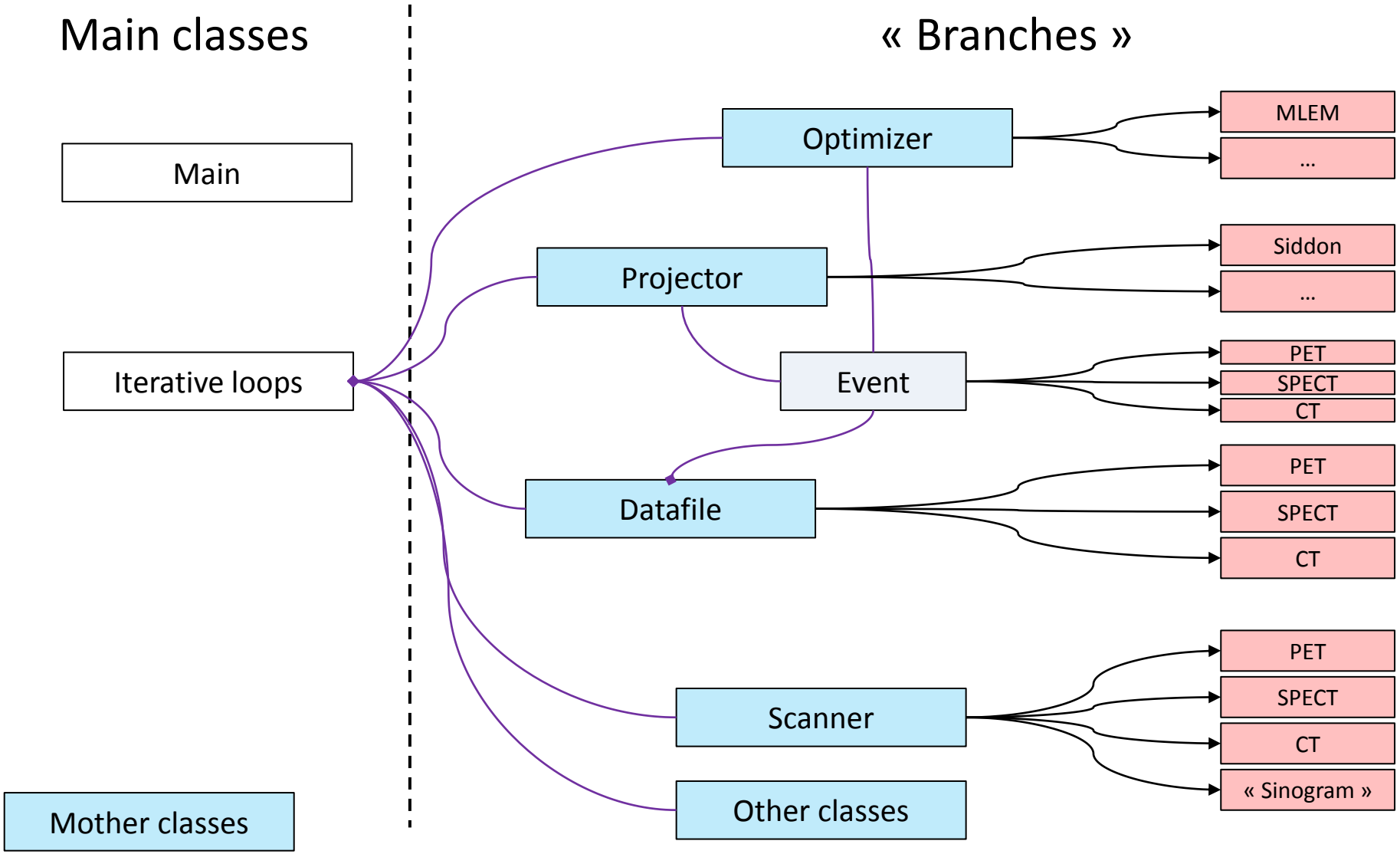
Customizable and Advanced Software for Tomographic Reconstruction

