Process Book
CS - 6630 Visualization

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Project: INEPT - Interactive Needle Electroanatomical Potential Tracking

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1 Basic Info

Table 1: Author Info for: INEPT - Interactive Needle Eletroanatomical Potential Tracking

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Link to Project Repository: https://github.com/kgillette/dataviscourse-pr-INEPT.git
INEPT tool is not being published on public website for confidentiality issues. Data will be hosted publicly at a future date.

2 Overview and Motivation

Ischemic heart disease (IHD) is the leading cause of early mortality in the modern world. IHD leads to the death of over 7 million people around the world each year. The method for diagnosing IHD has not changed for over a century with electrocardiograms (ECGs) being the primary diagnostic tool. However, clinical ECGs lack the necessary spatial context to accurately guide further treatment. Our lab hopes that by increasing the electrode density in and around the heart, in the experimental setting, we can characterize the onset, development, and progression into irreversible tissue damage. By increasing our understanding of the disease state and how it affects the heart globally, we can further our understanding of the disease and translate that to clinical improvements.

Ischemia, in humans, typically results due to an imbalance between the amount of blood delivered to a tissue and its metabolic demand. Typically, this imbalance occurs due to the narrowing of the coronary arteries responsible for perfusing the cardiac tissue. This narrowing is due to the buildup of atherosclerotic plaque in the coronary arteries. As the diameter of the artery occludes over time, the blood delivered to the cardiac tissue diminishes and the risk of developing ischemia increases. Furthermore, any increase in heart rate increases the metabolic demand of the cardiac tissue and the likelihood of developing a supply and demand mismatch. In order to evaluate sensitivity to ischemia, presumed patients undergo a stress test in which they are hooked up to a clinical ECG and made to exercise such that their heart rate increases and the ischemic likelihood can be evaluated. Unfortunately, the nature and progression of ischemia is poorly understood and the accuracy of diagnostics can be as low as 40% accurate. This poor performance necessitates the need for the progression of how we evaluate and interpret ischemic episodes.

The clinical indicator of ischemia is the potential along the ST segment of an ECG. The ST-segment is indicated in figure 1. This segment corresponds to the isoelectric portion between the main upstroke, the QRS complex, and the repolarization wave known as the T wave. The point evaluated can be seen in figure 1 indicated by the red marker. As a heart becomes ischemic, currents persist in the heart during the ST segment that are not present in a healthy heart. These currents exist due to the potential difference between the healthy and ischemic tissue in the heart and cause deflection in the ST segment. However, the sheer magnitude of the potential at the ST segment can be misleading, especially the further an electrode gets away from the ischemic source. Additionally, multiple ischemic zones throughout the wall can superimpose their signals and negate any observable potential during the ST segment, giving the impression of a healthy heart. How these zones are visualized throughout the wall can be seen in figure 2 as the opaque
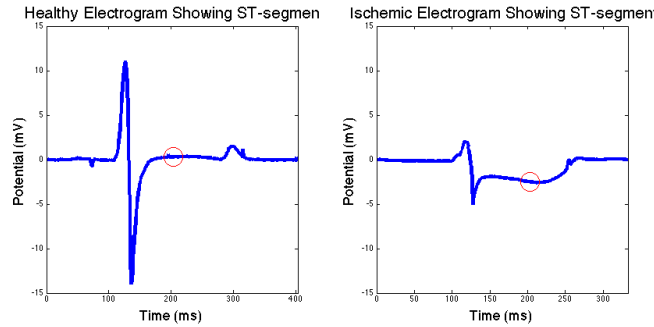
Figure 1: **Example Waveforms of a Healthy electrogram versus an Ischemic electrogram. ST segment is indicated by the red marker.**

light green regions suspended in the heart model. The ambiguity associated with evaluating ischemic zones based on potentials alone necessitates the development of an additional metric for evaluating ischemic zones. It is our thought that by evaluating the potentials throughout the heart wall using plunge needles embedded in the cardiac tissue, we can use the morphology of the signals to infer the directionality of currents throughout the tissue and detect sources indicative of ischemic zones.
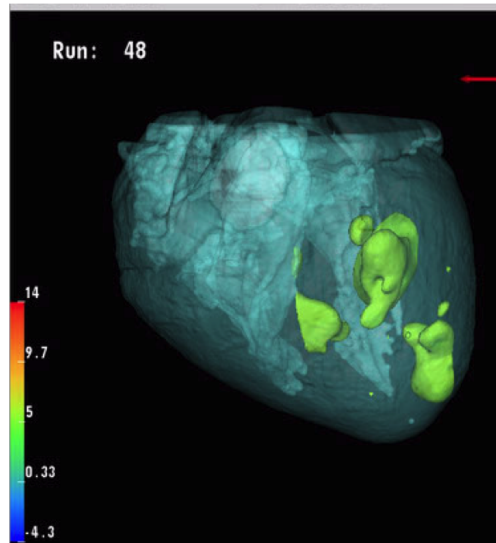

Figure 2: **Visualization of the Ischemic Regions (green) Developing in the Myocardium (blue)**

3   Related Work

The motivation for this project was to design a platform that would allow a user to examine the many dimensions of this electrophysiological data in a seamless manner. Currently, the research lab in which this data was pulled from has developed a series of scripts to analyze and process

some of the views proposed for this project. However, after learning the degree of interaction that was truly possible using D3 several additional views were planned. The motivation for incorporating these views came from scientific mysteries and debates. For example, the region in which ischemia primarily develops is overly simple and does not accurately describe all of the clinical cases of ischemia. Therefore, by incorporating a histogram that tracks the location of ischemic tissue we can verify, experiment after experiment, where the ischemia develops and how those zones grow. Additionally, the ST40 plot tracks the ST40 potentials of a single electrode of time. This is to examine how the electrophysiological parameters of a tissue changes over the course of an ischemic intervention. Additionally, we are able to examine the effects of preconditioning of ischemic tissue. In simple terms, preconditioning models a tissue's resilience to subsequent ischemic interventions. By watching how an electrode's measured potential varies over time we can gauge how various parts of the tissue respond to multiple ischemic episodes.

4 Questions

While our experiments are carefully designed to induce and capture ischemic episodes, the sheer amount of data that we collect over the course of an experiment can be cumbersome to analyze and interpret. Several tools have been developed in house in order to visualize either the spatial distribution of potentials throughout the heart or the transient progression of the disease. However, visualizing both the spatial and temporal progression of the disease in the same context is necessary for developing a more sophisticated model of ischemic heart disease.

Understanding the spatiotemporal progression of ischemic regions throughout the myocardium will help parameterize the computations necessary for interpreting the same ischemic sources from the body surface. The process of detecting the sites of unknown sources of potential from a known electrode location is known as the inverse problem. This problem is typically under-constrained and can result in non-unique solutions that can misguide diagnostics. Parameterizing this solution with more experimental evidence will increase the accuracy with which we can evaluate and detect ischemic regions.

