Integrating Ontologies with Three-Dimensional Models of Anatomy

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Introduction:
Three dimensional geometric models have been used in a variety of application areas, such as surgical simulation, planning, visualization, and teaching. In nearly all such domains, these models encode detailed spatial geometric information, but usually contain little additional information, such as knowledge about the structures these models contain or properties of those structures.

In some application domains, such as predicting the effects of penetrating injury on a victim, it is necessary to know about the internal anatomy in addition to the spatial geometry. Anatomic knowledge in 3-d geometric models is generally in the head of the viewer. Thus, this knowledge is inaccessible for computer applications such as decision support, or reasoning about the physiological and anatomic consequences of penetrating injury.

The goal of our work is to link an ontology containing anatomic knowledge with 3-d geometric models in order to support anatomic reasoning about the effect of a projectile on an inured subject. In can be difficult to determine the extent of internal organ damage after a person suffers a penetrating injury. One can observe external trauma, but internal damage cannot be seen without an imaging test such as CT, which is not available at the time the injured person is first examined in the field. Our hypothesis is that we can predict the anatomic and physiological effects of penetrating injury using 3-d geometric models that contain anatomic knowledge. The goal of our work is to develop methodology to link 3-d geometrical models derived from segmented image data with logical anatomic knowledge in order to simulate both the direct and indirect effects of a projectile injury.

Methods:
In this project, we are developing and linking representations (or "models") of two kinds of knowledge: anatomic knowledge and geometric knowledge. Anatomic knowledge, such as which organs are in a region of the body and how they relate to other components, can be represented in an ontology. Ontologies provide formal definitions of concepts and relationships among concepts. One source of anatomic knowledge is the Digital Anatomist Foundational Model (FMA, [1]), a domain ontology that represents a coherent body of explicit declarative knowledge about human anatomy. The FMA provides formal definitions of detailed anatomical concepts and relationships of anatomic structures in a computationally-accessible format. However, as the FMA is a logical representation of canonical anatomy, it lacks information on organ shape and absolute location.

Conversely, geometric knowledge regarding the location and shape of organs is represented in a 3-d geometric model. These models may be segmented to identify organ parts and sub-parts. We developed an ontology in Protege to represent the entities in that are common to most geometric modeling approaches in which source data are derived from segmented volumetric images. We call this a "canonical" ontology of geometry, as it is meant to capture generic geometric notions common to most geometric models. This ontology specifies the particular data members present in geometric models that are instantiated according to its class design.

We created code classes in C++ using the Insight Toolkit (ITK; [2, 3]). These classes were designed according to the classes in our geometry ontology. The ITK classes provide the geometric representation of anatomic structures in 3-d space. The ontology allows components within a geometric model to be annotated with terms in the FMA in order to link geometry and anatomy. The geometric objects created in the ITK ("abstract geometric objects") were created as a hierarchy of objects using knowledge in the FMA ontology to structure the relationships among these objects.

Programmatic access to Protégé from C++ was accomplished using a C++/Java interface layer implemented using JACE,[1] a public domain tool to access the Java JNI. We built C++ proxy classes to transparently access corresponding Protégé Java classes (e.g., KnowledgeBase.cpp, Cls.cpp, Slot.cpp, etc.). The advantage of this approach is that the C++ code to access Protégé methods and link our ITK classes with the FMA ontology was nearly transparent.

We used the Visible Human data set [4] as a source for anatomic image data. Anatomic structures, such as the chambers of the heart, were labeled in the segmented images from this data set. From volumetric images of the chest, we produced 3-d geometric models of the heart. We used the Insight Toolkit to load the segmented images and build 3-d tetrahedral mesh models.

A path of destruction can be specified in our geometrical model, and a set of intercepted geometrical elements can be deduced. These geometrical elements can be mapped to the FMA to infer the organs that are injured.

Results:

Our ontology represents a spectrum of primitive geometric elements used to construct 3-d geometrical models. It has sufficient generality to allow either images or meshes. It includes such entities as points, cells, meshes, and simplexes. These geometric elements relate to various attributes of the organism from which the geometry is derived (organ name and biomechanical properties) as well as attributes needed to simulate the effect of penetrating injury, such as boundary features, externality, and physical properties.

Our ontology of 3-d geometry enables us to add anatomic information to geometric models. Each voxel or vertex in our geometric models contains information about the organ to which that element belongs. Anatomic structures such as the ventricles and aorta are labeled in the geometry, and can be displayed using different color shadings (Figure 1).

