

Linking Ontologies with Three-Dimensional Models of Anatomy to Predict the Effects of Penetrating Injuries

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Abstract—Rapid diagnosis of penetrating injuries is essential to increased chance of survival. Geometric models representing anatomic structures could be useful, but such models generally contain only information about the relationships of points in space as well as display properties. We describe an approach to predicting the anatomic consequences of penetrating injury by creating a geometric model of anatomy that integrates biomechanical and anatomic knowledge. We created a geometric model of the heart from the Visible Human image data set. We linked this geometric model of anatomy with an ontology of descriptive anatomic knowledge. A hierarchy of abstract geometric objects was created that represents organs and organ parts. These geometric objects contain information about organ identity, composition, adjacency, and tissue biomechanical properties. This integrated model can support anatomic reasoning. Given a bullet trajectory and a parametric representation of a cone of tissue damage, we can use our model to predict the organs and organ parts that are injured. Our model is extensible, being able to incorporate future information, such as physiological implications of organ injuries.

Keywords—Geometric models, ontologies, simulation

I. INTRODUCTION

It 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 a CT scan, which is not available at the time the injured person is first examined in the field. Since survival depends on rapid diagnosis of the nature and extent of organ injury in penetrating trauma, methods to determine this information rapidly are needed.

We are interested in using geometric models to predict the anatomic and physiological effects of penetrating injury. But geometric models alone are insufficient because they lack anatomic knowledge. The underlying technology we are developing will link three dimensional (3-d) geometrical models derived from segmented image data with descriptive anatomical models (in ontologies) in order to simulate both the direct and indirect effects of a penetrating injury. Such methodology may be useful for triage of injured subjects by field medics.

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 of Anatomy (FMA) [1], a domain ontology that represents a coherent body of explicit declarative knowledge about human anatomy (Figure 1). The FMA provides formal definitions of detailed anatomical concepts and relationships of anatomic structures in a computationally-accessible format. However, as it is a descriptive model of anatomy, it lacks precise information on organ shape and absolute location.

Conversely, geometric knowledge regarding the location and shape of structures is represented in a 3-d geometric model. A geometric model is a spatial representation of objects using vertices and edges as modeling primitives. They are generally used to create visualizations of body regions or organs, or to provide spatial coordinate information in biomechanical simulations. While geometric models contain detailed spatial information, they generally contain no anatomic knowledge. Knowledge about the organs contained in geometric models remains in the head of the viewer. Thus, geometric and ontologic models of anatomy currently exist in largely disjoint worlds.

An early effort to explore the relationship between anatomy and geometry was undertaken by intersecting 3-d models with a wound path [2], but the geometric model contained no knowledge other than organ names. We are developing methods to integrate the two worlds of geometry and anatomy so that software can relate geometry to anatomic structures in the FMA. For example, software could reason about remote consequences of a localized injury by identifying the site of injury in the geometrical model, referencing the anatomic entities associated with that site, and working through relationships in the FMA to establish the other anatomic structures that are also likely affected because they are related to the injured organs.

II. METHODOLOGY

We developed an ontology to represent the entities that are common to most geometric modeling approaches for which source data is derived from segmented volumetric images. We call this a “canonical” ontology of geometry, as

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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 C++ classes (called “abstract geometric objects”) in the Insight Toolkit (ITK; [3, 4]) The ITK provides a large library of data structures and algorithms for working with imaging data and models derived from these data. The abstract geometric objects were designed according to the classes in our geometry ontology, and they are the data structures that we use to produce a geometric representation of anatomy in 3-d space. The ontology allows components within a geometric model to be annotated with class names in the FMA in order to link geometry and anatomy. Abstract geometric objects represent not only the spatial geometric data, but also include additional knowledge such as the organ location (named FMA class), boundary features, biomechanical properties, and tissue damage attributes.

Starting with leaf classes in the FMA (representing the smallest organ sub-parts in the geometric models), we use the FMA to build a hierarchy of abstract geometric objects, linking these objects with anatomic knowledge in the FMA (Figure 1).