Ultimately, the overall question that we are trying to address in using this project is how a heart responds electrophysiologically to ischemic pressures. More specifically, we want to investigate where in the ventricular wall do ischemic zones typically develop and also how those zones grow and along what axis. We plan on doing this through the utilization of two separate visualizations. One based on standard ischemic evaluation, using solely ST40 potentials. However, the threshold for what potentials would be considered ischemic is quite subjective motivating the use for developing a second way of determining ischemia. That is the goal of the needle electrogram plot. This plot, showing potentials through the wall can be used to verify ischemic zones by determining the direction and magnitude of injury currents flowing throughout the heart. These injury currents typically flow from healthy tissue into ischemic tissue and knowing this one can determine ischemic tissue by looking at the waveform captured by each electrode. Additionally, the volume effected by an occlusion of certain coronary arteries is also poorly understood. By inspecting needles both close to the occlusion and far away we can determine the region that experiences the greatest shock under ischemic interventions.

This visualization should allow a user to dynamically visualize both the spatial progression of the ischemic regions over the experimental time frame as well as the temporal progression of potentials throughout the experiment on an electrode by electrode basis. Through a comprehensive analysis, it should be possible to determine the sensitivity of certain regions of the heart to ischemia, as well as how the ischemic regions nucleate and spread throughout the myocardium. Additionally, there should be some context as to where the ischemic regions most likely form, either endocardially, epicardially, or within the mid myocardium. The sites that are most vulnerable to ischemia is a topic of debate in ischemia research and a method by which the most vulnerable regions can be evaluated instantaneously and over the course of the experiment.

4

5 Data

The data that will be used for this visualization comes from the experiments conducted by the ischemic research team headed by Dr.Rob S MacLeod at the Cardiovascular Research and Training Institute located at the University of Utah. This visualization is focused specifically on the transmural plunge needle electrodes used during the ischemic experiments. During one such experiment, the heart of interest is embedded with anywhere from 20 to 50 needles throughout the circumference of the ventricular myocardium. With ten electrodes along the length of each needle, there can be up to 500 electrodes placed throughout the myocardial volume, allowing for a reasonable sampling of potentials throughout the myocardium.

The signals captured by the needle electrodes are referred to as electrograms (EGs), rather than electrocardiograms (ECGs), to distinguish between the signals captured on/in the heart surface and those captured on the body surface. Each electrode has an EG associated with it for every run measured throughout the experiment. Each run consists of an EG of a single heartbeat. The EG data will be stored in a 3D matrix with the following dimensions: (#Electrodes X EG time series X Run#) Each experiment can have anywhere from 60 to 300 runs meaning that each electrode can have up to 300 associated EGs measured over the course of the experiment. This can lead to several thousands of EGs being collected per experiment. The sheer magnitude of data makes it difficult to holistically interpret the EGs and their spatiotemporal progression.
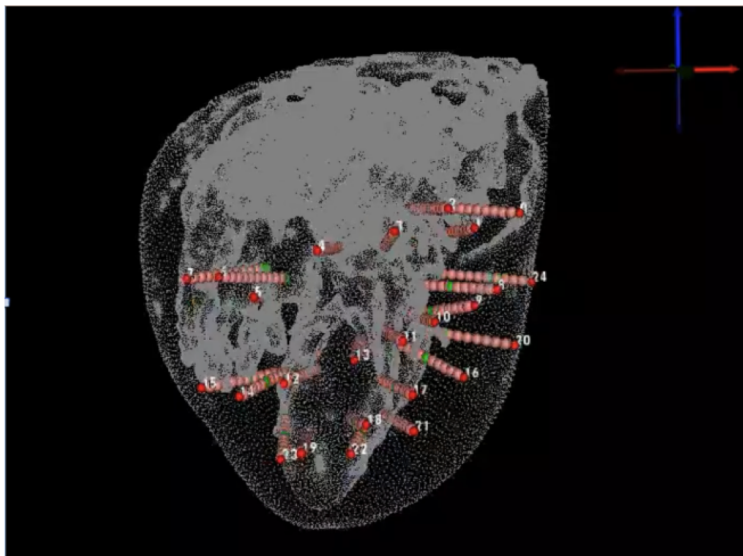

Figure 3: **A visualization of the Needle electrodes within the heart in 3D. Each needle has a total of 10 electrodes along its length.**

The 3D coordinates of each of the electrodes were also captured during the experiment such that the spatial organization of the needles can be rendered and realized in a volumetric view.

5.1 Data Processing

Plot (BEP), as well as classifying each of the electrodes by their depth into the transmural thickness. This depth will be identified by epicardial, endocardial, or mid myocardial. By assigning both region classifiers and depth IDs to electrodes we can cast the electrode positions into their corresponding regions of the BEP as well as keep track of the number of electrodes detecting

ischemic potentials in each of the three layers of the myocardial wall. The spatial information of each electrode will be stored in a matrix such that each electrode has a corresponding 3D coordinate position, a 2D coordinate position, the region in the BEP it belongs to, and the layer of the ventricular wall the electrode resides in.

Another component of the processing necessary for this project is the extraction of the ST potentials, evaluated as the time point that lies 40% of the way in between the end of the QRS complex and the peak of the T wave. These points, and others, are extracted through a user based fiducial detection algorithm that allows for further processing to be mostly automated. After each signal is processed by the user, matrices of each electrode's ST40 potential over each run will be aggregated. In the end, the 2D matrix should include the ST40 potentials of each electrodes over each run in the experiment.(#electrodes X # of Runs).

Processing that may be done, will be done in a dynamic sense and will include the averaging of potentials for a given electrode over a number of runs, potentially selected via a brush, such that the histogram reflecting the depth of the ischemia can be interpreted and averaged over a number of runs. Additionally, the ST40 of each electrode along a given needle can be averaged on a run-by-run basis and displayed on the ST40 line chart as a single curve. These averaging functions will allow the user to evaluate specific run intervals to make conclusions on how a series of runs affected the heart. An additional processing step that can be computed post brushing would be to show the change in the ischemia histogram from the left-most run in the brush selection to the right-most run. This would allow the user to examine the progression of ischemia solely over the runs selected. Additionally, the EGs for each run at the extrema of the brush selection could be overlaid in the EG plot to show how the EG morphology changes over the course of the selection.

6   Exploratory Data Analysis

Initially, researchers probed this subject through some similar individual visualization views to analyze the ischemia potential data, in particular visualizations similar to the ST40 plot and the electrogram plot, but the views were all stand-alone. There was no interaction component, so the researchers were arbitrarily choosing runs and electrodes to get a feel for the nature of the data. With all of these views combined, as well as additional views, researchers should be able to probe the data dynamically and much more efficiently.

