BI-LAYERED GAUSSIAN PROCESS EMULATION OF A RAT HEART MULTI-SCALE CONTRACTION MODEL

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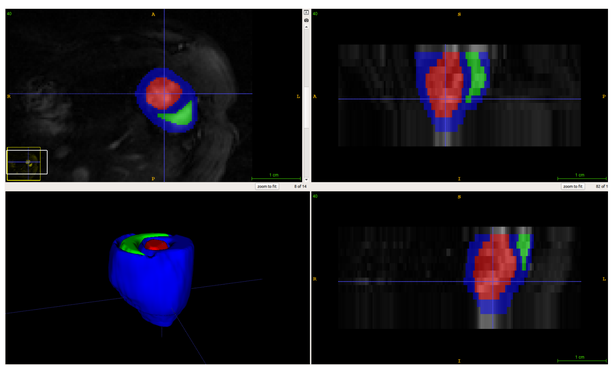
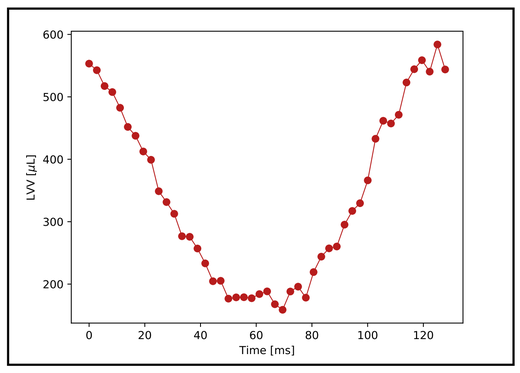
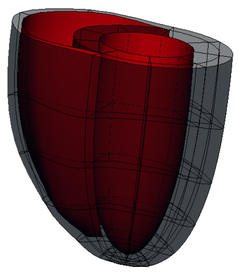
INTRODUCTION

We developed a mathematical model of a healthy rat bi-ventricular heart, starting from MRI data.







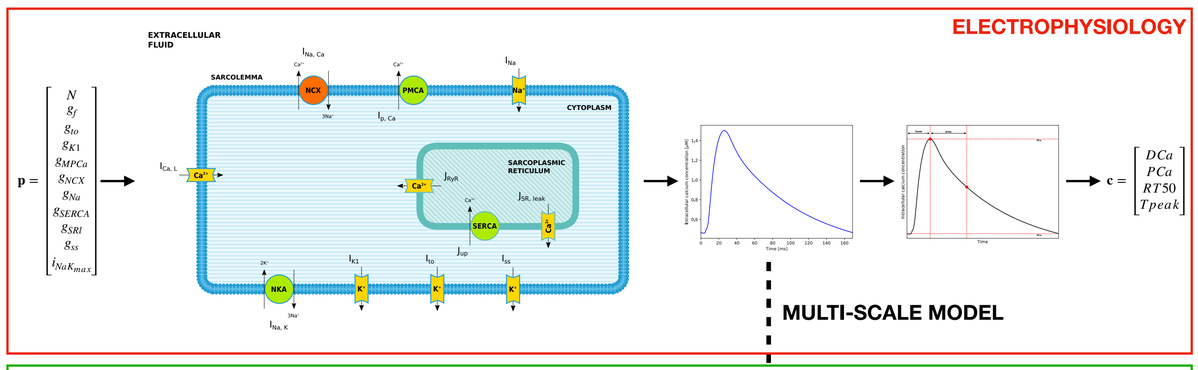
Finite elements cubic Hermite mesh

Left ventricular (LV) blood pool is segmented and a volume estimation is performed in order to extract LV volume variation during time. We combine this data with literature measurements to provide constraints during the fitting process.

GOAL

Predicting LV function by means of Gaussian process (GP) emulation of the arising multi-scale rat heart mechanical model.

MULTI-SCALE MODEL



$$\mathbf{p} = \begin{bmatrix} N \\ g_f \\ g_{to} \\ g_{K1} \\ g_{MPCa} \\ g_{NCX} \\ g_{Na} \\ g_{SERCA} \\ g_{SRl} \\ g_{ss} \\ i_{NaK_{max}} \end{bmatrix} \qquad \mathbf{c} = \begin{bmatrix} DCa \\ PCa \\ RT50 \\ Tpeak \end{bmatrix}$$

$$f(\mathbf{q}, t) = (q_1 - q_2)\left[q_3 \frac{1}{t} + e^{\frac{t-q_3}{q_4}}\right]^{-1} + q_2$$

$$\mathbf{m} = \begin{bmatrix} p \\ ap \\ z \\ c_1 \\ ca_{50} \\ k_{xb} \\ k_{TRPN} \\ T_{ref} \end{bmatrix} \qquad \mathbf{d} = \begin{bmatrix} EDV \\ ESV \\ EF \\ IVCT \\ ET \\ IVRT \\ Tdiast \\ PeakP \\ Tpeak \\ maxdP \\ mindP \end{bmatrix}$$