Architecture overview

Practical implementation

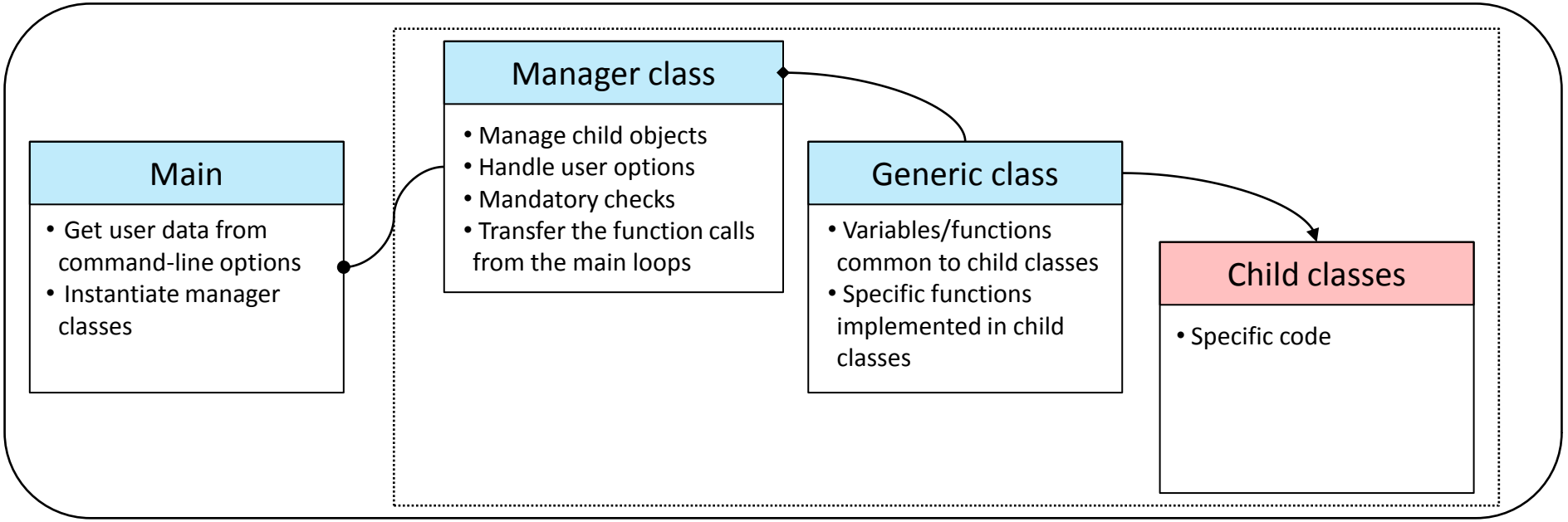
- Programming performed in standard C++
- Message Passing Interface (MPI) Clustering for the high-level splitting
- Parallelism at the event level is implemented through OpenMP
- No use of any external libraries as much as possible (ITK/VTK, Boost, etc..)
- I/O image file format : interfile
- Command-line options in the first version of the platform

Generic architecture



➢ Keep the specific features in child classes

Generic « branch » management



- “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

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
Azymutal 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

```
# 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)

# rsector 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

```
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

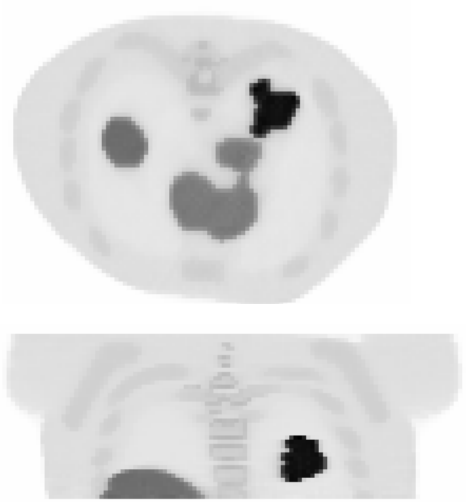
Current implementation

CASToR reconstruction :

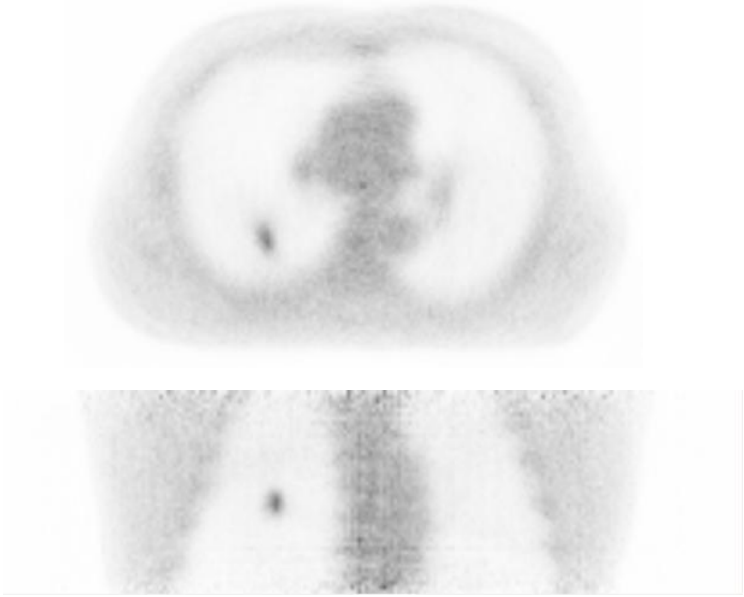
- Siddon line-projector
- OSEM
- GE DRX scanner model

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 (2iterations, 16 subsets)
- GE scanner model