The need to view the electrodes deemed to be ischemic by potential compared to others found to be ischemic based on their morphology was a major motivation for the design. Researchers are fed up with how subjective potential thresholding is and the inability to have a global idea of what is happening throughout the heart, which necessitated multiple synced views to better inform exploration of the data.

There is a huge debate in this field about where in the heart ischemia develops, which is why we decided to include the endo/mid/epi histogram. The high level analysis of a single electrode as well as the effect of preconditioning (the phenomenon in which a tissue reacts forcefully the first time it becomes ischemic, and has a more muted response with each subsequent run) on ischemic response would help achieve the research goals as well.

7   Design Evolution

7.1   Initial Brainstorming

Initial brainstorming for the visualization (see inserted PDF below) was conducted based on the types of information that need to be portrayed for the user. These data types are namely the electrograms, ST40 potential data, the 2D and 3D position data, and the depth classification for

each electrode. Multiple views are needed to effectively portray the data to meet the project objectives.

Such views were narrowed to include the histogram to show depth classification for electrodes, an electrogram line chart that must be able to show multiple electrode selections (possibly an entire needle), an ST40 line chart, and either a bullseye or 3D volume rendering for location data. The depth classification will be shown using a histogram plot with bins of endocardium, epicardium, and middle. To further analyze the ST40 potential distribution within a set of electrodes, a diverging scatter bin plot will be used. This view could be paired with color channels implemented on the electrodes in the 2D or 3D location views. Interactivity between different data types was also brainstormed to ensure cohesion within the data. Such considerations were implemented in the creation of drafted visualization designs. In general, all design implementations must be interactive and linked to allow the filtering and analysis of data.

Sheet 1 : Brainstorm

Ideas ⟹ data types:-
electrograms,
St40 data,
position (2D/3D),
depth classification (endo, epi, mid)

electrograms ⟹ line chart, How to show
multiple? - electrodes on needle

use color   ⟶ time series of electrode
to distinguish   at different stages
ID channel   overlay line chart
                stacked, but not overlapping

St40 data ⟹ bar chart with averages>
                line chart over all runs of
                single electrode
※ ST40 can be positive & negative
        ⟹ use diverging   color scale?
   ⟹ rainbow color scale
                ⟹ use a diverging scatter
                bin plot?
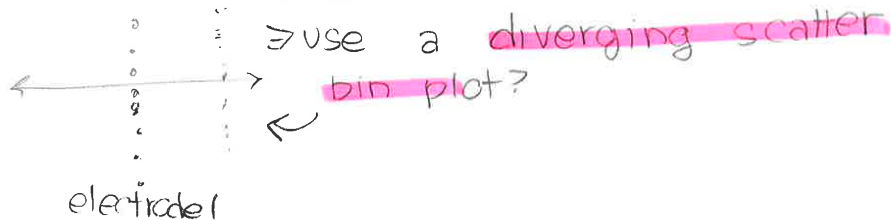
electrode1

position 2D/3D: ⟹ use bullseye plot
⟹ 3D interactive   ⟹ save 2D projections as
                3D ⟹ certain frames

depth classification ⇒ use histogram
  to bin thresholded/ischemic electrodes
    ⇒ use pie chart!
    ⇒ use channels on bullseye plot
    (squares, triangles, etc)
    ⇒ use coloring on electrogram
    view to indicate spatial depth
    for needle.

Initial view sketches
—————————————

Electrogram sketches

#1   ST40

or

#2
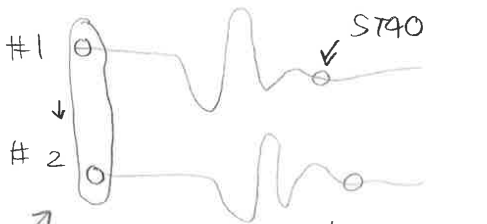
⇒ this sketch
  allows bin coloring,
  > 6 electrodes to
  view depending
  on screen.
⇒ what about showing needle in stacked?

⇒ better comparison
between EG's in
general, but how
to connect/differentiate
(legend?)

ST40 Data Sketches

electrode #

ST40 Pot

⇒run #
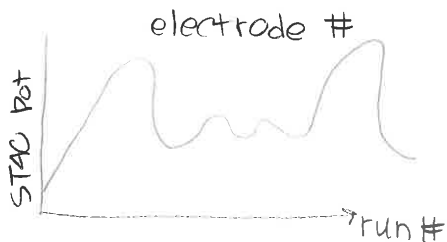
⇒ could overlay multiple

maybe loses
data?

avg st40 potential

runs 1-10   run10-20   ⇒runs

2

Position 2D/3D Sketches

↗ 3D Heart
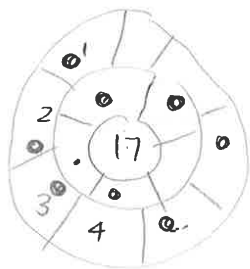
← directly related.

⇒ uses **clinically** relevant **bullseye** plot (only 2D) user may lose perspective

⇒ could be interactive, allows the needle showing, pretty ♀

⇒ what about both?

Depth Classification

⇒ endo, epi, mid (need all 3)

Histogram:
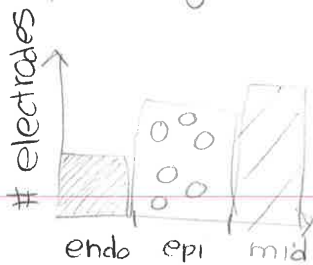
⇒ good for comparison
↳ could easily allow for comparison between different selections

Pie chart:

⇒ bad?

Bulleye grouping

mid ⇐ ▲ ◰ ⇒ endo
◉ ⇒ epi

⇒ could be cluttered, hard to distinguish

Interactivity Ideas:

Given hundreds of electrodes:
⇒ link the views with corresponding views (visual highlighting of selection).

- Bullseye plot to needle/ electrogram
    ⇒ could use connected lines

pair!?

- use channels ⇒ selected electrodes have big shape
- Bullseye on the other side to st40 plot ⟩

ST40

EG
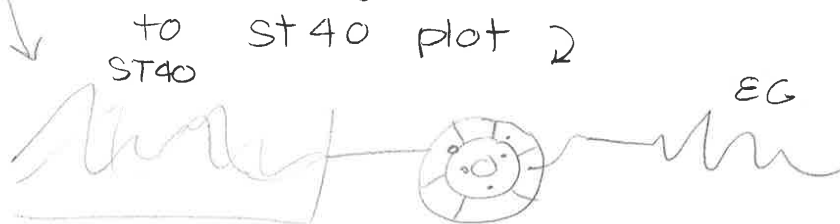
- lines connecting all other electrodes on needle in either 2D or 3D views.
    ⇒ bubble enclosure?
    ⇒ coloring, etc

- make sure you can click the 2D & 3D selections

4

Other interactivity linking:

- color the depth class plot into the background of electrograms on plot ⇒ will only be possible with stacked view.