STRATEGY

1st layer (electrophysiology)
$$f_{elec}\colon \mathbb{R}_+^{11} \to \mathbb{R}_+^4, \quad \mathbf{p} \mapsto \mathbf{c}$$

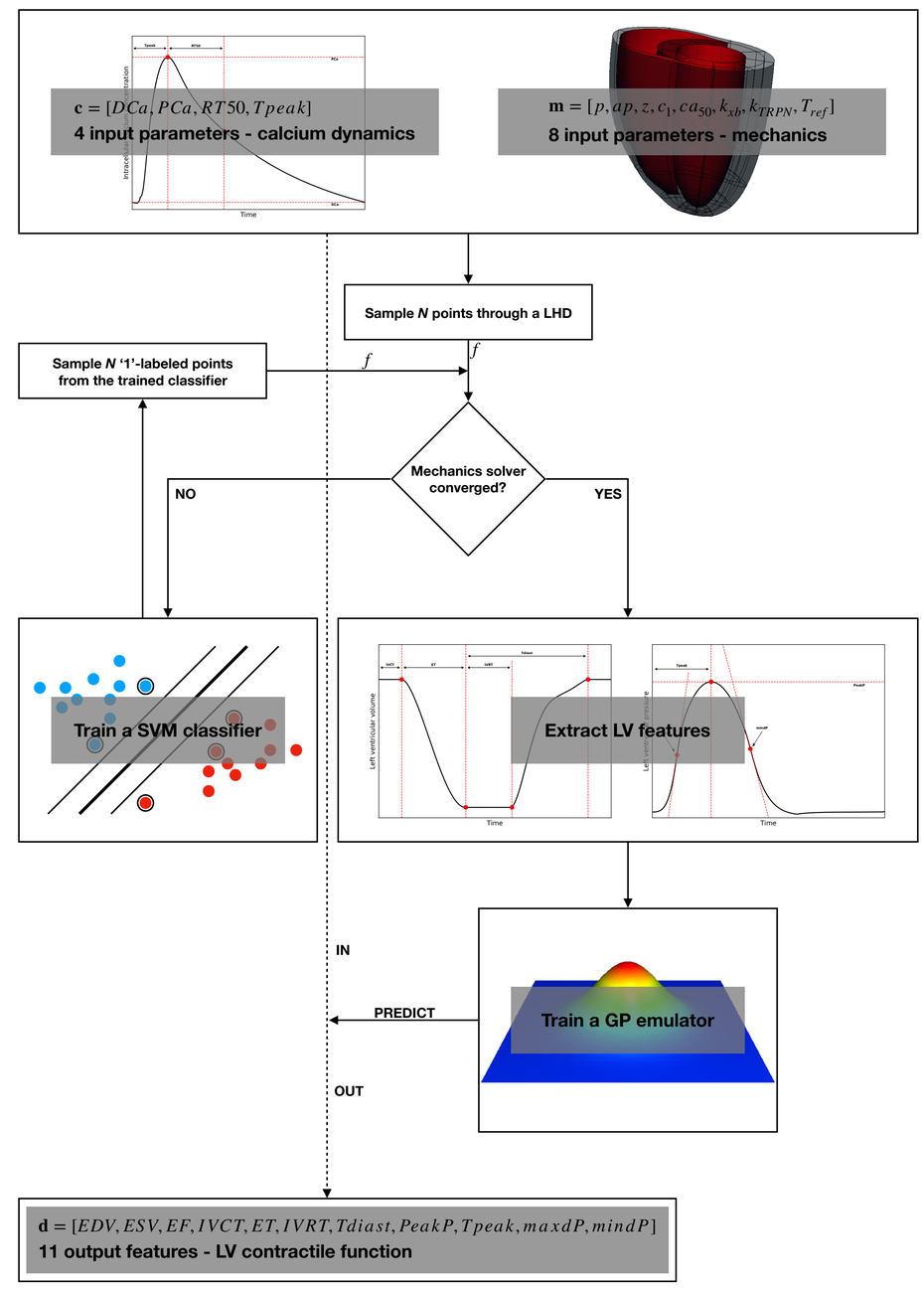
2nd layer (mechanics)
$$f_{mech}\colon \mathbb{R}_+^4 \times \mathbb{R}_+^8 \to \mathbb{R}^{11}, \quad (\mathbf{c}, \mathbf{m}) \mapsto \mathbf{d}$$