Dynamic reconstruction

30s frame

5min frame

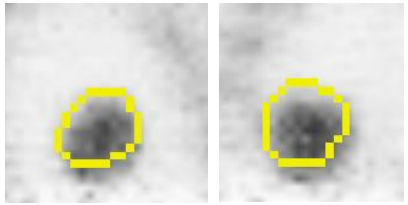
10min frame

3D reconstruction *4D reconstruction*

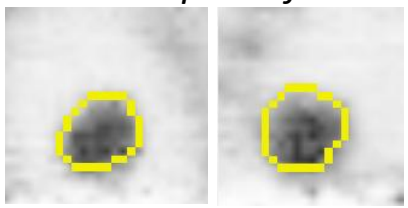
- GATE simulation of a NCAT dynamic dataset
- Linear Temporal regularization using Gaussian basis functions

Motion-corrected image reconstruction

No motion correction *Reference bin*



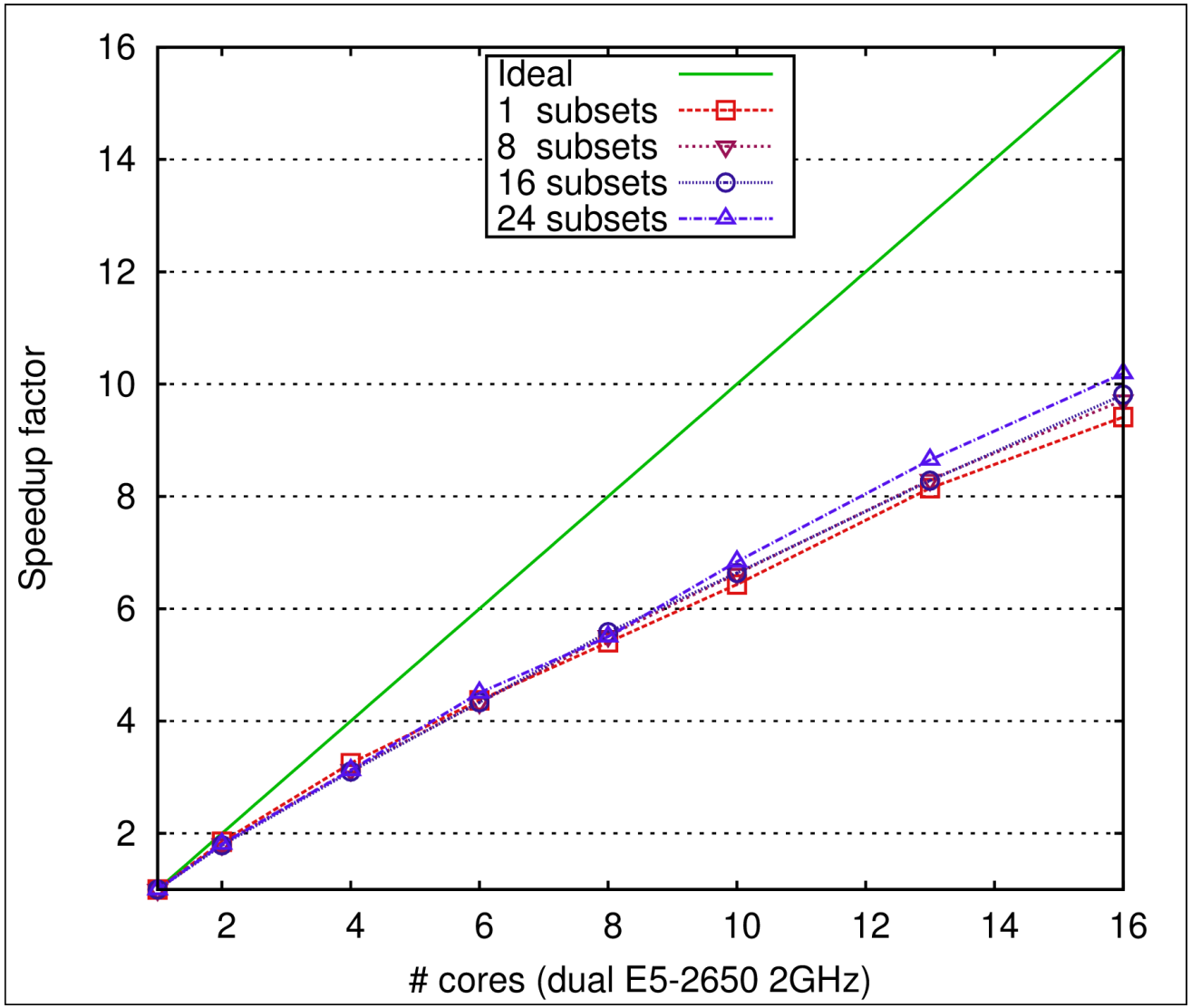
MCIR- Optical flow



- Transformation parameters estimated from optical flow registration algorithm
- Amplitude-gated, 8 bins

Current implementation

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

- **http://www.castor-project.org**
- thibaut.merlin@univ-brest.fr

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