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Improving Pediatric Cardiology Consultation Methods by Introducing Digital Interactive 3-D Heart Models: A Proof of Concept Study

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Improving Pediatric Cardiology Consultation Methods by Introducing
Digital Interactive 3-D Heart Models: A Proof of Concept Study

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
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List of Abbreviations

GUI	Graphical User Interface
2-D	Two-Dimensional
3-D	Three-Dimensional
SRS	Software Requirements Specification
ROI	Region Of Interest
DT	Dynamic Thresholding
STL	Stereo Lithography
JDK	Java Development Toolkit
IDE	Integrated Development Environment

Glossary of Terms

1. Graphical User Interface – a user interface that does not rely on text alone but takes advantage of a computer’s graphics components (images, frames, windows, icons, buttons).
2. Two-Dimensional (2D) – a flat surface; having the dimensions of height and width only.
3. Three-Dimensional (3D) – an object that occupies space; having the dimension of depth as well as height and width.
4. Java Development Toolkit (JDK) - defines the Java API and contains a set of command-line utilities, such as `javac` (compiler) and `java` (interpreter).
5. Integrated Development Environment (IDE) – software that helps programmers write code efficiently. IDE utilities offer the ability to edit, compile, build, and debug.

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ABSTRACT

The purpose of a pediatric cardiology consultation is to inform, or educate, the patient and family of all aspects surrounding a certain congenital heart defect. Consultation education methods and materials may include verbal descriptions, two-dimensional (2-D) heart diagrams, and take-home pamphlets. Because the human heart is a complex three-dimensional (3-D) object, the problem lies within the clarity to which these methods are performed by the doctors and understood by the patients and families. Therefore, during a consultation the cardiologist must a) possess the ability to describe a defect visually as well as verbally and b) ensure that the patient and family have a clear understanding of the situation.

In this work a method to improve patient consultation is outlined. Heart model segmentation methods from Cardiac MRA images are discussed by using the *Materialise Mimics 10.11* software. *EduView*, the proposed software application solution, provides the user

with traditional verbal descriptions and 2-D heart diagrams along with the ability to interact with a digital 3-D human heart model. By including a 3-D approach, the purpose is to assist the cardiologist in explaining a defect while further educating the patient and family. *Sun Microsystems Java* technology was utilized in order to program the application. Implementation of the software solution is outlined and the results from two surveys involving parents of children with congenital heart defects and pediatric cardiologists are presented. This study outlines a proof of concept. There is significant potential for extending and marketing this tool for future clinical use.

Chapter One:

Introduction

Problem Statement

Patient consultations in any branch of medicine inherently possess a two-fold challenge – communication and comprehension of information between doctor and patient. Along with these challenges, pediatric cardiology consultations must provide a means to relay information in such a way that children (18 yrs and under) will understand. The challenge is intensified within cardiology because of the complexity of the human heart. In dealing with children patients the role and importance of visual based learning becomes primary.

The problem with the current consultation approach lies within the attempt to use flat, non-interactive two-dimensional (2D) representations to explain the fully three-dimensional (3D) human heart. Although anatomical heart models are a tangible 3D heart representation they are fragile and inanimate. The education issue can be addressed by utilizing current imaging techniques along with

automatic or semiautomatic segmentation and analysis of diagnostic image scans.

Imaging technology methods, specifically magnetic resonance imaging (MRI), computer tomography (CT) and ultrasound (US), within cardiology practices continue to improve. Due to the advancement in technology these techniques are becoming more important in clinical diagnosis. Their non-invasive capability makes them an ideal tool in cardiac treatment. There are benefits tied into the improving quality and increasing quantity of the image scans. One such benefit is found in the segmenting process. Segmented anatomical models can be created more rapidly while improving in quality. This pre and post processing of the captured data is designed to further assist doctors in diagnosis and treatment.

This study focuses on the development of a more visually engaging and interactive method to educate during a patient consultation. The resulting application would not only assist the patients and families but also assist the doctors.

Solution Statement

EduView is designed to be an alternate and interactive solution for the education of congenital heart diseases. The solution is an interactive program that allows a user to choose a congenital heart

defect to view. Once chosen the user has the ability to interact with both a 3D 'normal' heart reference model along with a 3D 'diseased' heart reference model. This allows a user to see the differences between the two models while allowing them to understand the 3D shape complexity of the heart. Also, for each chosen heart disease there will be a textual description of the malformation. Lastly, the user can view the more traditional 2D heart image depictions of the 'normal' and 'diseased' heart.

Contribution

EduView goes beyond the bindings of literature and 2D image representations into the interactive 3D realm. Because *EduView* is software, it can be loaded onto any computer and taken anywhere. Adding representative 3D heart reference models for both the normal and diseased cases adds a new approach toward patient education. Users have more control in what they want to see and understand. This is achieved through the various heart conditions to choose from, the textual and 2D descriptions of the diseased hearts, as well as the ability to interact with the 3D heart models.

Chapter Two:

Literature Review

Current visual methods utilized by pediatric cardiologists for patient consultation are take-home pamphlets with illustrations, heart diagrams (see Appendix E), anatomical heart models, two-dimensional (2D) heart animations, and looking at patient specific image scans (MR or CT) [1]. These methods present a challenge to the patient and family in fully understanding a complex 3D object. Because the current visual methods lack the ability to express the full dimensions of the heart, more emphasis is given to verbal descriptions. As a result, patients and families must rely on the physician's verbal descriptions to piece together the problem in their mind.

In medicine, a specialized node exists called medical imaging. This field is dedicated to generating visualizations to aid doctors and other medical professionals in better understanding and visualizing the anatomy of their patients. Also it allows them to perform mock surgeries to gain valuable experience and practice before an actual procedure. These visualizations draw on one main ingredient –

existing 2D image sequences. These captured images, generally from CT and MRI, provide the datasets that allow for the three-dimensional segmentation and visualization of the anatomy [2, 8].

Within cardiology, the ability to evaluate a patient's heart function non-invasively lies almost exclusively with cardiac MRI volumetric data. CT may provide higher quality scans than MRI but because the scanning process relies on X-rays it is considered too risky. Modern cardiac MRI scanners have the ability to capture the complete heart beat sequence. The scanners manufacturing software provides the toolsets to generate maximum intensity projections (MIP) of volumetric data [4, 9]. This function along with other segmenting algorithms found in the software provides the cardiologists with patient specific 3D heart models to view. Other cardiac segmentation methods require the creation of mathematical models to map out the geometry [6].

The need to provide better educational material during a patient consultation has not been overlooked. Scientific Software Solutions creates not only educational software but also educational field guides and prints [3]. They provide some of the most in-depth teaching materials for congenital heart disease. Their *PedHeart* suite includes instructional material not only for medical professionals but also for parents and adult patients [7].

In order to develop this application, a programming language needed to be chosen. *Java* (Sun Microsystems, Inc., Santa Clara, CA) was chosen for its portability and robust attributes. It possesses the ability to function across platforms. Also, like the C programming languages, *Java* is an object-oriented language (OOL). As a result, the creation and manipulation of objects make it a very powerful language. *Java* is well documented too. The *Java* API and tutorials for Swing components and features are very useful [5]. *Java3D* is a powerful object-oriented 3D renderer [10]. By default, it relies on OpenGL for graphics processing. However, it can be tailored to function with DirectX. Its libraries can be imported into a *Java* project for ease of use. Because its framework is based on *Java* technology, it was the logical choice to create the scenes in order to render the heart reference models.

Chapter Three:

Materials and Methods

MR Data Acquisition

Studies were performed on a High Definition (HD) 1.5T superconducting magnet (GE Signa Excite, GE Healthcare, Waukesha, Wisconsin). In order to obtain the coronal, sagittal, and transverse planes, a series of three-dimensional (3D) fast multiplanar spoiled gradient (SPGR) echo images were acquired. The pulmonary CE-MRA volumetric scans were ECG-gated and acquired during suspended respiration. Each image slice was obtained in sequence of multiple intervals or cardiac cycles of 20 s or less suspended respiration. If the quality of the image acquisition was poor for a particular interval, the interval would be re-scanned. 60 slices were acquired in order to window the entire region of interest. For one study, the slice thickness was 4 mm with 2 mm spacing between slices along with a repetition time of 3.976 ms and an echo time of 1.452 ms. The other study had a 4.8 mm slice thickness with 2.4 mm spacing between slices along with a repetition time of 3.956 ms and an echo time of 1.436 ms. For

both studies, the images were captured at a 512 x 512 pixel resolution with a pixel spacing of 0.8594\0.8594 mm. Between 9 and 14 images were acquired per cardiac cycle.