We have superimposed a projectile trajectory and deduced the path of injury and produce a list of damaged structures. For example, assuming a linear path for the bullet and a parameterized region of tissue injury (decreasing tissue destruction along the bullet path), we can describe and display a conically-shaped region of tissue injury (Figure 1). In addition to displaying the injured region, a user can query the model by selecting points. Because we have linked the 3-d model to the FMA, we can identify which organs or organ parts are injured, and quantify percentage of an organ that is damaged.

We are also developing and using the FMA ontology to reason about which structures are adjacent to the path of injury so that we can predict the extent of organ damage. The FMA contains information about which organs are adjacent to other organs. Using this adjacency information, it is possible to suggest organs adjacent to the path of injury that are nearby and possibly damaged.

The FMA is also useful in order to answer questions that require anatomic abstraction. For example, we would predict from our geometric model that the left ventricle has been injured, but by reasoning from the FMA based on partonomic relationships, we would also know that the pericardial sac has been penetrated and that the left side of the heart has been injured (since the left ventricle is contained in the left side of the heart).

Conclusion

We have demonstrated an approach to integrate geometric models with ontologies of anatomic knowledge so that software can help deduce the anatomic consequences of injury. The utility of our methodology is that software can reason about remote consequences of a localized injury. This entails identifying the site of injury in the geometrical model, finding the corresponding structure in the FMA, and reason about relationships in the FMA to establish the other anatomic structures that are also likely affected by their proximity to the projectile path.

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[1] http://sourceforge.net/projects/jace/

Our methodology is extensible, and we can include additional information in our models to permit their use in other application domains.

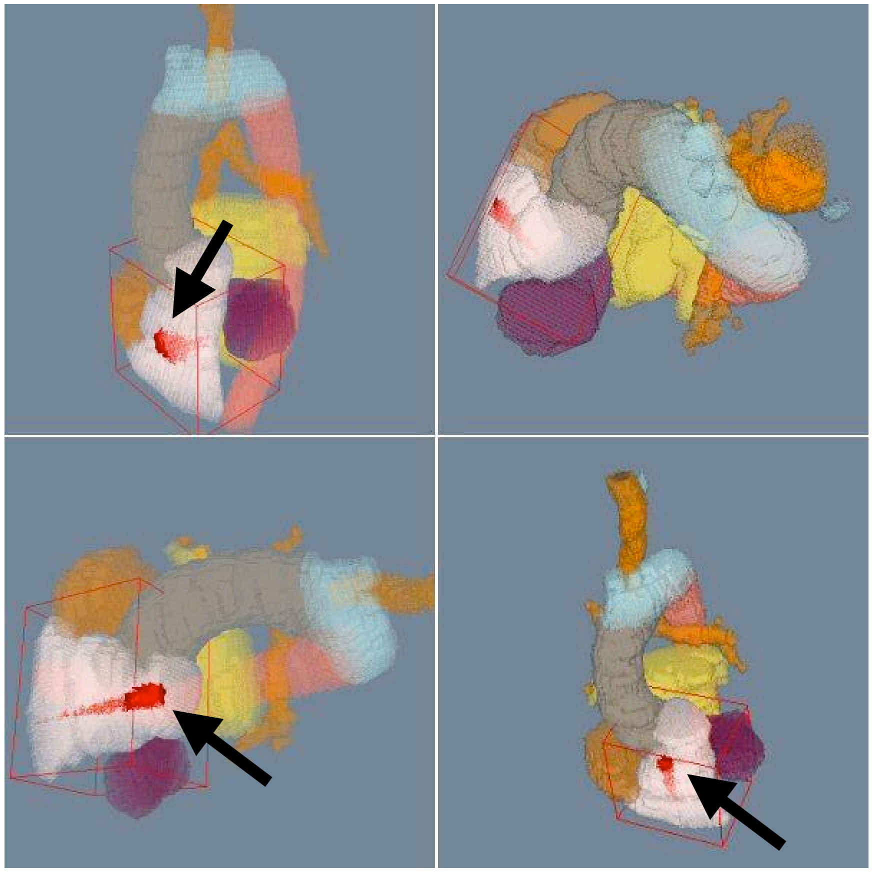

Figure 1: Four views of a three dimensional geometric model of the heart with anatomic structures labeled (shaded structures in the geometric model correspond to anatomic structure classes in the FMA ontology). A trajectory of penetrating injury was superimposed (top left image), and regions of tissue injury are predicted and demonstrated in the geometrical model (conically-shaped region shown by arrow). We can determine the identities of injured anatomic structures and infer the possible injuries to adjacent structures using knowledge in the FMA ontology.

References:

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