We used the Visible Human data set [5] as a source for anatomic images. Anatomic structures, such as the chambers of the heart, were labeled in the segmented images from this data set (Figure 2). From volumetric images of the chest, we produced 3-d geometric models of the heart. We used ITK to load the segmented images and build 3-d solid tetrahedral mesh models. A hierarchy of abstract geometric objects was created and populated with knowledge from the

FMA.

A path of destruction can be specified in our geometrical model, and a set of intercepted geometrical elements can be deduced. We described the region of damage commonly associated with penetrating injuries by creating a conically-shaped parametric region around the projectile path, and we designated this region a “conical region of tissue damage.” Geometrical elements within the conical region of damage can be mapped to the FMA to infer the organs that are injured.

III. RESULTS

A. Geometry ontology

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 (Figure 3). 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 effects 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 (“in_organ” attributes in Figure 3). Anatomic structures such as the ventricles and aorta are labeled in the geometry, and they can be displayed using different color shadings (Figure 4). The display parameters for each organ are stored in the corresponding abstract geometric object. The path of penetrating injury and its surrounding region of tissue damage can be similarly

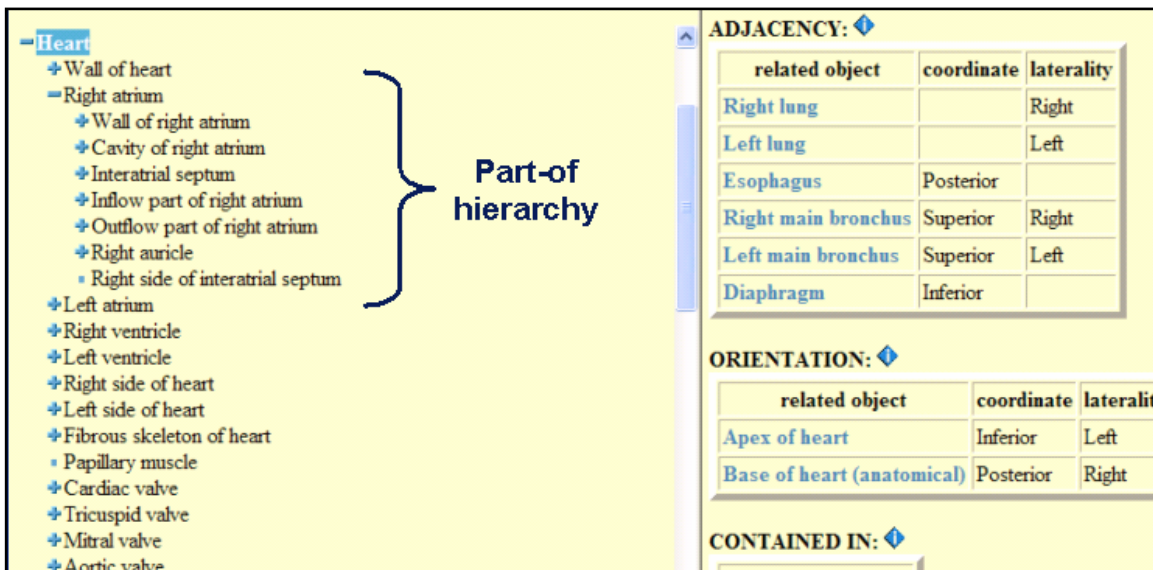


Figure 1: The Foundational Model of Anatomy (FMA). A portion of the FMA ontology is shown here, focused on the heart. Organs and organ parts are shown in the hierarchy on the left (a “partonomy”). Knowledge about individual organs or organ parts is shown in the panel on the right, and includes information such as adjacencies, containment, and vascular supply.