Multi-scale model
$$f\colon \mathbb{R}_+^{11} \to \mathbb{R}^{11}, \quad \mathbf{p} \mapsto f(\mathbf{p}) := f_{mech} \circ f_{elec}(\mathbf{p}) = \mathbf{d}$$

We create a multi-layered emulator with two layers, one for each physics system, and we combine them to emulate the full map. For each layer, a GP emulator is built.

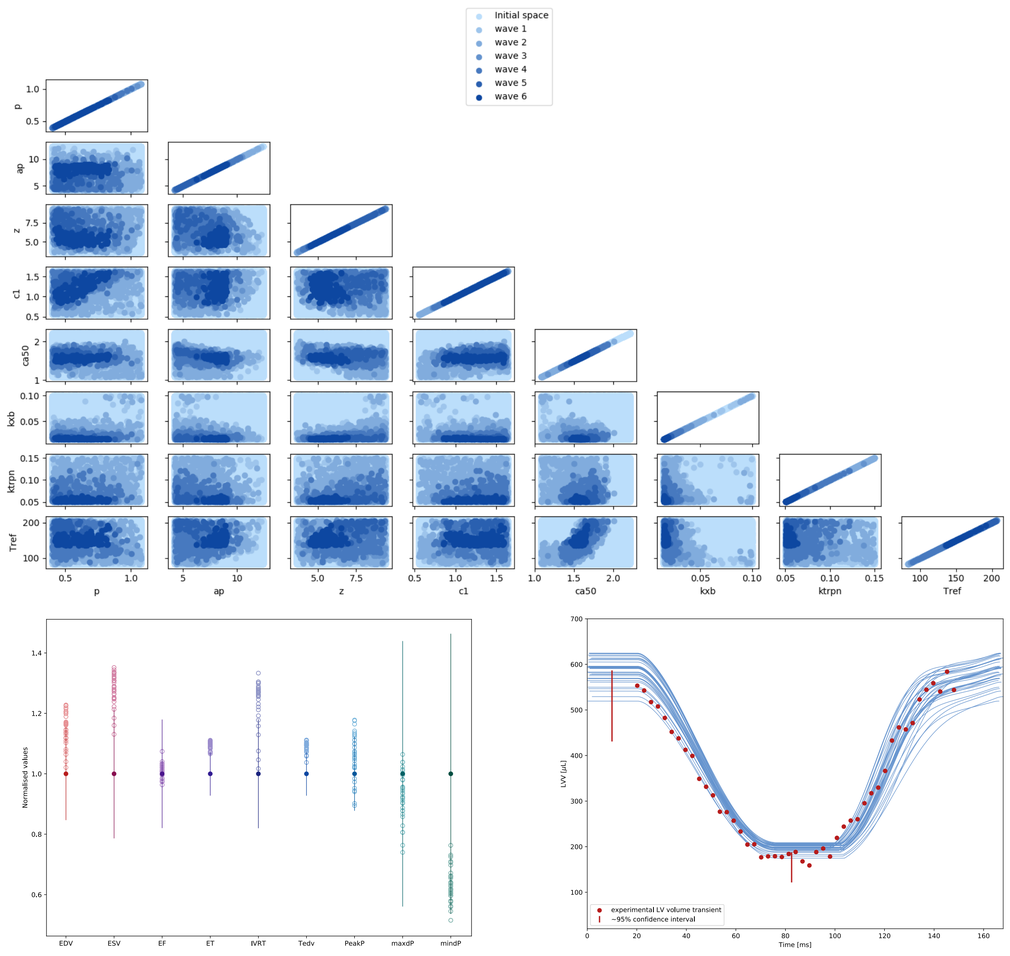
SECOND LAYER EMULATION

Some parameter sets lead to unstable or incomplete simulations. To filter them and ensure we get enough points to further train the GP, we designed a framework based on support vector machine (SVM) binary classifiers.



TOWARD A FULL MAP EMULATION: FITTING THE RAT HEART MECHANICS

We make use of Bayesian history matching (HM) technique to fit the mechanics-related parameters, allowing the simulated LV features to be close to the experimentally observed counterparts, with constraints generated from experimental and literature measurements.



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