- If only one electrogram is shown ⇒ color background accordingly

- stacked view to single view for electrograms

single view

- brushing on plots! ST40 plot to filter through runs
  ⇒ could also be used to average runs

- region selection of bullseye plot

- endo, epi, mid selection

- zooming on ST40 / electrogram so you can better see trends

- threshold selecting
  ⇒ could use ST40 or drop down menu
  ⇒ horizontal line on ST40 plot for threshold.

5

Filter & Refine Ideas!

⇒ go back through & choose
selections of what best
fits user (highlighted with
pink).

Comments / Concerns for selections:

• Choose bullseye at a minimum
due to clinical relevance & utility
⇒ would be nice to have
3D (optional)

• For electrograms, stacked is
preferred, but would be nice to
change views on demand

• ST40 ⇒ don't use histogram
because it loses data, but
averaging electrodes/ overlaying
would be nice.

• Diverging scatter bin plot could
be great but could be shown
using channels on bullseye plot.

⇒ WE NEED MULTIPLE VIEWS
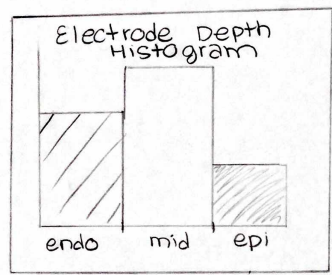⇒ STEP 2

6

7.2 Designs for Visualization

The first design (see design 1 pdf below) features a bullseye plot showing 2D location within the heart, histogram for classifying electrodes within the endocardium, epicardium, or middle given meeting the ischemia threshold, a ST40 potential line chart, and a horizontal plot that shows all the electrograms for selected electrodes. Operations or interactions within this visualization are mainly:

- A slider bar that changes the value of the run, directly updating both the electrode depth histogram and the bullseye plot.

- Horizontal threshold bar on the ST40 plot that can be moved to change the current threshold value. Directly influences the electrode depth histogram and would change visual highlighting within the bullseye plot.

- Interactive and linked electrode selection in each view.

Advantages of this plot include that is it simple to navigate, user friendly, and allows for basic data analysis required by the user. However, the diagram lacks the ability to show multiple comparisons between electrograms due to the horizontal arrangement and doesn't include a diverging scale to show differences in ST40 potentials that is critical to understand current flow. Additionally, the visualization is lacking the ability to show whether an electrode is ischemia or not on the bullseye plot, thus relating to the electrode depth histogram.

Step 2/3/4 Design 1

Layout:

Electrode Depth Histogram

endo   mid   epi

Bullseye Plot

1 6 7 11 10 5 8 2 9 4 3

slider bar

updates

ST40 Potentials

ST40

runs

threshold

Electrogram Plot
Needle: ①

① ~ ② ~ ③ ~
↑ electrode Number

→ spans entire width
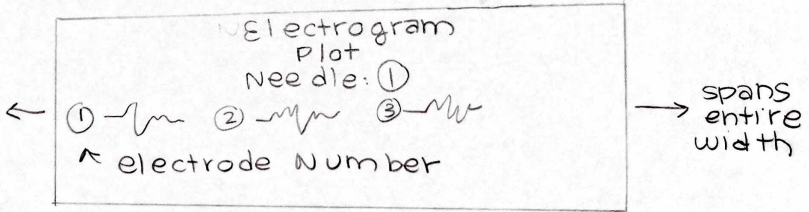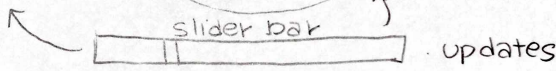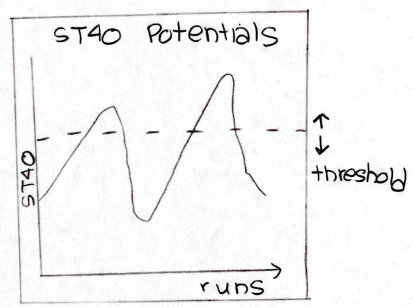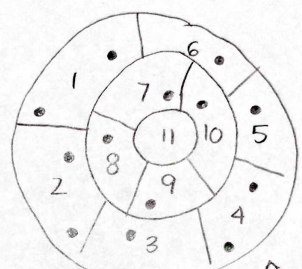
The second design (see design 2 pdf below) is more complex than the first design. It involves a needle electrogram view, a bullseye view, an ST40 plot, an electrode depth histogram, and a diverging scatter bin plot. In this case, operations and interactions include:

- Changing the run using the diverging scatter bin plot that updates the bullseye, electrode depth histogram views, and the Electrogram plots.

- Zooming and scrolling within the diverging scatter bin plot.

- Full needle electrogram view that can be shifted to single selection view.

- Electrodes on the needle electrogram illuminate on the bullseye or 3D view.

- Change the threshold value for ischemia based on a horizontal bar in the ST40 plot.

- Changing from a 2D bullseye to a 3D rendered volume.

In general, this visualization design has a high level of interactivity with the user by including the diverging scatter bin plot. Additionally, the user has more context to the physical heart given an actual displayed needle in the needle histogram plot and the ability to switch to a 3D volume of the heart. However, the view is more complex and would involve resetting selections, updating 5 views instead of 4, and lacks a relation between electrode depth and the electrodes.