MR 3D Reconstruction

Volumetric data from each MR study was imported and analyzed using *Mimics* (Materialise, Leuven, Belgium) software. Once imported, window levels were adjusted to assign the pixels that made up the heart tissue a lighter shade of gray. In each study, a specific heart structure was independently chosen by its pixel value and assigned a colored mask that spanned throughout the entire image sequence. In this manner, the data was segmented using semi-automatic methods (thresholding, region growing, morphological edits) and manual editing (multiple slice edit, edit mask in 3D).

3D volumetric surfaces were constructed from the segmented data. Once the surfaces were calculated, they were imported into *Mimics* finite element analysis (FEA) module. The surfaces ranged from 50,000 to 170,000 faces or triangles. In order to import and render the surface model for visualization, the models needed to be remeshed. Within the FEA module, several tools for triangle reduction and surface smoothing were used including triangle reduction, filter sharp triangles, remesh part, detect self intersections, and smoothing.

The remeshed surface model was exported as an ASCII .stl model. The .stl model was imported into *Maya 6.5* (Autodesk Inc., San Rafael, CA) to cleanup merged vertices and to convert the model into an .obj file. The overall process to create and refine the 3D heart model from MR scans was approximately 3 hours.

Software Development

Java was chosen as the programming language to create *EduView*. *EduView* was developed using the latest development kit, *Java SE Development Kit (JDK), Version 6*, on a *Windows XP Pro* platform workstation. *Java3D* version 1.5 was used in order to create the three-dimensional virtual scenes to render the 3D heart models. A *Radeon 9250* (Advanced Micro Devices Inc., Sunnyvale, CA) 256 MB PCI version with OpenGL support graphics card was used to display the virtual scenes during development.

User Interface

The application's user interface design was built using *Java* Swing components. The interface contains two halves, a top portion and a bottom portion (Appendix D). The top half houses the heart conditions list panel as well as the 3D diseased heart panel and the 3D normal heart panel. The bottom half contains a congenital heart

defect textual description panel and both the 2D diseased heart panel and the 2D normal heart panel. The placement of both the 3D and the 2D panels allows the user to give a direct comparison between the chosen diseased heart and the normal heart. The size of the frame is 1020 pixels wide by 720 pixels high. User screen resolution should be no less than 1024 pixels wide by 768 pixels high.

Heart Conditions List Panel

The heart conditions list, named `ConditionListPanel` in the `EduView.java` source file, can contain multiple congenital heart defects. The list is populated through reading the contents of a local text file. Reading the text file is one of the first executions to be made by *EduView*. The user can choose a condition in the list. Once a choice is made, the intelligence of the system, both the `MainManager` and `ViewManager` classes, are notified. This relay calls an update to the defect description panel, the 3D diseased heart panel, and the 2D diseased heart panel. Table 3.1 outlines the various processes of the heart conditions list panel.

Table 3.1 Heart conditions list processes

- put items read from the text file into a String array
- add elements to the list object from contents of the String array
- create the list
- call to system intelligence if user changes the current condition

Diseased 3D Panel

This module, named Defect3DPanel in the .java source files, serves as one of two three-dimensional scenes of *EduView*. The module consists of a virtual Canvas3D scene where the diseased heart geometry and lights are loaded and rendered. The heart geometry consists of vertices, faces, and materials in the form of an .obj file. The module reads the .obj file and renders it to the scene. The geometry is assigned to a BranchGroup object so that the scene is aware of its existence. In order to view the loaded heart geometry, a directional light is created and given a color and coordinates. Based on action listeners and event handlers, the mouse is given control to move the heart object around in the scene. The geometry has Transform3D objects attached to its TransformGroup object. This allows a user to rotate, translate, and zoom the heart object to see all angles in virtual space. A reset button is provided if the user wishes the heart model to return to its original position. Each selection of a

heart condition from the heart conditions list will refresh the scene and pass initial position coordinates to the heart model for display. Table 3.2 outlines the various processes of the diseased 3D heart panel.

Table 3.2 Diseased 3D heart panel processes

- Create the scene
- Load the .obj file, assign it to the Scene object
- Load heart position coordinates
- Assign Transform3D matrices to the TransformGroup object
- Assign the Scene object containing the geometry to the TransformGroup object
- Assign the TransformGoup object to the BranchGroup object
- Grant mouse control and assign it to the BranchGroup object
- Create directional light and finalize the scene
- Reset geometry if user clicks the reset model button
- Refresh scene with a new heart model if user chooses another heart condition to view

Normal 3D Panel

This module, named Normal3DPanel in the .java source files, serves as the last of the two three-dimensional scenes of *EduView*. The module consists of a virtual Canvas3D scene where the normal heart geometry and lights are loaded and rendered. The heart geometry consists of vertices, faces, and materials in the form of an .obj file. The module reads the .obj file and renders it to the scene. The geometry is assigned to a BranchGroup object so that the scene is

aware of its existence. In order to view the loaded heart geometry, a directional light is created and given a color and coordinates. Based on action listeners and event handlers, the mouse is given control to move the heart object around in the scene. The geometry has Transform3D objects attached to its TransformGroup object. This allows a user to rotate, translate, and zoom the heart object to see all angles in virtual space. A reset button is provided if the user wishes the heart model to return to its original position. This panel is initialized and rendered once at startup. User interaction has no affect on this panel. Table 3.3 outlines the various processes of the normal 3D heart panel.

Table 3.3 Normal 3D heart panel processes

- Create the scene
- Load the .obj file, assign it to the Scene object
- Load heart position coordinates
- Assign Transform3D matrices to the TransformGroup object
- Assign the Scene object containing the geometry to the TransformGroup object
- Assign the TransformGoup object to the BranchGroup object
- Grant mouse control and assign it to the BranchGroup object
- Create directional light and finalize the scene
- Reset geometry if user clicks the reset model button

Defect Description Panel

The congenital heart defect textual description panel, named DescriptionPanel in the .java source files, displays the text that describes the chosen congenital heart defect. It receives the path to the defect description text file from the system intelligence.

JEditorPane and JScrollPane are the swing components that create and hold the text within the panel. The text area is non-editable and has the ability to be scrolled. Also, as the borders are approached, the text is set to wrap on white-space, not on characters. The text file is loaded in as a URL object and displayed in the editor pane. Upon user interaction, the editor pane document object is cleared and the editor pane is set with the new text from the URL object. Table 3.4 outlines the various processes of the defect description panel.

Table 3.4 Defect description panel processes

- | |
|--|
| <ul style="list-style-type: none">- Create the JEditorPane object- Create the JScrollPane object and add the JEditorPane object to it- Read and load the text into a URL object- Set the editor pane with the URL object to display- Refresh text area and set the editor pane with the URL object upon user interaction |
|--|

Diseased 2D Panel

The diseased 2D panel, named Defect2DPanel in the .java source files, holds and displays the diseased heart graphic. It provides the user with the standard method of viewing a congenital heart defect. The graphic displays the malformations for a chosen defect. The graphic is drawn and rendered with the Defect2DImagePanel class within the Defect2DPanel class. This is achieved using an Image object that holds the heart graphic and is displayed on the canvas. Each time a user changes the heart condition, the Defect2DPanel class receives the path to the graphic along with the condition name. These parameters are passed to the Defect2DImagePanel class to refresh and update the Image object with the proper graphic. Table 3.5 outlines the various processes of the diseased 2D panel.

