STIR: Software for Tomographic Image Reconstruction Release 2

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[1]*Abstract*. **We present an update to *STIR*, an Open Source object-oriented library in C++ for 3D PET reconstruction. This library has been designed so that it can be used for many algorithms and scanner geometries, while being portable to various computing platforms. This second release enhances its flexibility and modular design, but also adds extra capabilities such as list mode reconstruction, more data formats etc.**

I. INTRODUCTION

STIR is an Open Source library for PET image reconstruction and manipulation, which originated in the PARAPET project, a European Union funded collaboration on 3D PET reconstructions. STIR is used by a fairly large number of scientists. It has about 400 registered users, although usage can probably more accurately measured by membership to its mailing lists (170 for the announcements list, 115 for the user's list and 48 members for the developer's list).

The previous version of STIR was restricted to reconstruction (and manipulation) of PET emission data in sinogram format. This release adds additional C++ class hierarchies and templates such that reconstruction of PET transmission data and list mode data is possible. In addition, the framework is made more flexible to allow using STIR for other problems, such as finding detection efficiency factors.

II. ADVANTAGES OF OBJECT-ORIENTED PROGRAMMING

Unlike procedural programming languages which separate data from operations on data defined by procedures and functions, object-oriented programming languages consist of a collection of interacting high-level units, the objects, that combine both data and operations on data. This renders objects not much different from ordinary physical objects. This resemblance to real things gives objects much of their power and appeal. They can not only model components of real systems, but equally as well fulfil assigned roles like components in software systems.

Variables and methods common to every object of a certain kind define a class. Inheritance between classes allows the programmer to define a hierarchy of classes, where each object takes on the attributes and behaviours of its ancestors. This hierarchy is an inverted tree structure (with the root at the top and the leaves at the bottom) where each lower level of the tree defines more specific attributes about a particular class of object.

As each object not only contains data but also defines all possible interactions with the data, object-oriented programming leads itself to modular design.

III. DESCRIPTION OF THE LIBRARY

The collaborators to the PARAPET project designed a library of classes and functions for 3D PET image reconstruction [1,2]. This library was released as Open Source in June 2000. After the end of the PARAPET project, the software was renamed to STIR and is currently maintained by one of us..

The modular design of STIR uses the object-oriented features of C++: self-contained objects hide implementation details from the user, and hierarchies of objects are implemented using inheritance. In addition, we use C++ templates, a powerful feature of C++ that allows writing generic code for different data-types but which is specialized by the compiler, such that the generic code does not suffer from performance penalties.

The library has been designed so that it can be used for many different algorithms and scanner geometries. It is portable on all computer systems supporting the GNU C++ compiler or Microsoft Visual C++, but we expect no major problems with other ANSI C__ complaint compilers.

The building block classes included in STIR can be described as follows:

- templated multi-dimensional arrays (any dimension and any data-type) and numerical operations, including n-dimensional Fast Fourier Transform (FFT) ;
- various filter transfer functions (3D, 2D and 1D);
- information classes about the data to be reconstructed such as PET scanner characteristics, sinogram formats, images etc;
- forward projection operators (ray tracing method using a variation of Siddon's algorithm [3]);
- backprojection operators (incremental, beamwise interpolating backprojection using Cho's algorithm [4,5]; or using ray tracing);
- classes for other data manipulations in PET such as normalization.
- classes for both analytic and iterative reconstruction algorithms, including penalties;
- reading and writing (I/O) data in various formats, either natively or via conversion. Interfaces are implemented to other IO libraries;
- classes for parsing parameter files allowing the user to make choices for e.g. filters, data formats,

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algorithms etc at run-time.

- Framework for automatic testing of many components of the library.

Special care has been taken regarding extendibility and re-use of code. For example, if a new forward projector is implemented, addition of only 2 lines is necessary to allow all reconstruction algorithms to make use of the new projector. In addition, the software comes with extensive documentation, including automatically generated HTML (or other formats) from comments in the code using the *doxygen* tool (http://www.doxygen.org).

IV. Brief Description of New Features

A. Reconstruction hierarchy

The most important change in this release involved a redesign of the reconstruction classes. A new hierarchy has been created for generalized objective functions, which are then used by the iterative algorithms.

Most reconstruction algorithms are derived from some optimization criterion, such as least-squares minimization, maximum likelihood or MAP. The algorithm then attempts to maximize the corresponding objective function. However, in practice various modifications are made to these algorithms such that a true objective function no longer exists. Examples are the One Step Late Median Root Prior algorithm [6,7] which defines a 'gradient' of a prior, although no function exists; or cases where the forward and back projector are not transpose operations.

The generalized objective functions in STIR compute a 'sub-gradient' (i.e. 'gradient' over a subset of the data). This allows generic algorithms such as (preconditioned) gradient-descent to work on any objective function implemented in STIR. Most algorithms in PET image reconstruction crucially involve the sub-gradient computations and can be implemented without detailed knowledge of the data. Well-known examples are MLEM [8] (which is implemented in STIR to work on sinogram data [9] or list mode data) and OS-SPS [10] (which also works on transmission data).

In addition, the generalized objective functions and reconstruction algorithms are now templated in the type of the parameters over which the optimization is performed. This means that these parameters no longer have to correspond to images, but other data-types such as parametric maps or detection efficiencies can be used (if appropriate). For instance, we have implemented a subset version of the PIRA [9] algorithm, reusing all of the existing OSEM code (this implementation is currently not yet part of the distribution).

B. IO

Another new feature is an extendable and modular way to add new IO routines using 'factories'. In addition to its native format Interfile, STIR comes with interfaces to external libraries such as the ECAT Matrix library (Merence Sibomana et al), and Analyze^{TM} AVW^{TM}.

C. Scatter simulation

This release includes our implementation [12] of the Single Scatter Simulation algorithm [13,14]. This implementation has been tested in [12,15,16].

V. Discussion and Conclusion

In this paper, we described an update to STIR, a flexible library which can be used to study current and implement new reconstruction algorithms for a wide variety of scanner geometries. The use of object-oriented software has helped greatly to (a) compare analytic and iterative methods, (b) develop new iterative algorithms (c) adapt and apply the developed reconstruction algorithms to various designs of positron tomographs. The powerful constructs promoted by object technology can yield elegant, quality code. This programming paradigm makes it possible to envision incremental refinements to the building blocks described in this paper with maximum code reuse by providing a framework for effectively defining standards using the inheritance mechanism. This approach streamlines development and improves reliability.

STIR is available for download at http://stir.hammersmithImanet.com and http://stir.sourceforge.net. Note that at the time of submission of this proceedings, some of these features are still in internal testing.

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VI. References

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