ECG Simulation

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1 Purpose and Background

1.1 Purpose

In this lab, we will make use of the simulation program ECGSIM, which carries out simulations of body-surface ECGs from cardiac bioelectric sources. The user (you) can alter these sources by changing features of the action potentials in regions of the heart and then immediately generating a new set of heart and body surface data.

The goal of using a program like ECGSim is to understand relationships between characteristics of the heart tissue and the resulting measurable features of the electrograms and electrocardiograms. You have seen some examples of these relationships in the experimental lab exercise, especially the frog lab and the ECG Lab; you have also seen the limitations and challenges in these experiments, some of which a simulation can easily overcome.

1.2 Background

The best source of background for the ECGSim program are the papers written by the authors of the program:

1. ECGSim; An Interactive Tool for Studying the Genesis of QRST Waveforms by van Oosterom and Oostendorp.

2. Genesis of the T wave as based on an Equivalent Surface Source Model, by van Oosterom.

From the perspective of the class and how we have discussed the ECG, this program represents a complete simulation of the spread of activation through a human heart and the resulting electric potentials on the inner and outer surfaces of the heart and the outer surface of the body. It contains a time varying source model, a realistic volume conductor model, and approximations of the biophysics that links the sources to the surface potentials. The program has predetermined locations of the sources, shape of the heart, and heart within the torso volume conductor–these facets of the simulation are all fixed. What the user can alter are the parameters of the action potentials of each region of the heart. The model starts with a default sequence of activation, *i.e.,* the order in which the action potentials fire. The user can adjust for any region of the heart the timing and the duration of the action potential as well as its resting potential (and hence amplitude). In this way, most features of the source of the ECG are freely adjustable. As soon as each adjustment is complete (and in some cases while the adjustment is in progress), the program computes the resulting potentials throughout the heart and thorax.

Another notable feature of the program is the ability to view the output in many different forms, *e.g.,* activation time, repolarization time, action-potential duration, transmembrane potential, and extracellular surface potential, distributed over the surfaces of the model and as functions of time. It is also possible to compare the time signals resulting from a modified version of the simulation settings against the default settings.

An essential conceptual aspect of ECGSim is that it is running a simulation based on an underlying discrete model of the heart. Adjustments made to the model parameters act over a region of the heart, *i.e.,* not for each cell individually. It is possible to alter the region of influence of changes in the parameters but within limits; the lower limit is the size of the underlying triangular elements that make up the discrete heart model. The Heart Display menu allows for visualization of the model nodes and/or triangles, which is useful to appreciate the resolution of the underlying simulations.

2   Lab Procedure

2.1   Before the lab!!

Try to download the ECGSim program from **www.ecgsim.org**. Their newest release
(**Version 2.2.1**) seems to work fine, but report any problems to us quickly. We can discuss any problems you have during the lab time so that you have a functioning version by the time you leave the lab (at the latest).

2.2   Lab Day

1. Meet in the HSEB 3100B, a computer laboratory in the Health Sciences Education Building classroom at 12:00 on Friday. You can bring your own laptop or use a desktop (Windows) computer in the lab.

2. Download from **www.ecgsim.org**, unpack, and launch the program.

3. Follow instructions below to learn about ECGSim and use it to answer some specific questions.

2.3 Capturing images

For the report on this lab, use a screen capture utility to grab images. On Mac/OSX systems, this is as simple as Command+Shift+4, then selecting an area or interest. By default, this will save the region in PNG format to the desktop. Command+Shift+4 then space allows you to select the entire window and save it to the desktop. A more complete guide to taking screen shots and saving them as different file types can be found on **MacRumors:Guides**

Windows has a screen capture utility as well. The screen shot is copied to the clipboard and can be pasted into paint and saved in a variety of image formats. Use ctrl + PrintScreen to capture the entire screen, or alt + PrintScreen to capture just the active window.