Step 2/3/4 Design 2

Needle Electrogram

Bullseye view

→ lights
up
electrodes
on needle

→ changes to
single selection
view

3D view

ST40 Plot

ST 40

run

change run
by clicking

DOS ↑
0 ←
neg ↓

run 1   run 2   runs

possible zooming
& scrolling

Electrode Depth

endo   mid   epi
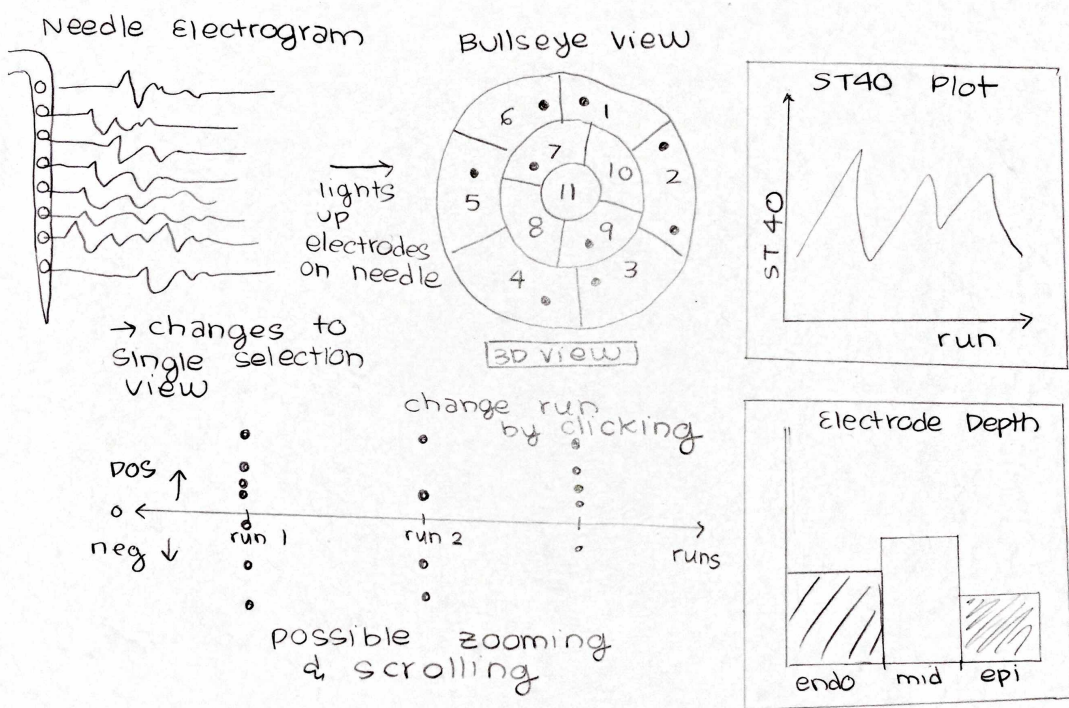
A last design takes advantage of four views arranged differently than the first two designs. In this instance, the four views include a needle electrogram, an electrode depth histogram, a bullseye plot, and a ST40 potential line chart. This design has a high level of interaction and involves:

- Changing the run using a slider bar that updates that bullseye and electrode depth histogram.

- Full needle electrogram view that can be shifted to single selection view.

- Electrodes on the needle electrogram are classified into tissue depth using background coloring.

- The bullseye plot uses a diverging color scale to show ST40 potential distribution across all shown electrodes.

- Change the threshold value for ischemia based on a horizontal bar in the ST40 plot.

- Selecting regions within the bullseye plot that updates the depth histogram and ST40 plot with an average of all electrodes in region.

This last design is visually symmetric, maintains all critical views necessary for the user to perform data analysis, and has a high level of interactivity that the other designs were lacking. However, the diverging color scale on the bullseye plot limits the ability to link electrode depth and electrode selection.

Step 2/3/4 Design 3

Bullseye Plot

slider bar
⟹ changes runs

ST40 Plot

ST40

run ↗   time

threshold

match coloring

Electrode Depth

endo mid epi

Needle Electrogram

click electrode
for single view
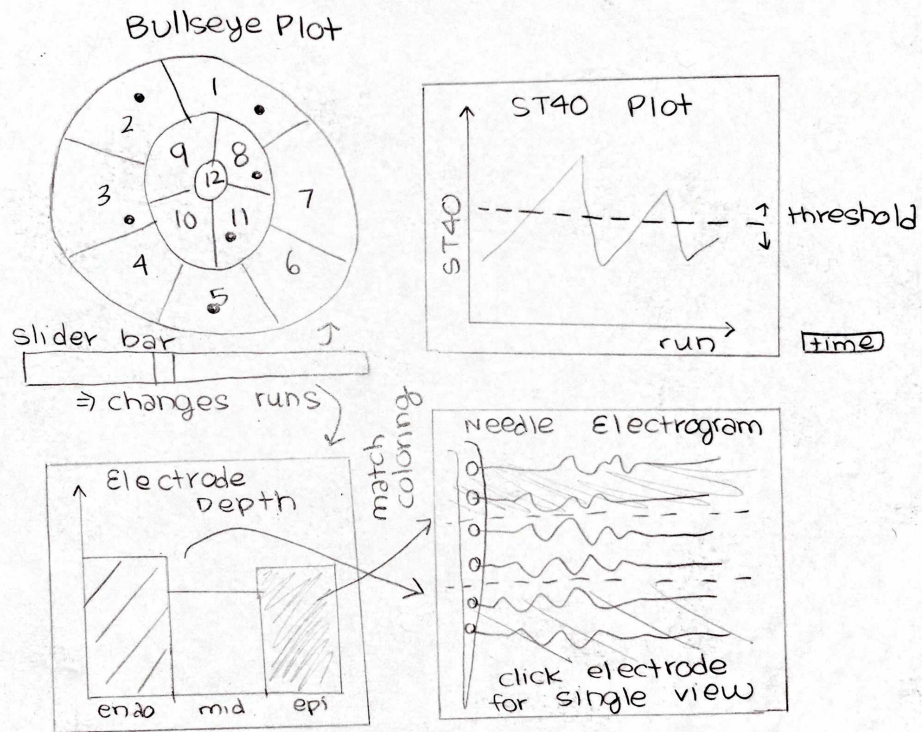
7.3 Final Design

The final design incorporates aspects from three of the rough draft designs. It involves five views arranged according to the desired user interaction. The five views are the ST40 potential line chart, the electrode depth histogram, a bullseye plot, a diverging scatter bin plot, and finally the full needle electrogram. This design incorporates many of the previously mentioned user interaction with the addition of a few. The interactions include:
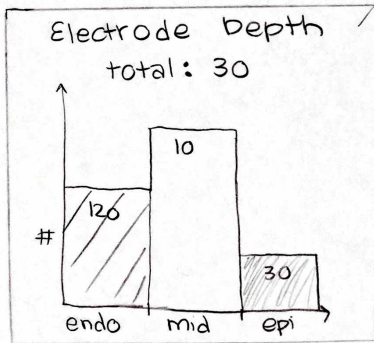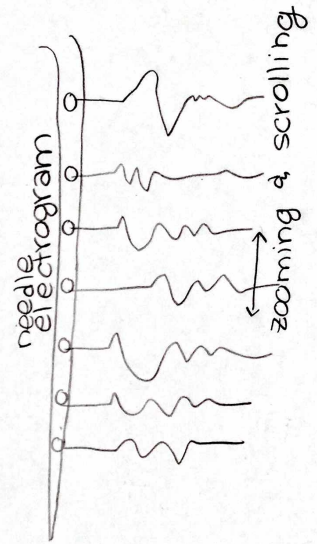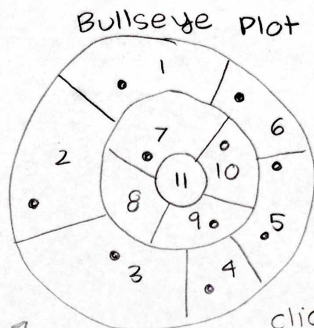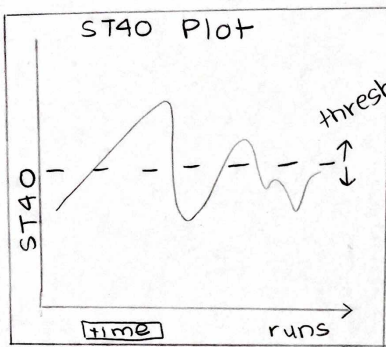
- Changing the run using the diverging scatter bin plot that updates the bullseye, electrode depth histogram views, and the Electrogram viewer.

