The NA-MIC Kit: ITK, VTK, Pipelines, Grids and 3D Slicer as An Open Platform for the Medical Image Computing Community

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ABSTRACT

Medical Image Computing researchers often face the problem of moving promising new algorithms from the proof of concept stage into a form compatible with clinical use. Algorithm developers lack the time and resources to engineer their code for robustness and compatibility, while end-users are anxious to try new techniques but require well designed and tested user interfaces to make practical use of them. The NA-MIC Kit is a collection of software and methodology specifically designed to address these problems and facilitate the rapid advancement of the field.

1. INTRODUCTION

Biomedical research relies increasingly on imaging to organize observations of the biophysical world and to quantify these observations in pursuit of better understandings of biological systems, pathology, and treatments. Advances in computer science have led to stunning improvements and great hope for continued growth through the introduction of faster and more sophisticated processing, distributed computing, and high speed networking (Grid) technologies to facilitate the analysis of high resolution, multi-modality images from increasingly large subject populations. However the medical image computing community has historically been fragmented in its approach to software development and distribution. A result of this fragmentation has been a significant amount of re-implementation of common tools (file I/O, filters, core algorithms, user interfaces, etc.) and at the same time a lack of reproducibility of results due to the complexity of algorithms and variations in the implementations of these core components.

The NIH recognized the need for improved integration of computer science into medical research and acted through the formation of the National Centers for Biomedical Computing (NCBC) program, a part of the NIH Roadmap Initiative [1,2]. One of the seven centers funded to date through the NCBC program is the National Alliance for Medical Image Computing (NA-MIC) [3] that was formed specifically to address the issues raised above. In creating the NCBC program, NIH emphasized the need for solutions with freely available source code that can be modified and extended for academic and commercial use. Operating since late 2004, NA-MIC brings together several ongoing threads of development that addressed various aspects of the medical image computing software problems and combined them with the goal of providing the open platform needed by the community. Dubbed the NA-MIC Kit, this platform provides a set of well developed tools needed by algorithm developers, software engineers, and application domain scientists and continues to develop and improve these tools through targeted development efforts and close interaction with the end-user community. The NA-MIC Kit is described in more detail in the following sections.

2. COMPONENTS OF THE NA-MIC KIT

The NA-MIC Kit includes three major types of software technology: programming toolkits, end-user application software, and system infrastructure. The *programming toolkits* rely heavily on the proven utility of the Insight Toolkit (ITK) for image segmentation and registration and the Visualization Toolkit (VTK) to support visualization and interactive rendering and manipulation [4,5]. A set of GUI components customized for VTK-based application development called the KWWidgets are also being developed and promoted [6]. NA-MIC has adopted the 3D Slicer as the *end-user application* environment to provide a cross-platform GUI built on VTK and ITK [7,8]. 3D Slicer, based primarily on VTK, already provides initial implementations of many of the core medical image computing requirements and is increasingly relying on ITK as the method of choice for new algorithms. The *system infrastructure* part of the NA-MIC Kit includes the LONI Pipeline system for assembling computational building blocks into analysis streams suitable for application to large population studies [9]. In addition, a close collaboration between NA-MIC and the Biomedical Informatics Research Network (BIRN) provides a scalable set of distributed computing and database tools for use with the NA-MIC Kit

[10]. Cross platform system configuration, testing, and distribution tools (CMake/CTest/CPack, Dart2) are also being developed [11,12]. All of the elements listed above are being actively developed through the engineering core of NA-MIC. In addition to these elements, the NA-MIC Kit draws on 'best of breed' utilities and applications provided by the Open Source community at large (including: teem, CVS, svn, MediaWiki, Condor, Globus, and many others) [13-18].

3. DRIVING BIOLOGICAL PROJECTS

Within the wide field of biomedical imaging, the initial focus of the NA-MIC Kit has been in the neuroimage analysis of schizophrenia, and in particular the integration of structural, functional, and connectivity studies using Magnetic Resonance (MR), functional MR (fMRI), and Diffusion Tensor MR (DTI). This admittedly narrow initial focus provides a proving ground for the integrated tool sets to work out issues related to merging multi-model and time-varying volumetric data. While this main effort in neuroimaging progresses, additional collaborations are underway to apply the NA-MIC Kit technologies to a broader range of fields including musculoskeletal modeling and simulation from CT and MR, orthopedic biomechanical analysis, and image guided surgery. We expect an increasing number of application areas to drive the robustness, completeness and utility of the NA-MIC Kit.