Table 3.5 Diseased 2D panel processes

- | |
|---|
| <ul style="list-style-type: none">- Create a panel to hold the Defect2DImagePanel object- Pass the image path and defect name to the Defect2DImagePanel object- Create and initialize the Image object- Draw the graphic to the canvas for display- Refresh Image object and repaint canvas upon user interaction |
|---|

Normal 2D Panel

The normal 2D panel, named Normal2DPanel in the .java source files, holds and displays the normal heart graphic. It provides the user with the standard method of viewing a normal heart. The graphic displays the anatomy of the normal heart. The graphic is drawn and rendered with the Normal2DImagePanel class within the Normal2DPanel class. This is achieved using an Image object that holds the heart graphic and is displayed on the canvas. This panel is initialized and rendered once at startup. User interaction has no effect on this panel. Table 3.6 outlines the various processes of the normal 2D panel.

Table 3.6 Normal 2D panel processes

- | |
|---|
| <ul style="list-style-type: none">- Create a panel to hold the Normal2DImagePanel object- Pass the image path and defect name to the Normal2DImagePanel object- Create and initialize the Image object- Draw the graphic to the canvas for display |
|---|

System Intelligence

The core of the intelligence can be found in the public class MainManager. The MainManager is aware of the path of all graphic information for the chosen congenital heart defect, all the data obtained from parsing the text file, the Normal3DPanel, the

Defect3DPanel, the Normal2DPanel, the Defect2DPanel, and the DescriptionPanel. Within the class lies another class, ViewManager. Apart from MainManager, ViewManager contains the details of updates for the 3D model, the 2D graphic, and the defect description text file. However, ViewManager does nothing unless the MainManager gives it information. When a user chooses another heart condition, the MainManager tells ViewManager to update the Defect3DPanel, the DescriptionPanel, and the Defect2DPanel. ViewManager contains the defect name and path to the heart model, the heart graphic, and the heart description for a chosen heart condition.

The Parser class parses the text file, hearts.txt, into a DataSet array list. The data in the array is the following: the directory to find the heart information, the heart condition, the heart model, the heart graphic, and the heart description. The class also creates a ConditionList array list composed of conditions only. A programmer has access to the data parsed from the text file by calling any of the get methods in the DataSet class.

Survey Development

Two survey populations were selected in order to gather statistical data to validate the design, quality, and effectiveness of *EduView*. The first group was composed of parent volunteers from a

cardiac support group. Its members were comprised of children with congenital heart defects and their families. The second group was composed of pediatric cardiologists. These cardiologists routinely provide standard pediatric cardiology consultations as a means of relaying information about congenital heart defects.

The parent group received two presentations. The first presentation was a demonstration using standard two dimensional visuals and verbal descriptions given by a pediatric cardiologist. The second presentation was a demonstration of *EduView* presented by its developer. The clinician group received only a demonstration of *EduView* presented by its developer. After the presentations, both groups received a survey.

In order to conduct the surveys, an appropriate Institutional Review Board (IRB) application was completed, processed, and approved. The survey was designed to maintain the confidentiality of the volunteer. Informed consent was not required because the survey contained no identifiable tags. The parent survey (Appendix A) was developed into four sections. The first section contained four non-Likert scale format and nine 5-point scale Likert (Strongly Agree, Agree, No Opinion, Disagree, Strongly Disagree) demographic or background questions. The second section contained three 5-point scale Likert questions about the standard 2D presentation. The third

section contained three 5-point scale Likert questions about *EduView*. Sections two and three gauged the satisfaction of the user as well as the understanding level of the user of the presentations. The last section contained two 5-point scale Likert questions and two questions asking the user for his/her consultation method preference. In addition, a space was provided for additional comments or questions regarding the presentations.

The clinician survey (Appendix B) was developed into three sections. The first section contained four non-Likert scale format and two 5-point scale Likert demographic or background questions. The second section contained four 5-point scale Likert questions about the user's satisfaction with conventional patient consultation methods. The last section contained seven 5-point scale Likert questions about the user's satisfaction and understanding of the *EduView* presentation. In addition, a space was provided for additional comments or questions regarding the presentations.

Chapter Four:

Results

Segmented Heart Models

Figure 4.1 shows the segmented defect representative heart model. The model shown is of a repaired Tetralogy of Fallot MR

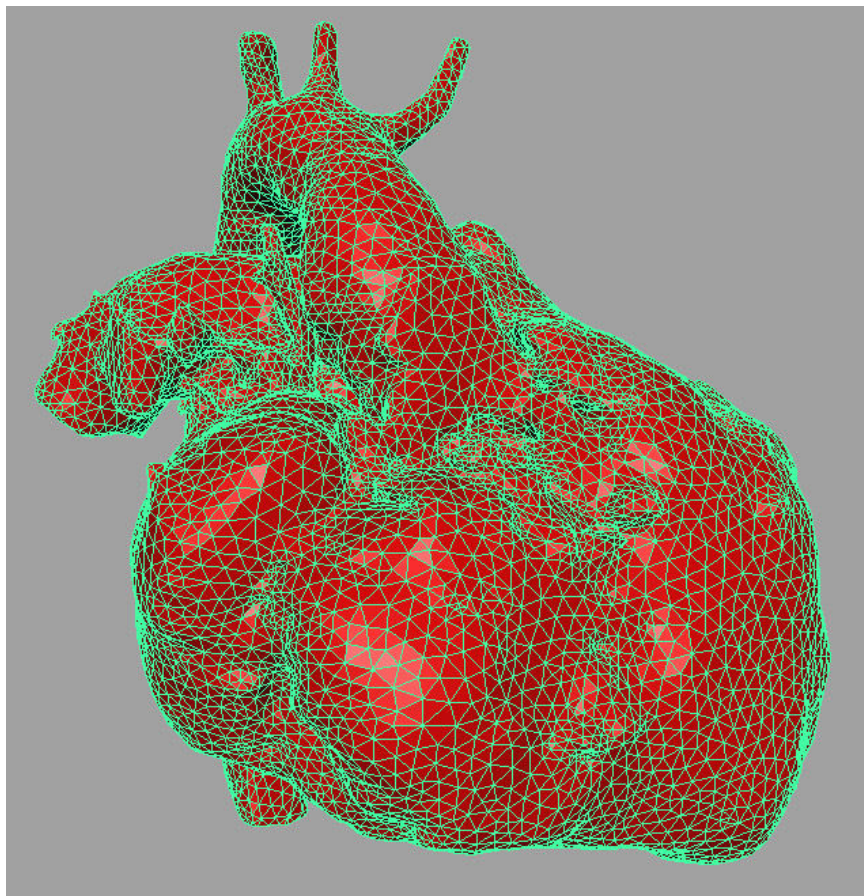


Figure 4.1 Segmented repaired Tetralogy of Fallot model

dataset with a right branch aortic arch. After remesh and cleanup, the final .obj model contained 22,196 vertices and 44,700 triangles.

Figure 4.2 shows the segmented normal representative heart model.

