Hardware Model of Cardiac Cell

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SIMULATION ENHANCES BIOLOGY

Our project is a collaborative effort between Cornell's Electrical Engineering and Neurobiology Departments to create a novel teaching tool for cross-listed courses. The ultimate goal is to give students a model cardiac cell to tinker with and learn from.

Our end product is designed such that students will be able to easily manipulate the ion concentrations/conductances surrounding the cell and see the ultimate influence on the voltage/currents of the cell.

This project will be of incredible use for any ECE/Neurobiology cross-listed courses and can also be utilized as a teaching tool for when Cornell's Neurobiology Department travels internationally.

WHY THE HEART?

For students in biology classes, one of the most valuable experiences is hands-on work with biologic systems. The heart provides the perfect teaching environment to learn about neurophysiology.

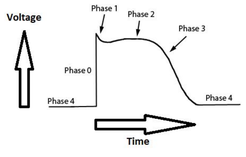
With our project, students will be able to see the effect neurological changes have on arrhythmia, heart attack, stress, and so much more. They will be able to induce and fix these conditions by changing the cell's ion concentrations through our on-board sliders and touchscreen.

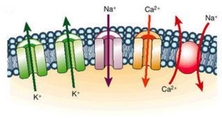
Normal Heartbeat

Irregular Heartbeat

NEURONS & THE HEART

The action potential of a cardiac cell occurs in five main steps



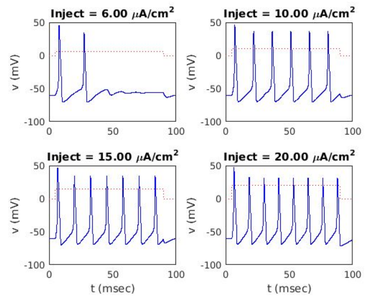


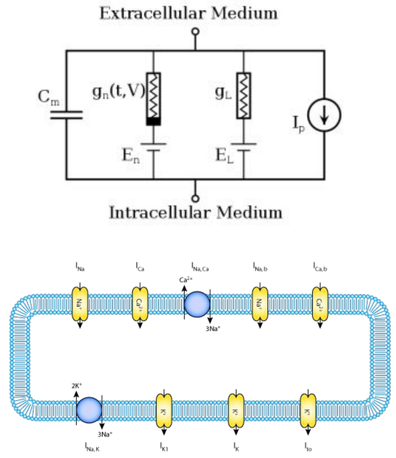
PHASE	NAME	REASON
0	Rapid Depolarization	Influx of Na^+ ions
1	Initial Repolarization	Closure of Na^+ channels
2	The Plateau	Influx of Ca^+ ions
3	Rapid Repolarization	Efflux of K^+ ions
4	Refractory Period	Resting Potential

COMPUTATIONAL HEART MODELS

Hodgkin - Huxley Neurons

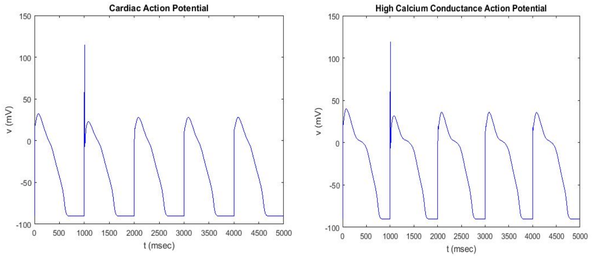
- Model describes how ion currents affect propagation of action potentials
- Describes neuron cell as membrane resistance and capacitance
- Ion channels modeled as voltage-dependent variable resistors



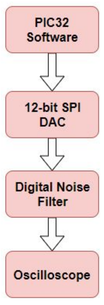


Reduced Priebe Beuckelmann Model

- Original Model describes human ventricle cell with seventeen variables
- Reduced six variable model shows essential voltage and current behavior
- Simplified model highlights behavior and is computationally effective

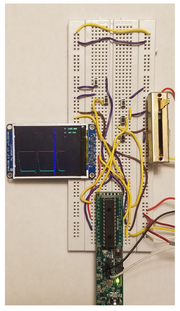


MODEL IMPLEMENTATION ON CHEAP MICROCONTROLLER

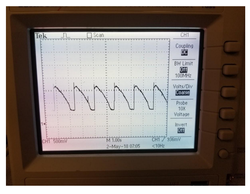


Hardware

- ★ **PIC32:** Microcontroller for data processing
- ★ **SPI DAC:** DAC outputs membrane voltages to oscilloscope
- ★ **RC Filter:** Filters out digital noise from DAC
- ★ **Oscilloscope:** Displays voltages for user viewing

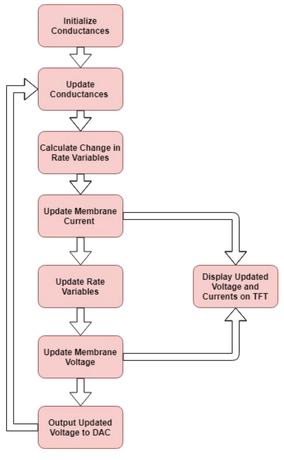


Software



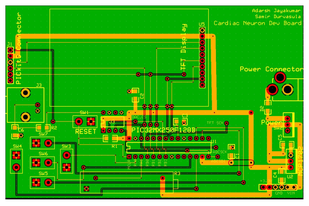
- ➔ Software uses exponential Euler's method to update K, Na, Ca ion conductances.
- ➔ Change in rate variables calculated based on the current voltage.
- ➔ Total membrane current is calculated based on individual ion currents
- ➔ Membrane voltage and rate variables are calculated based on ion currents
- ➔ Updated voltage sent to the TFT and oscilloscope for user
- ➔ Loop leads to infinite pattern of spikes resembling Reduced Priebe Beuckelmann neurons.

This behavior can be seen on the screenshots to the left



BIOLOGICALLY RELEVANT USER INTERFACE

Hardware



- ★ **Slider:** A sliding potentiometer is used to control ion channel concentration and conductance
- ★ **TFT:** An Adafruit TFT LCD screen is used to display user input and voltage/current traces
- ★ **Buttons:** Four directional arrows and one 'enter' button are used to navigate the TFT screen

The PCB design of the final dev board can be seen to the left

Software

- ➔ User inputs values for K, Na, Ca ion channel concentration/conductances
- ➔ User chooses which ion channel current to display
- ➔ Model outputs voltage and chosen current over time on TFT screen
- ➔ Cursor is used to measure voltage, current, and time values of traces
- ➔ Digital voltage is sent through DAC and RC filter to be outputted on the oscilloscope.

A sample screenshot of the TFT output is below