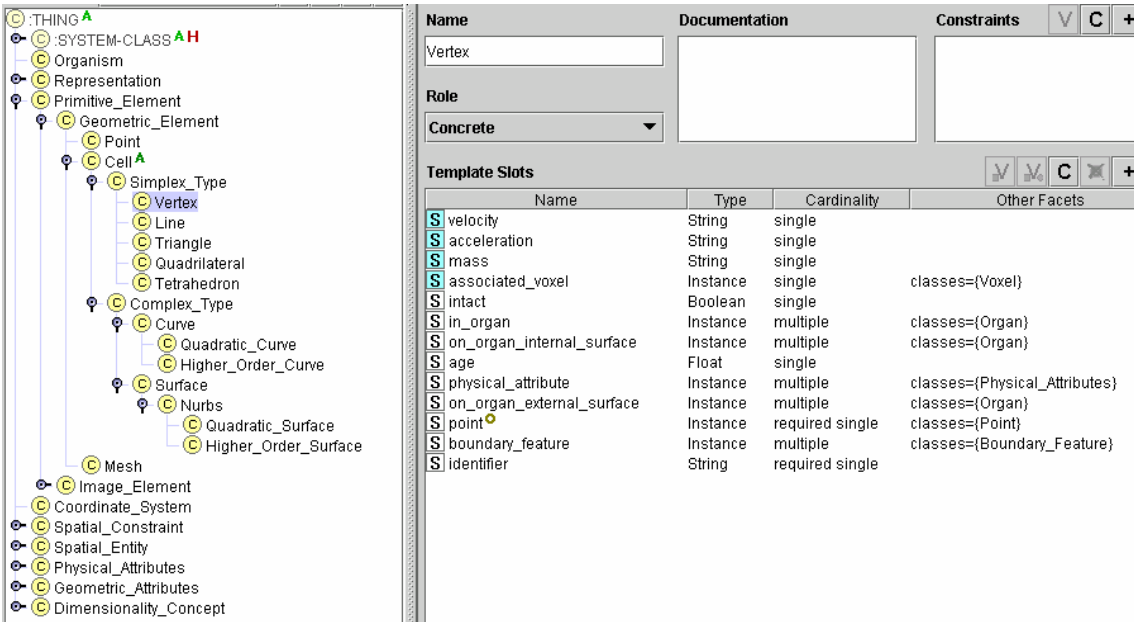


Figure 3: Screen shot of ontology of geometry developed for building canonical geometric models of anatomy.

represented in the same geometric model (Figure 4).

B. Reasoning with the model

We have superimposed a projectile trajectory, deduced the path of injury, and produced a list of damaged structures. For example, assuming a curved path for the bullet and decreasing tissue damage as the projectile decelerates, a conically-shaped region of tissue injury results (Figure 4). While we have assumed a simple parametric description of tissue damage, in practice, our modeling approach is flexible enough to accommodate more complex descriptions of regions of tissue injury. 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 methods for 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 (Figure 1). 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 for answering questions that require anatomic abstraction. For example, if we predict from our geometric model that the left ventricle has been injured, 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 within the pericardium and is in the left side of the heart).

IV. DISCUSSION

This work addresses the issue of linking two kinds of knowledge: geometrical knowledge about 3-d shape and locations of coordinates of objects in space, and anatomical knowledge about organ composition and spatial relationships to other organs. By representing anatomical knowledge in an ontology, it is possible to reason about how particular organs relate to other organs or organ parts. For example, we can infer from the FMA that the left side of the heart is composed of the left atrium and left ventricle, and that both are contained in the pericardial sac.