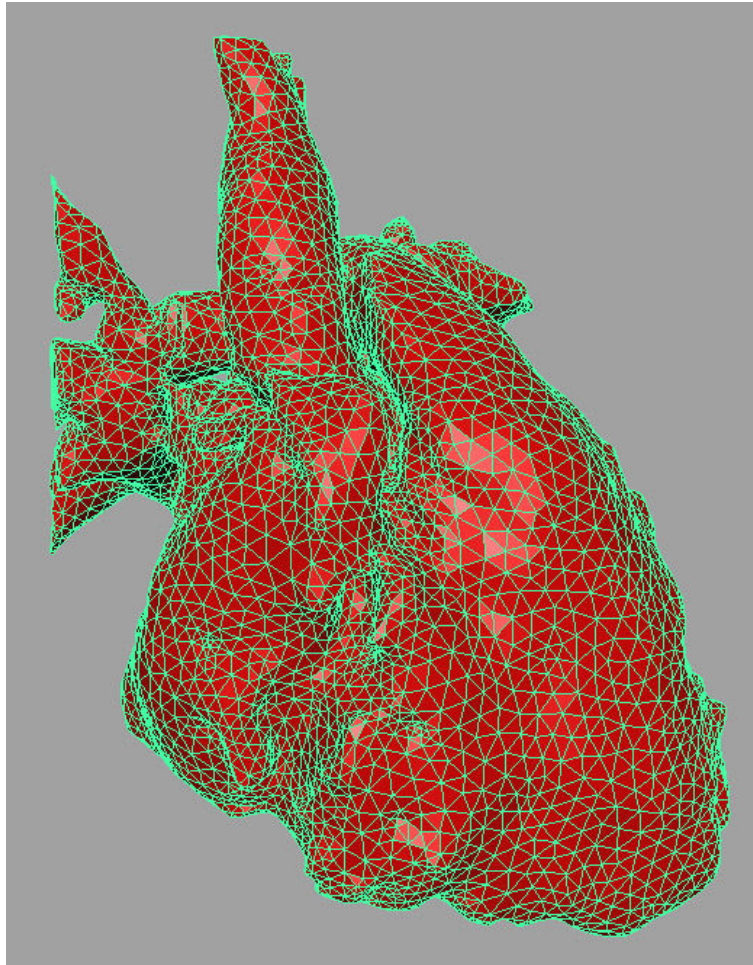


Figure 4.2 Segmented normal heart model

After remesh and cleanup, the final .obj model contained 73,386 vertices and 24,462 triangles. The same FEA remesh algorithms and cleanup methods were applied to both models. The normal heart model loads and renders quicker (~ 2 s faster) in *EduView* than the

defect heart model. This is due to the smaller number of surface triangles found on the normal heart model.

Software Components

User Interface

Using *Java* Swing components to create the interface was very useful due to its container hierarchy method and its variety of tools. The interface is broken down into JComponents. *EduViewFrame* extends *Jframe*, which is a high-level Jcomponent that houses all *Jpanel* components of *EduView*. All other classes of *EduView* extend *Jpanel*. Each Jcomponent can be aligned and enhanced using the layout and border features of Swing. Refer to Appendix C for sample *Java* Swing code. Figure 4.3 is a screenshot of *EduView* in its final form.

Heart Conditions List Panel

The conditions list is a *JList* component, which is filled using an *addElement* function call. The amount of conditions found in the parsed text file determines the size of the list. Each item in the list is given an index. A user can either double-click a condition or select a condition using the "Select Condition" button provided. The chosen condition index is given to the *MainManager* class for updating the

Defect3DPanel, Defect2DPanel, and DescriptionPanel. Only one condition can be selected at a time. Figure 4.4 shows the condition list panel.

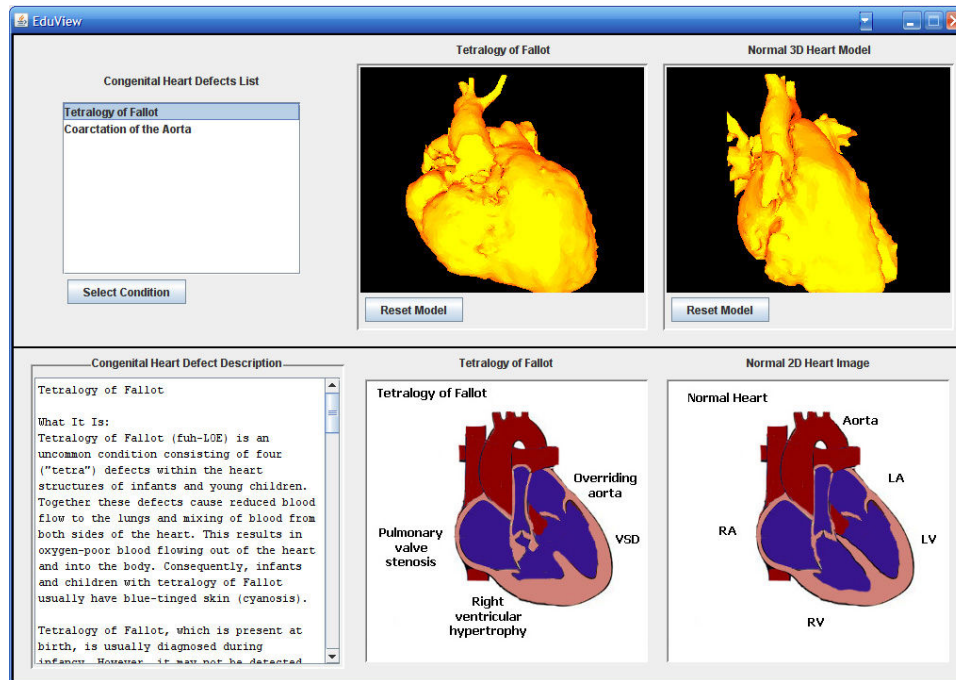


Figure 4.3 EduView application

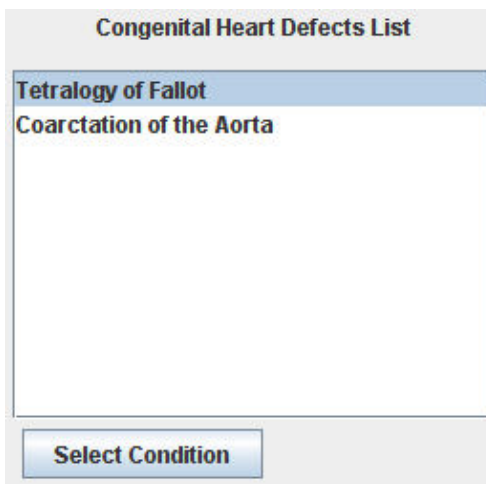


Figure 4.4 Heart conditions list panel

3D Panels

Both the diseased and normal 3D panels contain a 3D scene. The scene is a SimpleUniverse object. This universe object contains a Canvas3D object. There is a root group called a BranchGroup. The BranchGroup has all TransformGroups of a scene added to it. The Defect3DPanel and Normal3DPanel classes have an objLoader method to load any .obj file. The model loaded is given its own TransformGroup and Transform3D objects. Transform3D objects allow geometry to be rotated, translated, and scaled. Each Transform3D object needs to be a child of a TransformGroup. The heart model's TransformGroup is added as a child to the BranchGroup. The reset model button sets the heart model to the origin of the universe. A directional light has been added to the scene to illuminate the objects. The light is also added to the BranchGroup. Figure 4.5 shows the diseased 3D heart model loaded into the virtual space. The model depicted is the repaired Tetralogy of Fallot .obj file. Figure 4.6 shows the normal 3D heart model. The model depicted is the normal heart .obj file. Both models appear gold in color due to the color attribute given to the directional light in the scene. The choice of color was given due to the ability to maintain some shadow while not losing the ability to see details.

