The Center for Integrative Biomedical Computing (CIBC) is a research resource that carries out research on biomedical imaging problems and produces, distributes, and supports open-source software tools for biomedical image-based modeling, biomedical simulation and estimation, and visualization of biomedical data. The software tools are the product of our core research in imaging algorithms and scientific computing, in turn driven by our driving biological projects and other collaborations, and supported by our location in the Scientific Computing and Imaging (SCI) Institute. We have five main software tools that feature and incorporate our research. SCI Run, which has been cited in over 340 publications, is our main tool for modeling bioelectric problems and visualizing a diverse set of biomedical and biological data. Our tool for performing image segmentation, Seg3D, incorporates state of the art image tools from the Insight Toolkit (ITK) for image analysis. Our volume renderer, ImageVis3D, is a product of our cutting edge visualization research and is perhaps the fastest available tool for interactive volume rendering of out-of-core data. For users needing to create meshes for simulations, we have developed Cleaver, a new tool based on our recent algorithm for mesh refinement. Finally, our statistical shape modeling software, ShapeWorks, features our research into efficient point-cloud correspondence matching and enables users to perform analysis of 3D shapes. These advanced computational tools, are accessible to scientists, engineers, and physicians by the release of readily usable, fully supported, open-source software. In addition to our software dissemination, our team works closely with users, providing workshops, tutorials and documentation, advice, technical support, and education to enhance their success with the tools we provide.  

**ImageVis3D:** scalable GPU-based ray-guided volume rendering

Volume rendering is an important method for analyzing large-scale scalar fields. The major limitation of most volume rendering approaches is their inability to quickly adjust the data sampling rate (and thus data size) required for display. Using a volume renderer inspired by recent work, we demonstrate that the actual amount of data required for a scene is typically considerably lower than the memory available on a commodity GPU. To address this constraint, we have built a volume renderer which can quickly render massive datasets on commodity GPU hardware. The major contributions are:

- Identification of regions which require dense sampling.
- Locating transitions between data requiring dense sampling regions which exhibit considerable homogeneity.
- Ray termination when required.
- Efficient communication among regions currently rendered and those in the future to the 3D layer.

**SCI Run 5.0**

SCI Run is a problem solving environment or "computational workbench" in which a user selects software modules that can be connected in a visual programing environment to create a high level workflow for experimentation. SCI Run has always been a core element of the CIBC and is currently released as version 4.6 with binary versions for all major platforms. A new release of SCI Run 5.0 is planned for this spring and provides all the capability of the current version but now makes use of the following features:

- New underlying framework based on the Qt user interface development system.
- Provenance - enables users to record, edit, and play back the steps performed to build and operate a network.
- Python scripting interface to all of SCI Run's methods.
- Headless mode - complete separation of the user interface from the back end.

Example of SCI Run 5 rendering of the potential values on a heart using our TriSurf mesh from the forward/inverse toolkit. Note, the new GUI on the left which contains many new modules.

**Seg3D: state of the art image processing tool**

Seg3D is a volume segmentation and processing tool which combines a flexible manual segmentation interface with powerful higher-dimensional image processing and segmentation algorithms from the Insight Toolkit. Users can explore and label image volumes using volume rendering and orthogonal slice view windows.

Seg3D highlights:

- Fully 3D interface with multiple volumes managed as layers.
- Automatic segmentation integrated with manual contouring.
- Real-time display of ITK filtering output allows for computational steering.
- Supports many common biomedical image formats.
- Open-source with BSD-style license.
- Cross-platform: Windows, OSX, and Linux.

Segmentation of a porcine torso using Seg3D

Heart segmentation, highlighting needles used to identify electrode placement.

**Cleaver: adaptive multi-material meshing application**

Cleaver is a multi-material tetrahedral meshing application and library with documented API for generating meshes used in simulations. Important features of Cleaver include:

- Mesh generation that adapts to feature size.
- Close conforming to meshes internal to tissue boundaries.
- Progressive mesh subdivision ("cleaving") scheme provides rapid mesh generation that maintains alignment of elements with surface boundaries.

Mesh (4.5 million elements) generated on a frog model using a constant-sized stencil. Thus, smooth surfaces are more refined than they need to be.

New mesh (3.5 million elements), generated using adaptive stencils that were sized based on the feature size near the surface. Thus, fewer elements are needed to discretize the surface. Note that the size of the stencil can be made smaller or larger for a given feature size such that the discretization error in our mesh representation is below a certain threshold.

**Shapeworks: statistical shape modeling software**

Statistical shape analysis is a means to quantify variation in the shape of objects across time and across members of a cohort; the applications of shape analysis in biomechanics are growing rapidly and include orthopedic evaluations, brain development, heart remodeling, and genetic manipulation of skeletal structure. Our approach is based on automatically setting correspondence points across samples in order to align them and then quantify shape variations. The alignment step alone is valuable as it supports building atlases and comparing structures in both the same patients across time as well as across patients with similar disease states. Once individual samples are aligned, we compute means and other statistical metrics of variation. In addition, we extract the specific types or modes of variation in shape across the samples. The result is a quantitative method to compare complex anatomical shapes and correlate shape parameters with other clinical variables in order to tie structure to function.

Mean cortical surface shapes: Two views of the mean shape of the ensemble of left hemisphere cortical surfaces. Segmented left hemispheres, with 13 sulcal curves each, were used as input. 6 of these curves were selected as landmark curves and geodesic distances to these curves were used as features to optimize 6144 correspondences on each cortical surface. Sulcal depth was also used as an additional feature to guide the correspondence optimization. Note that it is possible to identify all of the major sulci, including the ones not used in the optimization.

Mean shapes of the left atrium from hearts of patients who present for atrial fibrillation: Reconstructed median shapes for the pre-ablation (a) and post-ablation (c) groups, highlighting a particular correspondence. Overlay of the two median shapes, showing the high degree of variability (b).

**First Summer Course on Image-based Biomedical Modeling (IBBM) Applied to Bioelectricity and Biomechanics**

July 14-24, 2014 at the Newport Resort and Hotel in Park City, Utah.

This course offers field-specific expertise and hands-on experience solving bioelectric or biomechanical problems that arise in current biomedical research and clinical practice. Participants will receive training in numerical methods, image analysis, and computational tools necessary to carry out end-to-end, image based, subject specific simulations in bioelectricity or biomechanics, using freely available software.