- Full needle electrogram viewer that can be shifted to single selection view.

- Electrodes on the needle electrogram are classified into tissue depth using background coloring.

- The bullseye plot uses a diverging color scale to show ST40 potential distribution across all shown electrodes.

- Change the threshold value for ischemia based on a horizontal bar in the ST40 plot, dynamically updates electrode depth histogram.

- Selecting regions within the bullseye plot that updates the depth histogram and ST40 plot with an average of all electrodes in region.

- Changing from a 2D bullseye to a 3D rendered volume with rendered needles.

- A selectable brush can be used to select a number of runs in the ST40 line chart. This brush can be used to either average all of the runs in the selection update the depth histogram and the potentials viewed in the bullseye plot.

Though some design changes may be implemented during creation, the final design appears to address the primary objectives as described previously. It allows the user to filter and analyze the data with high levels of user input, remains a high level of connectivity between the different views, and is relatively easy to use. Note that the threshold used on the ST40 plot directly influences the binning of the electrode depth histogram, therefore these selections have been placed vertically adjacent to one another. By changing the threshold on the line chart the user will see the new histogram produced by evaluating all electrodes by the new threshold. Additionally, the user is given global context of the degree of ischemia present in the tissue through the use of the diverging scatter bin plot. Using the diverging scatter bin plot as the effective slider for controlling the visualized run allows for the user to have as much information as possible before making their decision. While this view may be cluttered general trends will be accentuated through the redundant use of color and position on the diverging scale. With this information the user will be able to examine trends throughout the experiment in one frame in order to guide further exploration into the data. This design also allows for the the full needle viewer to take up much more vertical space. This will help with lessening the clutter of having 10 stacked electrograms. This design also incorporates a brushing feature in the ST40 plot. This brush can be used to make a selection of a number of runs in the experiment on which more complex operations can be performed. One operation could be to simply average the run data selected and update the bullseye plot and depth histogram. Another operation could take the leftmost selected run as control and measure the change between said run and the rightmost selected run. The desired operation can be selected from a drop down menu.

Step 5: Final Design

ST40 Plot

ST40 vs time / runs, with threshold (dashed line)

Electrode Depth
total: 30

endo: 120, mid: 10, epi: 30 (#)

color electrodes

Bullseye Plot

1, 2, 7, 6, 11, 10, 8, 9, 5, 3, 4

3D View → click to switch to volume

select run/runs by clicking/brushing

run, run 1, run 2, run 3

+, −
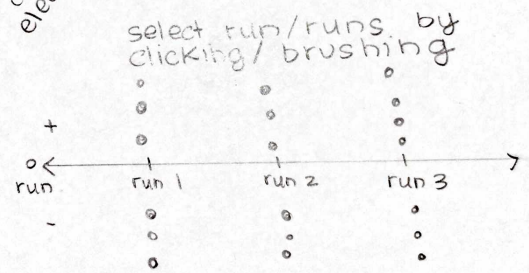
use color & position
Diverging scatter bin plot

needle electrogram

zooming & scrolling

7.4 Must-Have Features

Since classifying each electrode as ischemic is a crucial aspect of the visualization, the user must have some way to tell if a given electrode is above threshold (and therefore ischemic) and to what extent. This could be implemented using the following features:

- Visual highlighting (size increase or dark black outline) of electrodes on the bullseye and needle electrogram view that indicates ischemia.

- A diverging color scale on the electrodes in the bullseye plot. A red color would indicate a positive ST40 segment, while blue would indicate negative.The luminance of the color would be directly proportional to the normalized magnitude of the ST40 segment. In general, the diverging color scale would indicate whether a current was flowing toward or away from a tissue which directly relates to ischemia classification.

- Further represent ST40 potentials over all the runs using a scatter bin plot. This plot will take the place of the slider bar that controlled the run displayed on the Bull's Eye Plot.

- An input box or drop down menu that gives the user the ability to update the threshold value. Changing the threshold value would automatically lead to update of the diverging color scale, histogram, and needle electrogram view.

- Horizontal line on ST40 line chart that indicates the threshold value. This would let the user better identify during which runs an electrode is considered ischemia.

Another critical aspect for the visualization is data filtering. A user must be able to interactively filter the data based on live selections in the visualization. This leads to mandatory data filtering features:

- Ability to select individual electrodes. The selected electrode must be apparent through visual highlighting as mentioned above and after selection of an electrode within the bullseye view, the needle electrogram view should update, and vice versa.

- A slider bar should be included to select different runs and a specific run should also be selectable within the ST40 line chart by simply clicking along the curve. The slider bar or run selection should update both the bullseye and needle histogram views, but the selected electrode must stay highlighted.

- Needle electrogram view should have a background colored schematic that indicates the endocardium, epicardium, or middle electrode classification on the specific visualized needle.

- Ability to update the bullseye plot depending on the selection of endocardium, epicardium, or middle classification within the histogram or needle electrogram views. Such filtering allows a user to see how electrode tissue depth might influence the development of ischemia.

7.5 Optional Features

Many optional features for data filtering and visual design could be implemented:

- 3D volume rendering of the heart geometry with interactive needle selection. This view could be used to replace or augment the bullseye view. If interaction is not possible, a non-interactive 3D distribution of needles that rotates and simply updates with the current data selections could be used.

- Comparison of different runs on the histogram. With multiple run selections, implemented using a drop down menu, the histogram would become a grouped bar chart.

- Panning and zooming of the diverging scatter bin plot and the needle electrogram.

- Multiple selections of electrodes within both the needle electrogram and bullseye views. After selection, the ST40 line chart view would update to overlay all electrode selections on the same view. If selection is made within the bullseye view, the needle electrogram view would change to show side-by-side electrograms.

- In addition to showing multiple electrogram selections on the ST40 segment, there could be an option to average all selected electrodes. This would give the user the ability to compare needles instead of just electrodes.

- Drop down menu to convert the x-axis on the ST40 plot to time and back to runs again.

- Showing multiple run selections on the needle histogram plot. Electrograms would overlay.

- Brushing on the ST40 line chart that updates the histogram view and averages the potentials (updates the diverging color scale) on the bullseye plot.

- Drop down for selecting a particular region on the bullseye plot. The ST40 line chart would update by averaging the ST40 values for the region specific electrodes or by showing all 10 electrodes as an overlaying line chart. Similarly, the histogram view would only include the epicardium, endocardium, and middle classifications for the region subset.

7.6 Milestone #1

So far, we have not deviated at all from our final design. Here is a screen cap of what our visualization design looks like as of the 1st milestone.

Since the design is working well for us so far, our final implementation will probably look very similar to this one.