For each of the images you capture and save to your labs report, include a caption describing the contents and which feature of the image is of special interest.
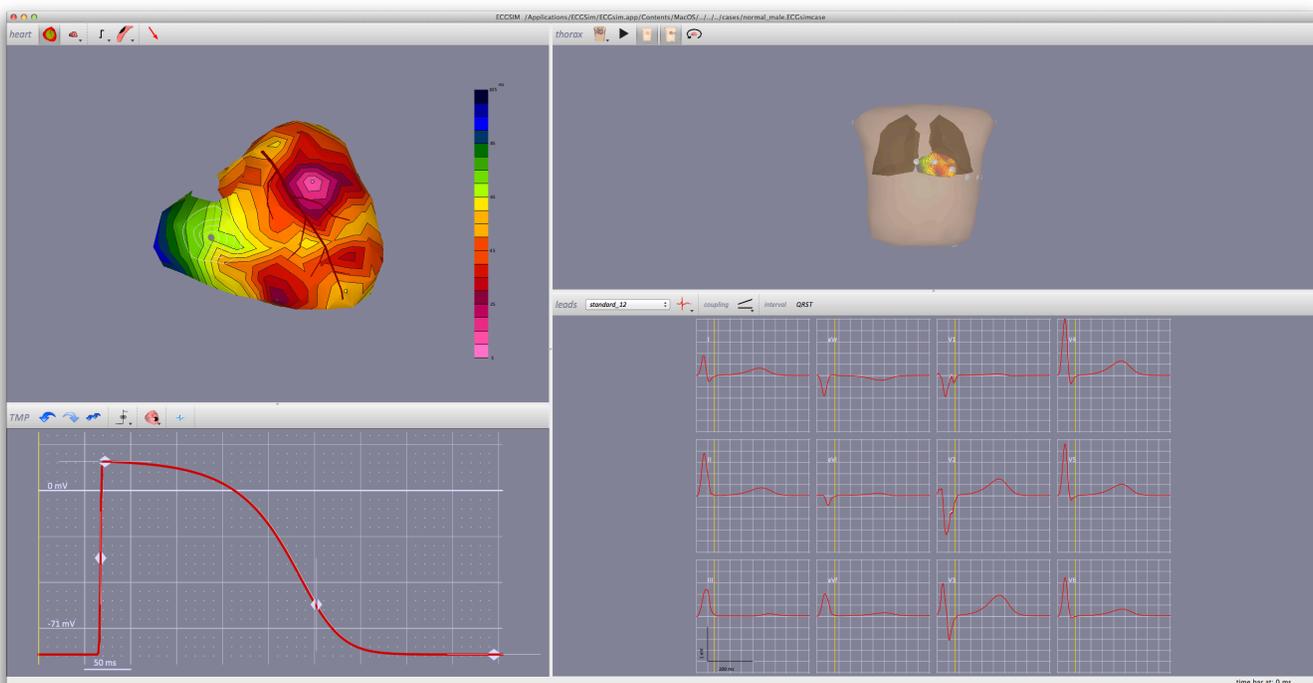
2.4 Learning to use ECGSim

Figure 1: Overview of ECGSim window layout. Each window has settings and interactions available to the use to set parameters and display results in a range of formats—see text for details.

ECGSIM allows you to see the electrical activation of the heart in a number of different forms, as a sequence of color maps of membrane potential, heart potential, and body surface potential and then summarized as a map of activation time or repolarization time. It also allows you to see the dipole vector as a function of time. The program allows the user to adjust features such as cell resting potential or action potential duration and amplitude from a selected region on the inner or outer surfaces of the heart. Figure 1 shows the standard layout of the display windows. The icons at the top of each window are shortcuts to specific functions while pull down menus along the top of the main computer window provide pathways to special menus and windows for adjusting simulation and display parameters.

Specific things to try in the lab include the following:

Adjust initial display and configuration settings

1. Under the *Thorax* menu, select the "Lock to heart" button.

2. Move the arrow over the borders between windows in the display and enlarge the heart and torso windows (upper row) by reducing the windows in the lower row. We will not immediately use the lower left panel and the lower right will serve just for indicating the point in time of the potential maps in the upper panels.