4. USAGE SCENARIOS

A major goal of the NA-MIC Kit engineering effort is to provide a framework in which code can be re-used in a variety of application scenarios with at most minor modifications. We see usage requirements falling into the following broad categories:

- Desktop Application: the common mouse and keyboard style of application must be available for interactive visualization and for exploring available algorithms and parameter spaces. 3D Slicer provides many of these tools.
- Large-Scale Analysis: a non-programmer user must be able to assemble a sequence of analysis steps and apply them to large subject population using a GUI interface. The LONI Pipeline supports this style of visual programming.
- Scripted: many highly useful image analysis tools are based on the Unix shell scripting paradigm. Well modularized command line executables with standardized argument syntax will support this style of analysis and will facilitate interoperation with other systems.
- Grid Computing: grid computing tools provide the ability to discover available computers at remote sites and launch jobs on these resources. To take advantage of these machines, the NA-MIC Kit must package algorithms for execution on a wide range of target systems (for example, by providing cross-compiled executables along with their dependent libraries, and by virtualizing I/O routines beyond the traditional local-filesystem metaphor).
- Reusable Libraries: for programmers implementing custom applications we must provide a clean and reliable API to allow integration of NA-MIC Kit technology into a variety of systems. In support of this goal, we are following the precedents established by the VTK and ITK projects to encapsulate as much as functionality as possible into modular and reusable libraries. As a consequence, our GUI applications and command line utilities can be 'thin wrappers' which share common high level libraries for data management and processing.

5. LICENSING CONSIDERATIONS

As mentioned above, NIH goals for the NCBC program include an emphasis on open software and on the ability to share techniques between academic research projects and commercial enterprises. The NA-MIC community has dedicated significant effort to discussion and analysis of how best to achieve NIH objectives while delivering usable and state-of-the-art tools to the medical image computing community. NA-MIC has determined, as a matter of policy, that elements of the NA-MIC Kit are to be licensed in a very open manner with as few strings attached as possible. In practice, this has meant that elements of the kit should be licensed under terms that are essentially the BSD style of license.[1]

5.1. The GPL Issue

Much of the widely available open source software is licensed under the terms of the GNU General Public License (GPL).[2] Many of these software packages address key areas of functionality identified as important for NA-MIC users including user interface toolkits and numerical processing libraries among other tools. The obvious appeal of these packages is tempered by the GPL requirement that any derived works incorporating GPL software must themselves be licensed under the GPL. In practice, the NA-MIC group has determined that this "reciprocal" aspect of the GPL is incompatible with nature of the medical imaging industry, where significant up front investment in development and testing is only recouped after FDA and other regulatory approvals have been obtained. The medical imaging industry has, to our knowledge, essentially universally

[1]. BSD (from Berkeley Standard Distribution) refers to the license used by an early Unix distribution. A BSD-style license has essentially no restrictions on use of software in commercial projects and allows redistribution in source or binary form.

[2]. GNU (for GNU's Not Unix) is a common and widely successful effort to provide core computing tools that are free in terms of their ability to be further modified and distributed.

rejected the idea of accepting GPL code in any work that might become a product.[3] In addition to concerns about commercialization, we also note that many academic researchers elect to distribute software in binary form during testing prior to publication, a practice incompatible with a strict interpretation of GPL requirements. Because it is our mandate from the NIH to facilitate both research and the transition of new technology into the larger world of clinical application, we have been careful to exclude GPL licensed code from the core of the NA-MIC Kit.

5.2. Licensing of Tools and Utilities

When we say that the core of the NA-MIC Kit is licensed with BSD style license, we mean specifically that the code which we encourage people to extend for the creation of new applications and implementation of algorithms; other code which is used either as self-contained shared libraries or as stand alone executables may be licensed under a variety of terms. For example, the CVS software for managing source code repositories is licensed under GPL and is an important part of our software methodology (code which is simply managed by CVS does not constitute a 'derived work'). Similarly, libraries such as teem are licensed under terms such that programs using them are not considered derived works and are thus compatible with NA-MIC licensing policy. As a concrete example, we are building GUI programs in the NA-MIC Kit, which rely heavily on extension of the core system, with the KWWidgets, which have a BSD style license, rather than on the Qt system which is only available under GPL or commercial licenses [19]. More information on software licensing in general can be found in Lawrence Rosen's book [20] and on the NA-MIC wiki pages on this topic [21].