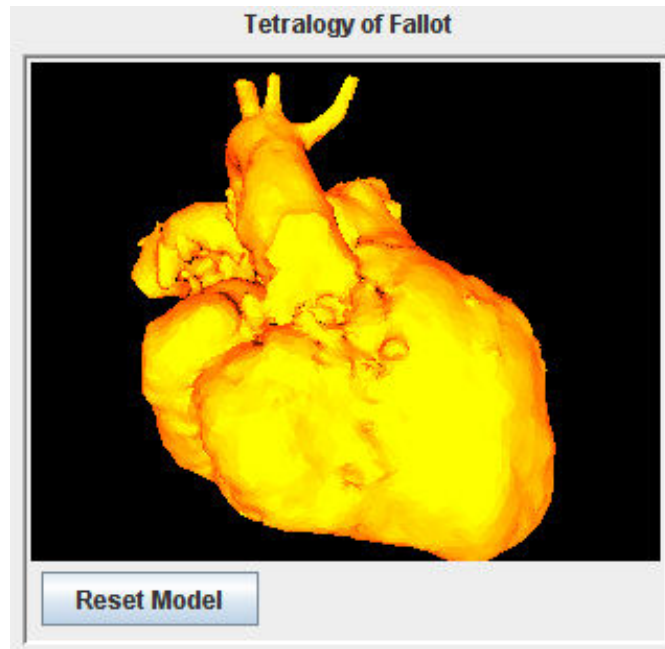


Figure 4.5 Diseased 3D heart surface model

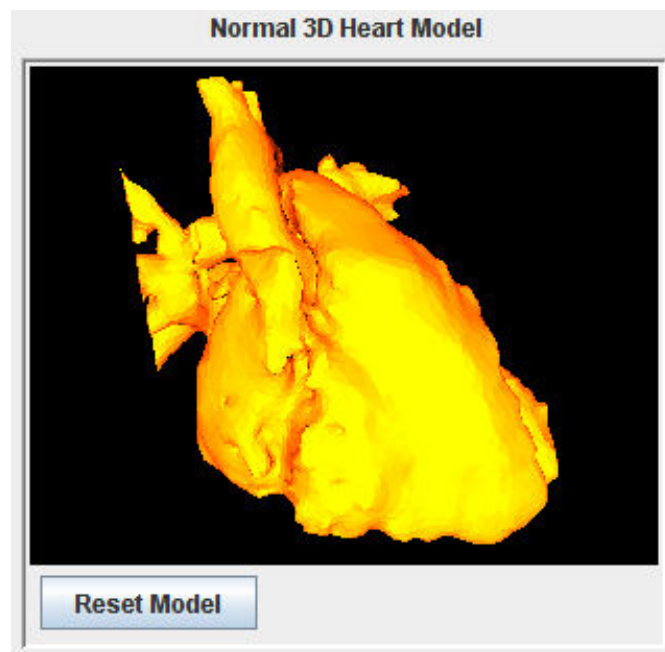


Figure 4.6 Normal 3D heart surface model

Defect Description Panel

The defect description panel is a JEditorPane component within a JPanel container. The JEditorPane object has the ability read a file and display the contents with the correct formatting and style of that file (e.g. an HTML file). JEditorPane is passed into a JScrollPane object to provide the ability to scroll the text displayed. The JEditorPane object calls the setEditorKit() and getDocument() methods in order to have the text to wrap on white space and not on characters (default). Upon user interaction, this panel also utilizes a Document object and its putProperty() attribute to refresh the text area. Figure 4.7 shows the congenital heart defect description JPanel.

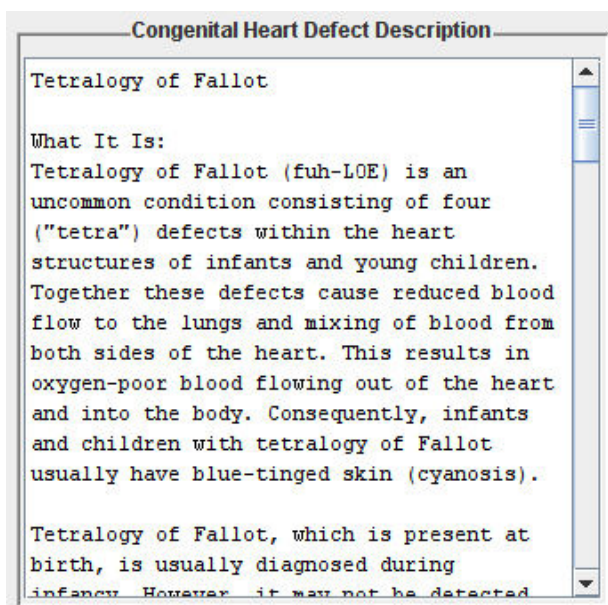


Figure 4.7 Heart description panel

2D Panels

Both the defect and normal 2D panels are comprised of two classes. These classes extend JPanel. The defect 2D class, Defect2DPanel, calls Defect2DImagePanel to update the defect graphic at startup and for user interaction. The normal 2D class, Normal2DPanel, calls Normal2DImagePanel to load the normal 2D graphic at startup. The functionality of both the Defect2DPanel and Normal2DPanel was split because of the need to add a border and use the JLabel object. These classes setup the canvas and panel for display. The Defect2DImagePanel and Normal2DImagePanel classes are responsible for drawing the graphics. Figure 4.8 depicts the Tetralogy of Fallot graphic while Figure 4.9 shows the normal heart.

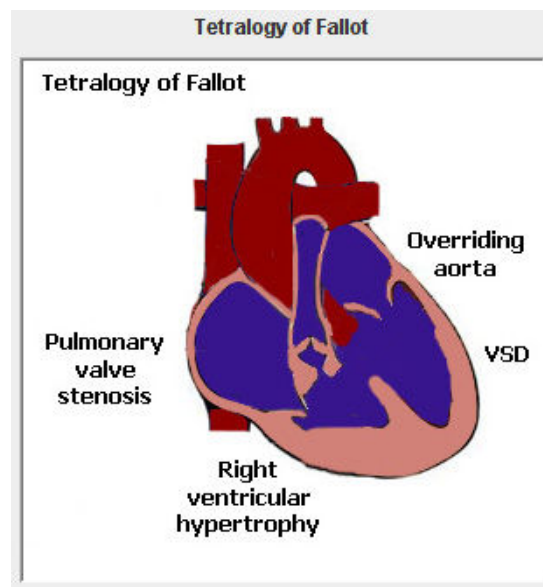


Figure 4.8 Tetralogy of Fallot 2D graphic

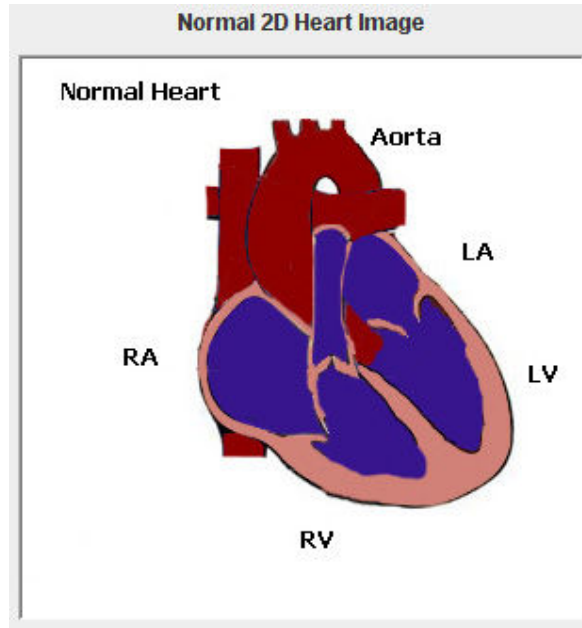


Figure 4.9 Normal heart 2D graphic

Survey Analysis

As stated in chapter three, the participants in this study included parents of children with congenital heart defects and pediatric cardiologists.

Parents

In total, 11 parents volunteered to participate in the survey from the cardiac support group. Of these, 7 or 64% were female and 4 or 36% were male. The age of the population group ranged from 25 years to 55 or more years. A variety of educational backgrounds (highest achieved) were listed including the following: 1 with a

masters degree, 2 with a bachelors degree, 2 with an associates degree, and 6 with high school diplomas. Of those 6 listed with high school diplomas, 3 stated "some college." One woman worked in a health-related field as a pediatric cardiac sonographer. 100% stated they were comfortable with using a computer. Lastly, every participant or 100% stated that they preferred the interactive, digital 3D tool over the conventional consultation methods.

Pediatric Cardiologists

In total, 6 pediatric cardiologists volunteered to participate in this study. Years of service as a clinician ranged from 1 to 20 or more years. Of these, 100% stated that they frequently administer patient consultations. The methods used by the clinicians include the following: hand sketches, anatomical heart model, verbal description, take home pamphlets, and 2D heart diagrams. 83% or 5 clinicians stated they were comfortable with using a computer. 100% agreed that current consultation methods require improvement and also stated that the interactive, digital 3D heart models would assist in patient and family education. Lastly, every participant or 100% stated that if they had a choice, they would choose to utilize the interactive, digital 3D tool and that the 3D approach is more useful than the 2D methods.

Initial hypothesis was that the results would be dependent upon demographic items. For instance, a well educated individual would not find that the 3D solution is any more useful for educational purposes than the standard methods. In fact, the data suggests that no variable has an influence on the outcome. Preference of consultation methods was not a function of any experience, background or demographic item. Further analysis is not needed because in each population group, regardless of any variable, the interactive, digital 3D tool is preferred over standard consultation methods. There is no correlation to make.