3. Many of the buttons located in the toolbar for each window have another link in the menu bar. To get a thorough description of the functionality of each button, there is a user manual under the *Help* menu.

4. Under the *Heart:Left Mouse* menu, select "Center"

5. Under the *ECGSim:Preferences* menu, uncheck "APD constant while shifting depolarization time" at the bottom of the window.

View heart potentials

1. Under the *Heart:Function* menu, select the "Potential field" option or click on the *Surface Function* button above the heart display (third button from the left).

2. Use the arrow keys to move forward and backward in time and observe the way the potential distribution changes over the surface.

3. Rotate the surface around and observe it from different aspects to help localize activity on the heart. Make sure to look inside the heart chambers as well as on the outer surface.

View activation time map

1. Under the *Heart:Function* menu, select the "Depolarization" option (again, the *Surface Function* button in the heart window can be utilized as well).

2. Rotate the surface around and observe it from different aspects to help localize activity on the heart.

3. You should be able to reconcile this single map, which shows the time at which the cells in that are become stimulated, with the sequence of events you saw in the display of surface potentials. Go back and forth between the two displays (potentials and depolarization/activation time) to make sure the link is clear.

View transmembrane potentials

1. Under the *Heart:Function* menu, select the "Transmembrane potential" option (again, the *Surface Function* button in the heart window can be utilized as well).

2. Use the arrow keys to move forward and backward in time and observe the way the potential distribution changes over the surface.

3. This sequence should again reinforce what the depolarization time map you looked at above suggested and how membrane potential is related to heart surface potential maps. Compare the transmembrane voltage with the extracellular surface voltage and make sure the relationship between the two makes sense to you.

View dipole vector loops

1. Under the *Heart:Show* menu, select the "Show Vector" option or click on the red arrow in the heart window.

2. Once again, use the arrow keys to move forward and backwards in time, rotate the image around, and observe the vector loop and the way the dipole vector follows this loop. Also examine how the loop changes depending on what location on the surface you choose.

3. Select three standard views of the thorax and for each, use the *Edit:Copy* command to save the view to the copy buffer of the computer. This is for practice only—you do not need to include these in the report. You can also use the import program to capture the content of the screen to a file. Note: if this approach does not work for saving the images from ECGSim, then use the "import" program or some other means to capture images from screen.

4. Deselect the vector dipole view before proceeding to the next section.

View Frank ECG

1. Next to the "leads" label on the control bar between the body surface potential window and the ECG time signal window, select "VCG_(Frank)" and observe the vector loops.

2. Compare these loops to those you generated for the ECG Lab. Describe how they agree, at least in qualitative terms.

Body surface potentials

1. Under the *Heart:Function* menu, again select the "Potential Field" option.

2. Under the *Thorax:Function* menu, select the "Adapted BSM" option (The furthest left button in the thorax window, then the option with the red contour lines).

3. Use the arrow keys to move forward and backward in time and observe the way the potential distribution changes over the surface.

4. Rotate the surface around and observe it from different aspects to help localize activity on the torso.

5. Looking at both the heart and torso surfaces, try and identify features that transfer between the two. Try and draw some general conclusions about how information from the heart transfers to the body surface. Does everything visible on the heart surface have a clear correlate on the body surface? Does each local feature of the heart surface project clearly to the body surface? Can you always look at the body surface map and predict what the associated heart map looks like?

2.5 Lab Exercises

2.5.1 Activation and repolarization maps

Be sure you understand the concept of activation time; it is the time at which the cells in a specific location undergo depolarization, *i.e.,* the rapid transition from the resting state to the excited stated. ECGSim allows you to display the activation (or depolarization) time for the heart beat in a single image on the heart surface. For the default heart beat in the simulation, switch back and forth between displaying the single activation time map and the sequence of heart-surface potential maps.

By selecting a point on the epicardial surface, you can also see the associated action potential and electrogram shape (by pushing the button with the light blue signal icon) for the associated

region. Try this for several locations and observe the relationship between action potential and electrogram.