7.7 Final Submission

This final implementation includes all of the views that were deemed necessary to have in the final form. These include the bullseye plot, the diverging scatter bin plot, the electrode depth histogram, the ST40 time series, and the needle electrogram plot.
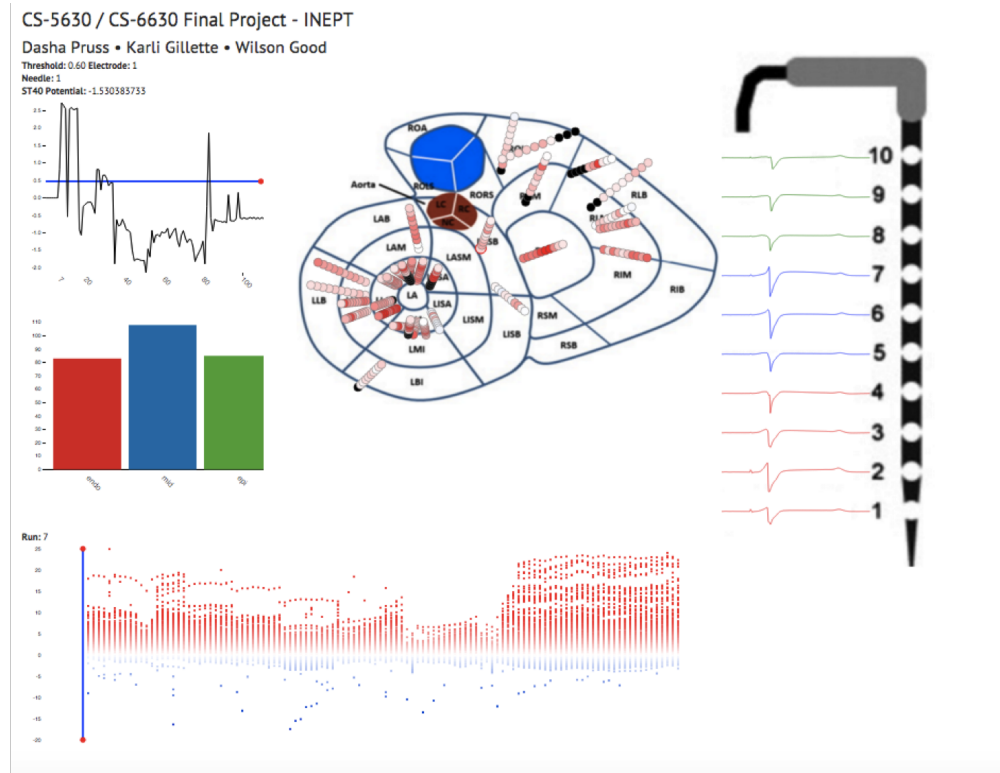
The design has had colors updated from the first milestone and has the full functionality as intended.

8 Implementation

8.1 Milestone #1

Thus far in the project, we have spent most of our time processing data and getting it into the proper format. We also created the basic views that were components of our final visualization design, as well as set up the means for interactivity between the views. We decided to use an event-driven approach similar to the one we used for homework 4. I will provide a brief overview of what has been done for each view.

ST40 Line Chart

So far, this view is displaying the correct data, but is displaying the data from one electrode without the option of changing to another electrode, and is displaying the data as a bar chart. We are going to change it to be a line chart as per our original design. This view shows ST40 Potential Values on the y-axis and run number on the x-axis. For the data set we are working with, there are 340 electrodes and 119 runs recorded for each electrode. This view will update when an "electrodeChanged" event is triggered, i.e. when an electrode is selected in the bullseye plot. We

also need to add the threshold value to the ST40 chart. This will look like a horizontal, draggable line on the ST40 line chart. When the threshold value is changed, a "thresholdChanged" event will be triggered, which will update the color scale in the bullseye chart and the scatter bin plot will update according to what the new threshold value is.

Bullseye Plot

We have the data for this view, but have yet to plot it. So far we are just displaying the base picture on which the electrode points will be mapped. After we add the electrode points, each will be represented as a colored circle, where color corresponds to aschemia level, as determined by what the threshold in the ST40 plot is set to. When an electrode is selected in the bullseye plot, an "electrodeChanged" event is created and updates the electrogram view and the ST40 plot views will update with the new electrode data. The bullseye plot will update when a "thresholdChanged" event is triggered, i.e. when the threshold in the ST40 plot is changed.

Needle Electrogram Plot

We have the data for this view as well, but similarly to the Bullseye Plot, we haven't gotten to displaying this data yet. This plot will show the electrograms for each electrode on the same needle that the current selected electrode is on (10 electrodes total). Currently, we are just displaying this as a picture, on which we will plot the electrograms later. This view will update when an "electrodeChanged" event is generated by the bullseye plot, and when a "runChanged" event is generated by the scatter bin plot.

Diverging Scatter Bin Plot

This view is correctly displaying its data. It displays similar data to the ST40 plot, but in this case it shows all of the electrode data at once. The x axis is the run number, and the y axis shows the potential of each of the electrodes, plotted redundantly through both height and color. We are going to add a brush to this view to allow the user to select a set of runs; when a group of sequential runs is selected, a "runChanged" event will be triggered, which updates the histogram, bullseye, and electrogram views with the data and new color scale from the respective selected runs. The diverging scatter bin plot color scale will update when the threshold value in the ST40 plot is changed through a "thresholdChanged" event.

Electrode Depth Histogram

This histogram displays how many of the selected electrodes that are above the selected threshold are endo, mid, and epi with respect to the heart wall. The histogram is currently working with a set of data, but it is not filtering based on threshold yet; we will add this once we add threshold functionality to the ST40 plot. The histogram will update when the "runChanged" event is triggered by the scatter bin plot, and when the "thresholdChanged" event is triggered by the ST40 plot.

Side note: we are having issues displaying the histogram on some machines. On the PCs we cloned our repository on, the view displayed fine, but on Macs the histogram would for some reason not display. Here is a screen cap of what the issue looks like on Mac computers:

We are still troubleshooting this issue. The histogram should display as it is on page 22 on all machines.

8.2 Final Project

The event handlers for run, electrode, and threshold were implemented as described in milestone 1. Each view interacts with every other view based on these selections. Text boxes were added to the viewer in order to present the user with the electrode number, its corresponding needle, threshold value, and the ST40 potential of that electrode. Though all views can be simultaneously shown, there is an issue with the container size defined in the html file. This issue results in the scatter bin plot being overlaid onto the needle electrogram plot. Though this can be resolved by increasing the container size, the scatter plot will move further down the page.