5.3. Clinical Usage

It is not uncommon for research groups which make medical imaging software available to include a "not for clinical use" clause in the terms of their license agreement. Indeed, until the current release 2.6, the 3D Slicer license included such a clause. The motivation for this clause, at least in the case of the 3D Slicer software, was to limit the liability of the copyright holding institution (Brigham and Women's Hospital) in case of any problems arising from misuse or programming errors. In the context of NA-MIC, this decision was revisited, again to ensure compatibility with the stated goals of the NIH. A precedent was found in the form of a disclaimer used by the AFNI project, an fMRI package distributed under the GPL [22]. The disclaimer included the following sentence: "*Clinical applications are not recommended or advised; this software is designed for research purposes only.*" Wording to this effect has been adopted in the current 3D Slicer license agreement to emphasize that while clinical usage is not strictly prohibited, responsibility for any such use falls with the user and not with the developers [23].

6. SOFTWARE ENGINEERING METHODOLOGY

From the beginning of NA-MIC, the group decided to adopt and build upon the successful software methodologies developed and used in the VTK and ITK projects based on a modified "Extreme Programming" paradigm augmented by custom tools [24,25]. Specifically:

- NA-MIC uses a cross-platform build system based around the CMake platform.
- NA-MIC relies on nightly builds and regression tests to identify bugs and programming constructs that aren't scalable across compilers. Catching these issues early in the development cycle significantly simplifies the work needed for releases.
- The Dart2 server and CTest client are being developed in NA-MIC to capture and archive nightly build and test information and present an easy-to-use web interface for tracking and probing this information.
- A new CPack system is being developed, analogous to CMake, to provide a cross platform way of describing the components of a software distribution such that a platform-specific delivery target can be created (e.g. a setup.exe for windows and a .rpm file for linux may be created from the same source code).
- NA-MIC uses open, web-based development tools including wikis, mailing lists, public CVS access, and a range of "best practices" that have become common in the open software community.

7. COMMUNITY BUILDING, INSIGHT JOURNAL

An important consideration in a project with the ambitious scope of NA-MIC is how to scale the development efforts beyond the initial core group while maintaining consistency in the programming methodology and the standards for algorithm accuracy. Following the lead of the ITK community and sponsorship of the National Library of Medicine, NA-MIC is encouraging all major code contributions to be accompanied by a submission to the Insight Journal, a recently formed on-line open-access venue the goals (and personnel) of which overlap significantly with NA-MIC [26]. The Insight Journal web site allows submission of multimedia "papers" on algorithm and

[3]. One notable exception is the use of the Linux operating system in some medical products such as the GE MR scanner console. This type of usage relies on a clause in the GPL license that allows the copyright holder to provide guidance as to what usage does and does not constitute a derived work; in the context of the Linux operating system, Linus Torvolds as copyright holder has held that programs running on the operating system do not constitute derived works. See reference [20], page 118.

software development topics that also include the full source code so that readers can test and extend the published methods. We believe this system provides a scalable mechanism for vetting software contributions by clear articulation of the software goals and implementation for peer review before making them a formal part of the released system.

8. SLICER 3.0 ARCHITECTURE

A major undertaking of NA-MIC during its second year of funding is the implementation of a new generation of the 3D Slicer application to leverage the rest of the NA-MIC Kit and be compatible with the design goals outlined in this paper. The major implementation effort will take place during 2006 and detailed design decisions will take place over the course of the development cycle, but several key pieces of the design are already in place:

- The Slicer Base, which currently contains both the data model and the GUI application infrastructure will be broken out into distinct reusable libraries.
- Slicer Modules will be similarly broken out so that each module can be used as a component in one of the usage scenarios described above. Compiling these modules as shared libraries allows them to be pulled into either a batch-oriented tool like the LONI Pipeline or an interactive application like the traditional 3D Slicer.
- Visualization will be based on VTK and GUI components will be based on KWWidgets. The application framework will be a 'thin' as possible, with most of the data management and application logic pushed down to into the reusable libraries.
- Medical image analysis algorithms will be implemented in 'pure' ITK, meaning that little if any of the algorithm's implementation will be influenced by the particulars of the visualization or GUI layers.

More information on plans for Slicer 3.0 is available on the NA-MIC Wiki [27].

9. CONCLUSIONS

The NIH NCBC program provides unique environment for the development of tools that address important problems facing the medical image computing community. By leveraging outstanding existing software systems and practices, and augmenting these with custom development as needed, NA-MIC Kit is an opportunity to address a wide range of projects in both the near and long term. By carefully choosing licensing strategies that are compatible with commercialization, we hope to facilitate the application of exciting new technologies to the treatment of human diseases.

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