Chapter Five:

Conclusion

Quantitative Analysis

Due to the nature of the responses of the two population groups, this portion of the analysis was rather straightforward. The parents (N = 11) and the pediatric cardiologists (N = 6) provided us with useful and encouraging data on the state of educational methods during a patient consultation. Preliminary data analysis reveals that there is a 100% agreement between the parents and the cardiologists with respect to preferring the 3D approach as a patient consultation method. This suggests that there is a need for improving current patient consultation methods. It also suggests that, for educational purposes, the 3D approach would greatly assist patient and family understanding of congenital heart defects.

Qualitative Analysis

It should be noted that 50% of the cardiologists and 100% of the parents provided comments about *EduView*. These comments

brought to light the real-life requests and struggles of parents concerning current and potential consultation methods. It exposed their deep desire to grasp and understand fully the nature of their child's heart defect. It also shed light on the cardiologists desire to improve their techniques. The possibility to utilize interactive 3D heart models for future clinical use intrigued both the parents and the cardiologists. To have the ability to explore the complexity of any congenital heart defect in full 360 degrees, including within the chambers, excited and prompted ideas for future additions from both population groups.

Final Thoughts

EduView is an application that can be installed on any platform (cross platform compatible). It is clean and simple to use. With accurate human heart reference models and corresponding 2D heart graphics, *EduView* can become a useful educational tool for patients and patient families.

The future for *EduView* is bright. Because this is a proof of concept study, *EduView* is a template or foundation for future marketable revisions. The concept has now been validated with 100% approval ratings from parents and cardiologists. In future versions, *EduView* could display patient specific heart models in the place of the

representative diseased heart model. This would allow both the patient and patient family the ability to study and understand their child's own diseased heart. Also, the idea of adding the fourth-dimension (4D) appealed to every participant. Each parent expressed desire to see the heart beating while simulating blood flow. Another future task would be to implement treatment animations or 3D visualizations to further aid in the understanding of various surgeries or procedures. As a result of these possible revisions, *EduView* could venture into the teaching tool market. Aspiring cardiologist residents and medical students could utilize *EduView* for educational purposes.

There are a couple limitations to this concept that need to be addressed. The process of segmenting the heart surface models is too time heavy. *EduView* would rely on a quick turn around from MR data into surface models to view and study. *EduView* also relies on MR data that contains the entire heart. Because cardiac MR is primarily used as a diagnostic tool, there is not a great need to capture the entire heart structure. A slight limitation would be that *EduView* requires the user to have both the *JDK* and *Java3D* installed to work properly. In order for *EduView* to execute and display, system environment variables of the operating system must be properly set. However, following the *Readme.txt* file will assist and expedite the install process.

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Appendices

Appendix A: Parent Survey

The purpose of this survey is to determine the potential benefits (if any) of various presentation methods that your physician could use in a pediatric cardiology consultation. This survey is an effort to improve the current consultation methods to better educate the patient/family of various congenital heart diseases. Your experiences and opinions are very important to us, and we would greatly appreciate your participation. Thank you very much for your cooperation.

Two-Dimensional (2D) – a flat surface; having the dimensions of height and width only.

Three-Dimensional (3D) – an object that occupies space; having the dimension of depth as well as height and width.

SECTION I: BACKGROUND INFORMATION

- 1) Are you:
 - A. Male
 - B. Female

- 2) Your age:
 - A. 18 – 24 years
 - B. 25 – 34 years
 - C. 35 – 44 years
 - D. 45 – 54 years
 - E. 55 years or more

- 3) The highest level of education you have achieved:
 - A. Completed high school or equivalent
 - B. A specialized certification
 - C. Associates degree
 - D. Bachelors degree
 - E. Masters degree
 - F. Doctorate degree

- 4) Do you work in a health-related field?
 - A. Yes
 - B. NoIf yes, what do you do? _____

Please read each statement and indicate the extent to which you agree or disagree.

- 5) You are very comfortable using a computer.
 - A. Strongly Agree
 - B. Agree
 - C. No Opinion
 - D. Disagree
 - E. Strongly Disagree

- 6) You consider yourself to be very knowledgeable regarding science as it relates to human health.
 - A. Strongly Agree
 - B. Agree
 - C. No Opinion
 - D. Disagree
 - E. Strongly Disagree

Appendix A: (Continued)

- 7) You understand the difference between a 2D and a 3D object.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 8) You have a clear understanding of your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 9) You have a strong need or desire to understand your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 10) You experience a high level of anxiety/stress as a result of your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 11) You experience a high level of anxiety/stress as a result of your lack of understanding of your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 12) Your cardiologist has done a satisfactory job of explaining the nature of your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 13) The level of usefulness of all diagrams, illustrations, etc. used by your cardiologist to explain your child's heart defect has been very good.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

SECTION II

Please answer questions 14 - 16 after viewing the first presentation.

- 14) You understood the presentation regarding your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 15) You experience a high level of anxiety/stress as a result of your lack of understanding of your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 16) The level of usefulness of all diagrams, illustrations, etc. used during this presentation to explain your child's heart defect has been very good.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

Appendix A: (Continued)

SECTION III

Please answer questions 17 – 19 after viewing the second presentation.

- 17) You understood the presentation regarding your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 18) You experience a high level of anxiety/stress as a result of your lack of understanding of your child's heart defect.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 19) The level of usefulness of all diagrams, illustrations, etc. used during this presentation to explain your child's heart defect has been very good.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

SECTION IV

- 20) Which presentation method did you prefer?
A) The first one
B) The second one
C) They were both about the same
- 21) Please briefly describe the reasoning behind your answer to question 19.
- 22) You understand the difference between a 2D and a 3D object.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 23) The second method would be more effective if the computer illustration used was an actual image of my child's heart.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

*Thank you for completing this questionnaire.
If you have any additional comments or questions regarding this survey, please use the space below.*

Appendix B: Cardiologist Survey

The purpose of this survey is to determine the potential benefits (if any) of various presentation methods that your physician could use in a pediatric cardiology consultation. This survey is an effort to improve the current consultation methods to better educate the patient/family of various congenital heart diseases. Your experiences and opinions are very important to us, and we would greatly appreciate your participation. Thank you very much for your cooperation.

Two-Dimensional (2D) – a flat surface; having the dimensions of height and width only.

Three-Dimensional (3D) – an object that occupies space; having the dimension of depth as well as height and width.

SECTION I: BACKGROUND INFORMATION

- 1) Years you have been a cardiologist.
 - A) Less than one year
 - B) 1 – 4 years
 - C) 5 – 9 years
 - D) 10 – 14 years
 - E) 15 – 19 years
 - F) 20 years or more

- 2) How often do you administer patient consultations?
 - A) Not at all
 - B) Occasionally
 - C) Frequently

- 3) If you answered 'Yes' to question #2, please circle the methods you utilize of the following: (circle all that apply)
 - A) Verbal description
 - B) Hand sketches
 - C) 2D heart diagrams
 - D) Take home pamphlets
 - E) 2D heart animations
 - F) Patient MRI or CT scans
 - G) Anatomical heart model
 - H) Other: _____

- 4) If you answered 'No' to question #2, are you familiar with current pediatric consultation methods?
 - A) Yes
 - B) No

Please read each statement and indicate the extent to which you agree or disagree.

- 5) You are very comfortable with using a computer.
 - A. Strongly Agree
 - B. Agree
 - C. No Opinion
 - D. Disagree
 - E. Strongly Disagree

Appendix B: (Continued)

- 6) You understand the difference between a 2D and 3D object.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

SECTION II

- 7) Current consultation methods adequately inform patients and families.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 8) Current consultation methods do not require improvement.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 9) Current consultation methods need to be refined.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 10) Having interactive 3D heart models would assist in patient and family education.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

SECTION III

- 11) You understood the interactive digital consultation method presentation.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 13) Interactive 3D heart models are easy to understand.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 12) Having interactive 3D heart models would assist in patient and family education.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 14) You would rather utilize conventional consultation methods.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 15) If you had a choice, you would choose to utilize the digital, interactive 3D approach.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 16) This approach would be more useful if the malformed 3D heart model was patient specific.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree
- 17) The interactive 3D approach is more useful than the 2D methods.
A. Strongly Agree B. Agree C. No Opinion D. Disagree E. Strongly Disagree

Thank you for completing this questionnaire.