Data Uploading and Wrangling

Some difficulties were encountered when performing the data uploading for this project. There is a lot of data that is being used for this project all of which have different contexts. It was discovered that D3 does not handle excel spreadsheets and such the matrices that were intended to be 3D had to be broken into separate files. This was most crucial for the electrogram data, which included the electrogram measured on each electrode for all 119 runs. This meant for showing this data several files had to be used. Additionally, it was found that in order to aid the wrangling of data in D3 the data needed to have headers that effectively classes the dimension they were allocated to. It was also rather difficult to cast the 3D coordinates of the needles into 2D such that they could be rendered in a fashion that made sense. This involved the removal of the z coordinate

and a rigid transformation to the appropriate location in the BEP. It must be noted that only 310 of the original 340 electrodes are shown within the bullseye plot, because three needles could not be found experimentally.

In terms of data wrangling, the data had to be manipulated into a usable javascript format from the CS that included both reassigning headers, parsing, and indexing. This data then had to be passed from the main script file into all the corresponding views. Additionally, data had to be interactively loaded for the needle electrogram plot based on the run selection. This included adding another queue within a function that executing upon changing the run event handle.

ST40 Line Chart

This view shows the ST40 potentials measured for a given electrode over all the runs in the data set. It also allows the user to select the threshold that is used to bin the electrodes on the histogram. This view is controlled by the user selection of electrodes on the BEP. This view is particularly useful for analyzing the hearts response to prolonged bouts of ischemia as well as subsequent bouts. Because the first 7 runs of this experiment were measured before needles were plunged into the myocardium and therefore were excluded from this dataset. When the electrode is changed the threshold bar remains in the same location while the y-axis shifts. This results in the threshold changing when a new electrode is changed.

Bullseye Plot

Implementing this view took a great deal of wrangling as it involved the manual transformation of 31 needles. However, this view was crucial as the anatomical locations of the electrode are crucial for analyzing the spatio-temporal evolution of the ischemic event. The spatial context of the BEP is given by the electrode positions at any time. One can then change the run in order to view how the potential changes as the ischemic load is increased an decreased throughout the experimental protocol. When the run is changed the ST40 data displayed on each electrode is changed. In the end, the 3D rendering was not used due to the larger amount of data that was already making the tool slow. This tool would have added additional computational delay with minimal added utility.

Needle Electrogram Plot

The needle electrogram displays all 10 electrodes for the given selected needle and updates from both the electrode and run selection. Since a global scale was applied while plotting the electrograms, there are some overlapping electrogram peaks and morphological wave data may be lost. However, this view still provided adequate visualization for interactively investing the electrograms.

This view, however, is lacking or has different attributes that were originally detailed in the final design from section 7.3. Instead of having background coloring, the electrograms are color coded. This allowed for less overall visual clutter within both the needle electrogram plot and the tool in general. Also, the single view for an electrogram is not available within the view. This aspect was left out because this tool is mainly important for investigating the spatial domain of ischemia and guiding a user toward further investigation in other programs like MatLab or SCIRun.

Diverging Scatter Bin Plot

The diverging scatter bin plot was relatively easy to implement. In the view, the red and blue colors indicate positive or negative ST40 values. Though the run number is not shown along the x-axis, the run number continually updates while dragging the bar. Unfortunately, this view occasionally bumps into the needle electrogram based on the container dimensions specified within the index.html.

As different than the final design as invisioned, a run selection bar was used instead of a brush, so only a single selection can be made. This not only gave uniformity to the selection bars, but negated the issue of loading multiple runs for the needle electrogram data. Though the run selection is slow, once the mouse is released, the run updates all relevant views.

Electrode Depth Histogram

The electrode depth histogram correctly shows all the electrodes, which are binned by depth, that exceed the threshold for the selected run. Upon changing the threshold within the ST40 plot, the electrogram plot upgrades appropriately. As specified in the final design, the bins are color encoded. Each depth corresponds to a different color and this color encoding matches the needle electrogram plot.

9 Evaluation

9.1 Milestone #1

Since we are still in the process of implementing our visualization, we haven't really been able to use it to address our questions yet. Once our visualization is fully functional and interactive, we will be able to use it to answer our research questions.

Our visualization does not work fully yet; we are loading the correct data into most of the views, but they are not yet interactive. For two of the views, we still need to display the data that is being loaded. This will be the first thing to work on in order to improve our visualization.

9.2 Final Submission

This final submission accomplished the goals set out in the initial project proposal. While not all of the additional features were implemented, the necessary features were sufficient to act as a useful tool for analyzing this dataset. The coordinate and linked views allow for the global context of the experiment to be realized while simultaneously sampling local phenomena. While global data is processed in the ST40 chart, the histogram, and the scatter bin plot the two additional views capture local data that changes over time. The BEP allows for the user to see the influence of ischemic regions on adjacent regions in the heart.

10 Peer Review

10.1 Classmate Peer Review

In general, the classmate peer review was positive stating that the creating a tool for ischemia exploration within a heart is both interesting and unique. However, there were a few concerns related to the functionality of the tool due to the amount of data and interactivity required:

- The electrogram plots may take a large amount of time to load so a loading bar might be useful.

- Many views going on that require in depth knowledge.

- Make sure to keep the colors consistent and not too overwhelming.

Additionally, there were several suggestions for design features that could be included:

- Overlaying electrograms for comparing electrograms on different needles.

- Delayed transition from 2D bullseye view to a 3D visualization view so the user can track the motion.

- Given a run, show whether ST40 potential is showing it to be ischemic and compare to a prediction based on the wave morphology of the electrogram.

10.2 Project Milestone 1 Review

The feedback from TA Alex Bigelow was positive in the fact that most our data had been wrangling and some views had already been initialized. Alex also made suggestions for data wrangling in terms of handling object arrays, for creating a threshold bar that only executes once you finish dragging, and ways to load in the different electrodes within the bullseye view. Since we have several views, he emphasized that our design justification would be crucial in the final project submission.

11 Project Schedule

Our plan is to delegate each of the five different views to different team members in the beginning, and then to stitch the code together in one major file once everything is functioning on a low level. After that, we will work collaboratively to add interactivity to each of the views, as well as to make a website showcasing our work and our 2 minute demo. Throughout the course of the project, we will regularly update our process book with the progress and findings we have been making, and during the last week we can refine and finalize it.

Date	Tasks	Person
Week 10	Peer Review of Project	Everyone
	Finish data processing	Wilson
	Read data into correct HTML format	Karli
	Get basic HTML structure of file set up	Dasha
Week 11-12	Create preliminary bullseye chart and needle electrogram	Wilson
	Create preliminary diverging scatter bin plot	Karli
	Create preliminary histogram and ST40 plot	Dasha
	Update process book	Everyone
	Submit project milestone (November 13th)	Everyone
Week 13	Merge code into once central file	Everyone
	Get interactivity working in respective views	Everyone
	Update process book	Everyone
Week 14	Project feedback with staff (Nov 23rd-25th)	Everyone
	Create website to showcase project	Everyone
	Create 2 minute screen cast/demo	Everyone
	Update process book	Everyone
Week 15	Wrap up any remaining loose ends	Everyone
	Refine and finalize process book	Everyone
	Submit final project (Dec 4th)	Everyone