Question: From your observations, how is it possible to tell from the morphology of heart potentials (electrograms) when a region has become activated, *i.e.,* is there a feature of the time signal that can indicate whether and when activation occurs?

Recovery is a term used when referring to extracellular potentials and is the complement of activation. It is the time at which a region experiences return to the resting (polarized) state and corresponds to the time at which the nearby cells undergo repolarization. Using the same heart beat as above, switch back and forth between potentials and repolarization time displays (there is a button for this above the display window that shows and down-sloping smooth step function) and observe the relationship. Also, in the lower left window compare the shapes of the action potential and the electrogram from the same location and look for a correlation.

Next, find a location on the heart surface where there are some notable potentials during the T wave and then control-click on that region in the heart display window; the action potential from that location will appear in the lower left-hand window; turn on the display of electrograms in that window (click on blue time-signal button in upper left of action potential window) and then compare repolarization time with the electrogram signal.

Question: From your observations, is there a feature in the morphology of the electrogram that could indicate when repolarization occurs, *i.e.,* if you had to predict repolarization from the electrogram only, what feature of the electrogram signal would be a reasonable surrogate for when the action potential ends.

Question: Can you describe an algorithm for detecting activation and recovery times from the electrogram signals? (This question is the practical application of the two previous questions).

2.5.2 AP duration and Activation recovery interval

Another important metric of the heart tissue electrical activity is the duration of the action potentials and there is a parameter available in the electrogram signal called the "activation-recovery interval", ARI, that is considered a reflection or surrogate of AP duration. To show action potential duration (APD) values, go to *Heart:Function* then select ARI. Again, this option is available via the toolbar in the heart window.

Question: Look at the pattern of APDs and describe (together with a figure or two) how this parameter varies over the heart surface, both epicardial and endocardial. Make sure to include in the lab manual the figure and some text to describe and interpret its contents.

Now select, some points on the heart surface and observe the local action potentials. Note that the APD is included directly in the action potential plot, and that this duration is manually adjustable. Based on sampling 5–10 points, confirm that the AP duration from the action potential display matches the APD values in the heart surface plot above it.

2.5.3 Altering tissue characteristics

The real power of ECGSim lies in simulating the electrocardiographic response to changes in action potential characteristics. All such changes occur by means of sliders (shown as four sets of two arrows pointing in opposite directions) in the lower left panel of the display. This window is where you can see the local action potential and electrogram shape for the currently selected heart location. The actual duration can be calculated using the provided scale and grid system in the window.

To see this behavior in action, in a few different regions of the heart, try shifting the duration of the action potential and observe the effects on both the electrogram and electrocardiogram shapes.

Question: From your observations about APD or ARI, identify (with a figure and text) one set of ECG (torso surface) signal features that depend on AP duration? Note that it is possible to plot both the default ECG and the one created by your manipulations simultaneously by pressing both the red and blue colored ECG buttons above the standard ECG plot. For the body surface potentials, either the default or the altered potentials (not both) can be displayed so click successively on one and then the other (above the BSPM window) to capture the change in the ECG from altering timing/duration of the action potential. Show and describe the results in a way that illustrates both the local changes you make to the action potentials and the effect of these changes on the body surface ECGs.

3 Lab Report

Introduction: Begin the report with a brief (half to full page) introduction about what the purpose of the lab was and what the program did, *i.e.,* what you think its purpose and capabilities were.

Methods: In the Methods section, describe briefly, in a paragraph for each of the 3 exercises, what you did to use the program to produce the figures in the results section—include any relevant settings but do not go into the details of things like how you acquired the images. Always keep in mind, the directions should allow us or someone with the background of your classmates and the lab description to replicate the experiments you performed.

Results: In the Results section, for each exercise, address the **questions** in the description above. Make sure to use both images and text to describe all your results. The emphasis is on qualitative descriptions but see if you can find ways to quantify the results where possible.

Discussion: Compare and contrast the experience in the experimental labs and this simulation lab. Generally, what are the advantages of simulation over experiments? What can one learn from experiments that is not possible with simulation? Use your specific experiences to support more general observations about experimental and simulation approaches to scientific discovery.