If you have any additional comments or questions regarding this survey, please use the space below.

Appendix C: Sample Java Code

```
/** main class of program. creates an EduViewFrame object**/  
public class EduView  
{  
  
    public static void main(String[] args)  
    {  
        //create the JFrame, EduViewFrame  
        JFrame frame = new EduViewFrame();  
        frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);  
        frame.setVisible(true);  
    }  
  
} //end EduView class  
  
/** Class that contains all JComponents of the program **/  
class EduViewFrame extends JFrame  
{  
    //file that is parsed  
    private static String fileName = "src/data/hearts.txt";  
  
    private DataSet[] data;  
    String path = "src/data/heartModels/Tetralogy of Fallot/";  
  
    //set dimensions of the JFrame  
    private int WIDTH = 1020;  
    private int HEIGHT = 720;  
    Dimension dimension = new Dimension();  
  
    /** Constructor **/  
    public EduViewFrame()  
    {  
        //parse hearts.txt  
        Parser parser = new Parser(fileName);  
  
        //setup the JFrame  
        setTitle("EduView");  
        setSize(WIDTH, HEIGHT);  
        setResizable(false);  
        dimension.setSize(WIDTH, HEIGHT);  
        setPreferredSize(dimension);  
        setLayout(new BorderLayout());  
        Container contentPane = getContentPane();  
  
        ...  
    }  
  
} //end EduViewFrame class
```

Appendix D: Software Requirements Specification

System Features

Controller

Description

Controller is a class to observe and then act when a user makes a button change in the GUI.

Stimulus/Response Sequences

A user clicks one of the conditions to change the heart displayed. Controller will note which condition was selected and set the appropriate 3D, 2D, and condition view by calling a function on the Manager object.

Functional Requirements

Function: Controller

Inputs: Button choice

Source: Buttons are chosen by the user

Effect: Call to Manager class

Pre-condition: Waits for user interaction

Post-condition: Waits for user interaction

Manager

Description

Manager is a class that receives input from the Controller class and makes appropriate calls to the 3DView, 2DView, and ConditionView classes.

Stimulus/Response Sequences

Manager will receive input from the Controller class. The input it receives will allow it to know which functions to call. It will call the functions with the appropriate parameters required by the function.

Functional Requirements

Function: Manager

Inputs: 3D model, 2D image and condition view

Source: 3D model, 2D image and condition view from the Controller class

Effect: Calls to 3DView, 2DView, and ConditionView

Pre-Condition: Waits for input from Controller

Post-Condition: Waits for input from Controller

3DView

Description

Appendix D: (Continued)

3DView is a class that renders both the heart reference model and diseased heart model.

Stimulus/Response Sequences

3DView will receive input from the Manager class. With the input, it will update by rendering the new model. 3DView will receive user interaction via the mouse. It will render as the user rotates the heart model.

Functional Requirements

Function: 3DView

Inputs: Position coordinates, mouse click

Source: Mouse click performed by the user, position coordinates from the Manager class.

Effect: Render to its render viewport

Pre-Condition: 3DView is rendered and displayed on the user's screen.

Post-Condition: Global coordinates of heart model and plane are changed if user rotated it.

2DView

Description

2DView is a class that renders a static background images of a normal heart and diseased heart.

Stimulus/Response Sequences

2DView will receive input from the Manager class. With the input, it will update by rendering the new heart images.

Functional Requirements

Function: 2DView

Inputs: Position coordinates

Source: Position coordinates from the Manager class

Effect: Render to its render viewport

Pre-Condition: 2DView is rendered and displayed on the user's screen.

Post-Condition: The diseased heart image is different.

ConditionView

Description

ConditionView is a class that updates diseased heart descriptions.

Stimulus/Response Sequences

Appendix D: (Continued)

ConditionView will receive input from the Manager class. With the input, it will update by entering the appropriate text for the selected diseased heart.

Functional Requirements

Function: ConditionView

Inputs: Text from a file

Source: Text file location from the Manager class

Effect: Render to its render viewport

Pre-Condition: ConditionView is rendered and displayed on the user's screen.

Post-Condition: The description text is different.

Appendix D: (Continued)

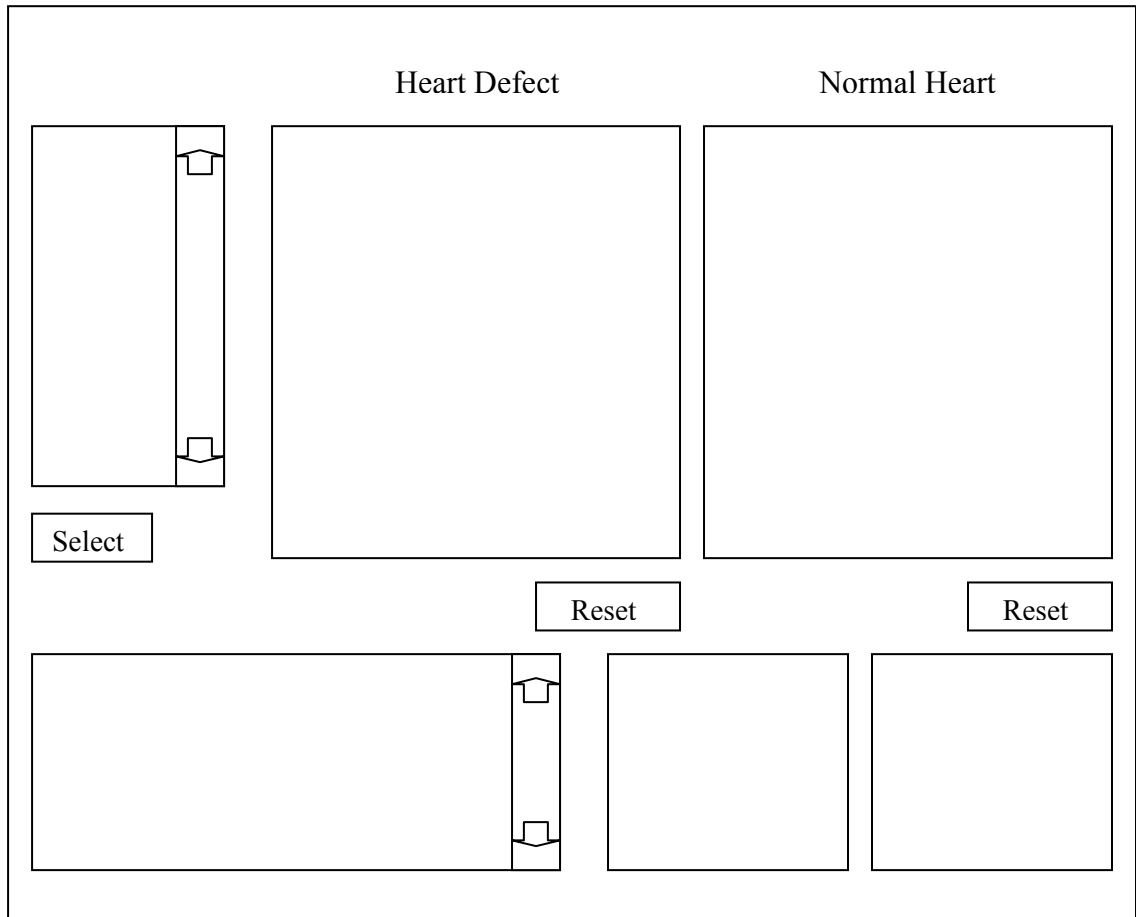


Figure D.1 Graphical user interface design

Appendix D: (Continued)