Geometrical knowledge is usually stored in the form of

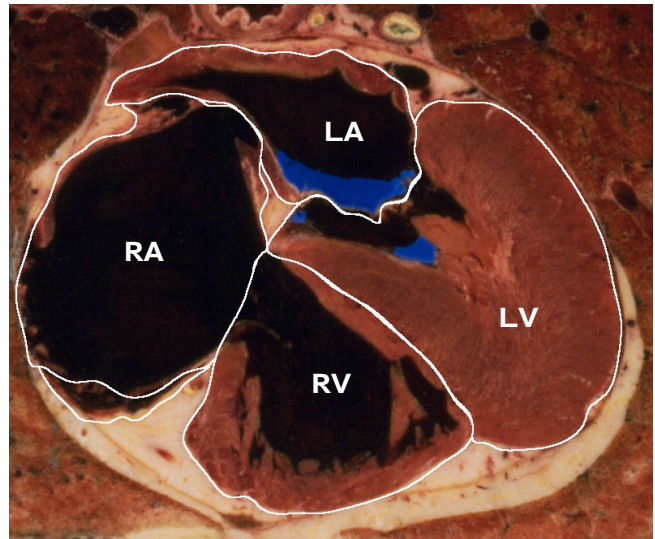


Figure 2: Cross sectional image of the heart from the Visible Human project. The chambers of the heart are segmented from the rest of the image using hand-drawn boundaries (lines in white).

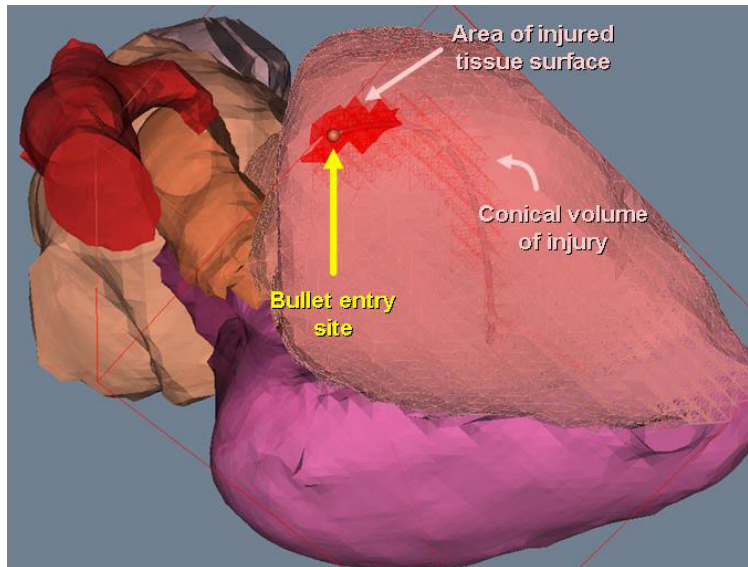


Figure 4: Three dimensional geometric model of the heart with labeled anatomic structures (shaded volumes in the geometric model correspond to anatomic structure classes in the FMA ontology). A trajectory of penetrating injury was superimposed (curved tubular shaded area). A conically-shaped region of tissue injury was predicted and displayed in the geometrical model (conically-shaped shaded region shown by arrow). We can determine the identity of injured anatomic structures and the volume of damaged organs from this geometric model. We can infer possible injuries to adjacent structures using knowledge in the FMA ontology.

models comprising images or meshes. Meshes usually contain color values for display but little if any other knowledge. Geometric models contain detailed information on organ location and shape, but much knowledge such as anatomical knowledge is in the head of the observer, not explicitly in the model. In order to develop intelligent computer applications that use geometrical models, ways to link them with ontologies are needed.

We have demonstrated an approach to integrating these two worlds so that software can relate geometry to anatomic structures in the FMA. The utility of our methodology is that software can reason about remote consequences of a localized injury by identifying the site of injury in the geometrical model, finding the corresponding structure in the FMA, and reasoning about relationships in the FMA to establish other anatomic structures that are also likely affected based on their proximity to injured organs.

While our current work has focused on predicting effects of a penetrating injury, we believe our approach can be generalized to other application areas. Because our abstract geometrical objects are extensible, we can add other information, such as spring constants, tissue material properties, etc. Such augmented models then could be useful in dynamic simulation of projectiles in motion. Alternatively, our models could incorporate information such as tissue radiosensitivity, and then they could be used in radiation therapy treatment planning to predict the effect of radiation beam energy or beam direction on tissues.

Currently, we are developing graphical interface displays to allow users to explore these complex geometrical models

and interrogate different regions of 3-d space in the context of anatomical knowledge. We are also developing ways to integrate navigation of the FMA ontology with exploration of geometrical models so that a user can simultaneously browse the FMA and geometry as two different “views” of the same structures.

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