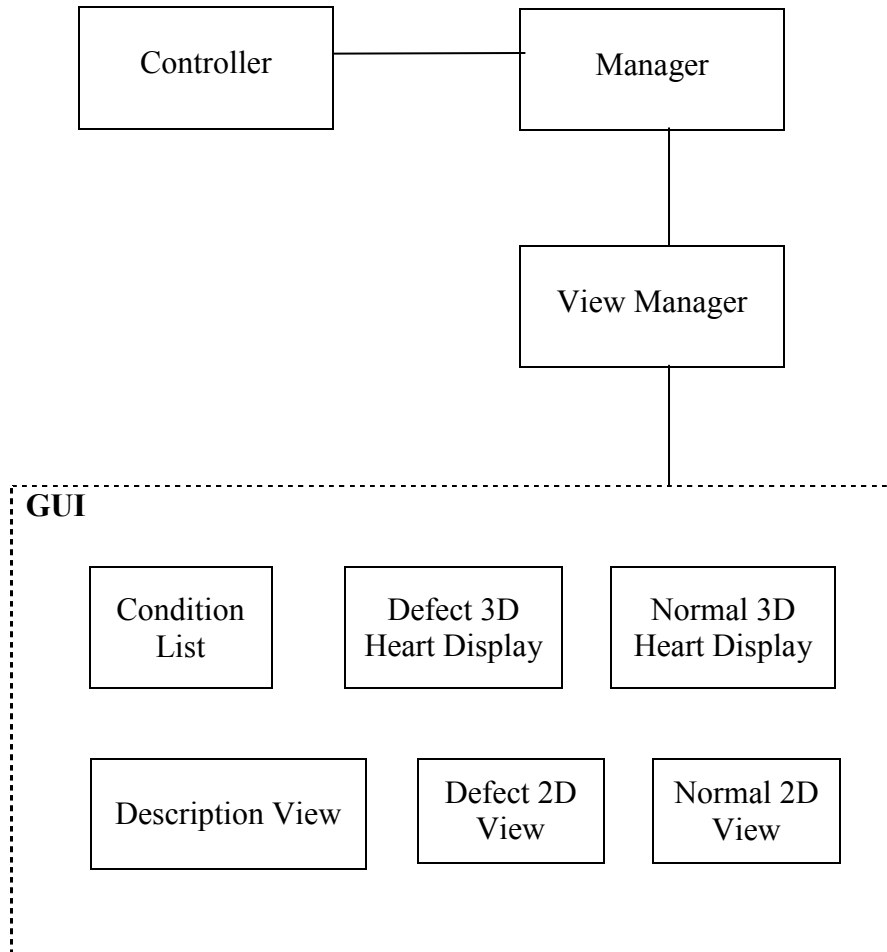


Figure D.2 Architectural model of the system

Appendix D: (Continued)

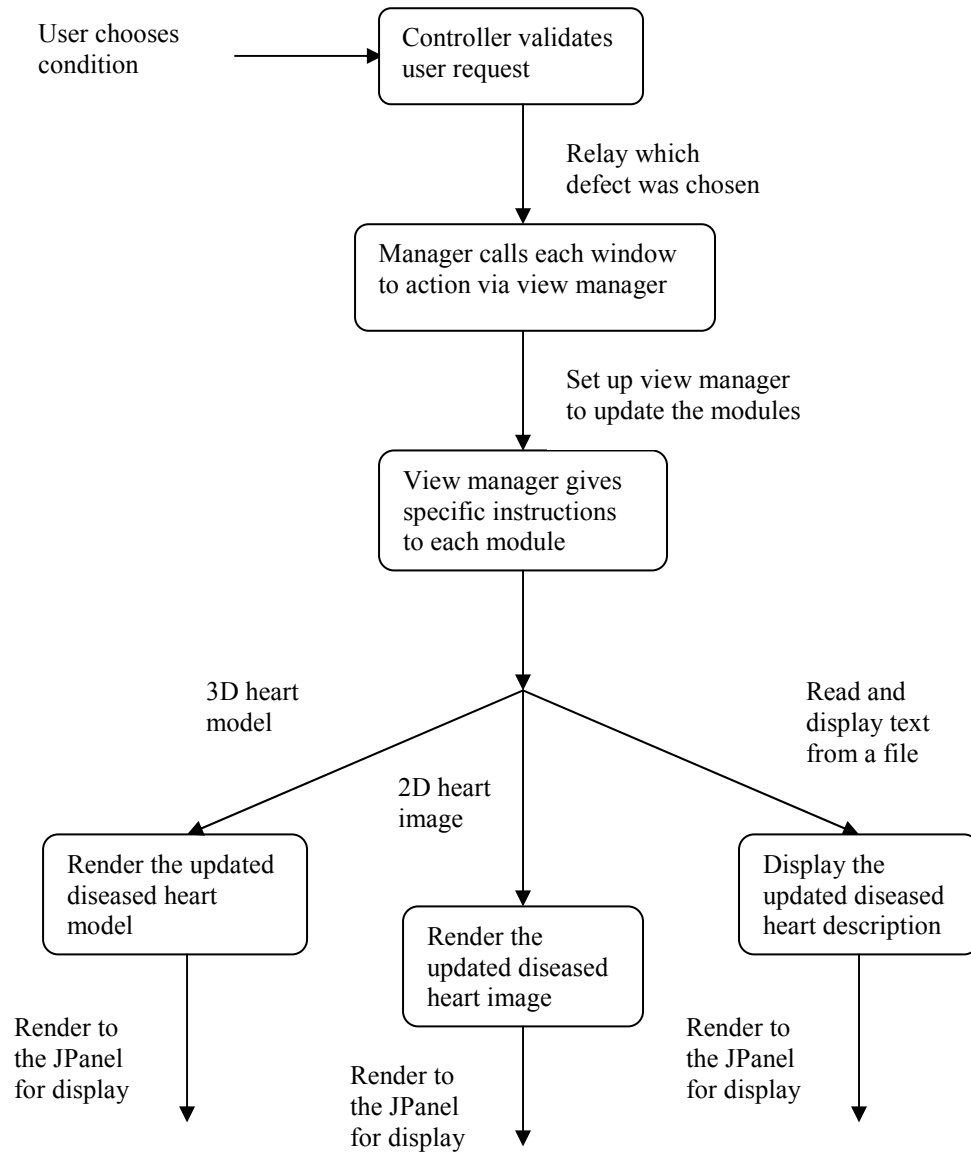
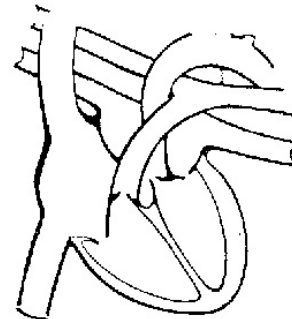


Figure D.3 Data-flow diagram of the system

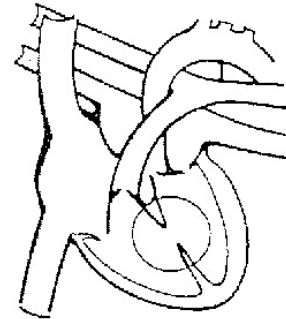
Appendix E: Sample Heart Diagram

VENTRICULAR SEPTAL DEFECT

- 1. What Is It?**
An opening in the wall that separates the two sides of the heart. This opening is in the lower part of the heart.
- 2. Why Did It Happen?**
Cause usually unknown. Generally not inherited from parents and definitely not fault of parents.
- 3. What Does it Do To The Heart?**
If the opening is large, heart must work harder. More blood goes to lungs and they are congested.
- 4. How Does It Affect The Child?**
If the opening is large, child may tire quickly, develop slowly, catch pneumonia easily, breathe rapidly, and appear pale. If it is small, has no effect and may close by itself.
- 5. Can It Be Fixed?**
Yes, if severe, it can be fixed. Most do not need fixing. Some need medicine.
- 6. What Can The Child Do?**
Play and work normally. Cannot hurt himself by hard exercise.
- 7. What Should The Parents Do?**
Follow doctor's advice on:
 1. giving medicines
 2. return visits to doctor
 3. special tests
 4. extreme care with dental procedures. Tell the dentist about the problem **BEFORE** he fixes child's teeth to avoid infection in the heart.



Normal Heart



Ventricular Septal Defect

This information is general. Only your doctor can give you precise details and instructions.
Source: The American Heart Association, David A. Geis



Figure E.1 Sample heart diagram for Ventricular Septal Defect