MATLAB EXPO

November 13–14, 2024 | Online

A real-time heart-in-the-loop: A novel method for validation of cardiac devices

Weiwei Ai,
University of Auckland

Mark Trew,
University of Auckland

Partha Roop,
University of Auckland

MathWorks®

Additional project contributors

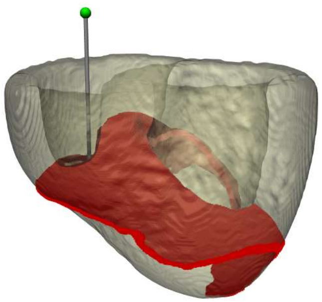
University of Auckland

- Nathan Allen, Avinash Malik, Nitish Patel, Vinod Suresh, Eugene Yip, Sidhartha Andalam

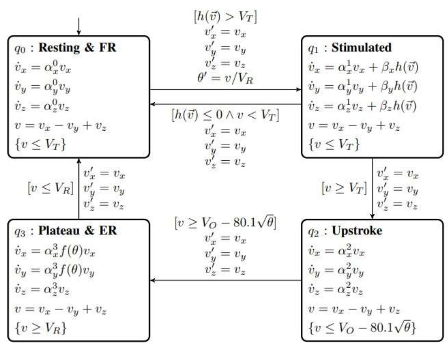
MathWorks

- Akhilesh Mishra

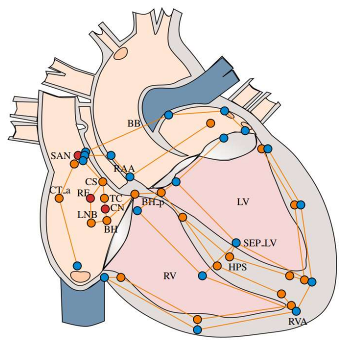
This project aimed to design and implement a heart model in Simulink that interacts in real-time with devices



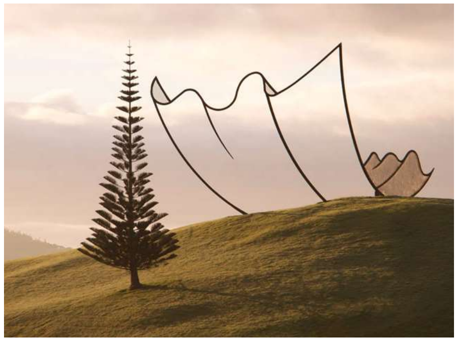
The problem and features



An automata framework



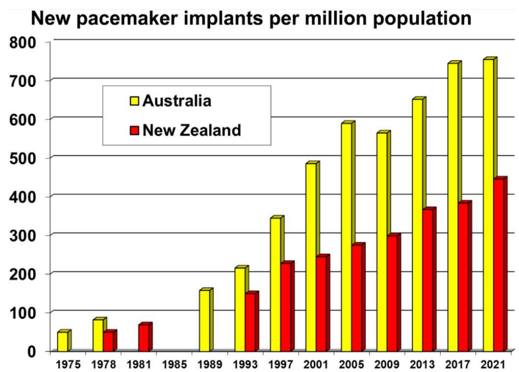
A real-time heart model



On the horizon

Can we better interpret device-heart interactions or know that device responses will be safe and optimal?

Mond et al. The Australian and New Zealand cardiac implantable electronic device survey. *Heart Lung Circ*. 32, 261, 2023.



PACE
PACING AND CLINICAL ELECTROPHYSIOLOGY

DEVICE ROUNDS | Full Access

Pacemaker-mediated tachycardia in a dual-lead CRT-D: What is the mechanism?

Christopher Monkhouse BSc, Alex Ca
Jonathan Behar MBBS, BSc, PhD

DEVICE ROUND

Failure of an Implantable Cardioverter Defibrillator to Terminate Ventricular Tachycardia: Why?

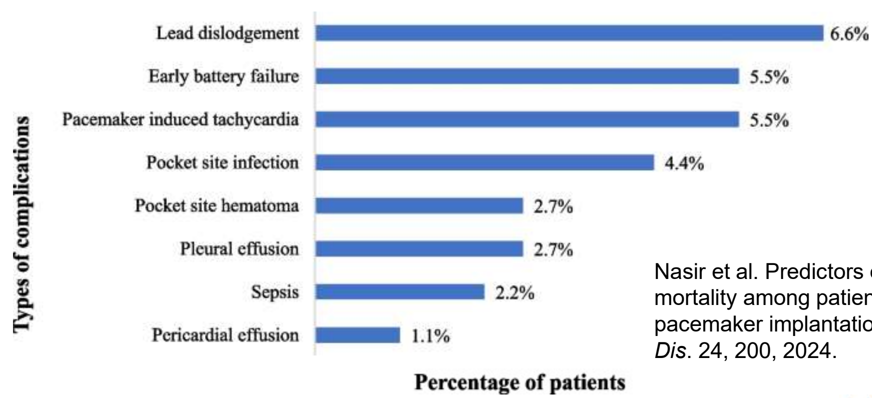
LETIZIA CONTI, M.D., NAM TRAN, M.D., HARAN BURRI, M.D., and MARC ZIMMERMANN, M.D.
From the Cardiovascular Department, Hôpital de la Tour, Meyrin-Geneva, Switzerland

PACEMAKER/ICD PROBLEMS OF THE MONTH

Atrial pacing above the sensor rate: What is the cause?

Amin Al-Ahmad, MD, Angela Tsiperfal, RN, Paul J. Wang, MD

From the Arrhythmia Service, Stanford University Medical Center, Stanford, California.



Nasir et al. Predictors of complications and mortality among patients undergoing pacemaker implantation. *BMC Cardiovasc Dis*. 24, 200, 2024.

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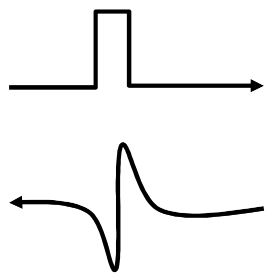
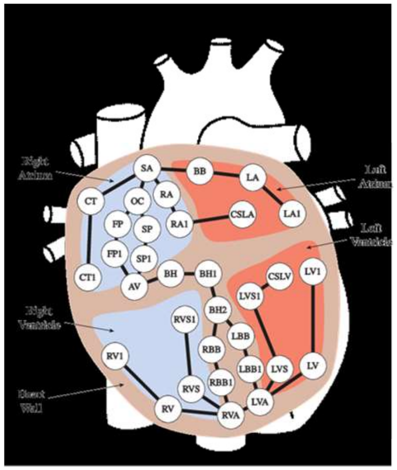
Can we better interpret device-heart interactions or know that device responses will be safe and optimal?

Pacemaker



Heart



Model

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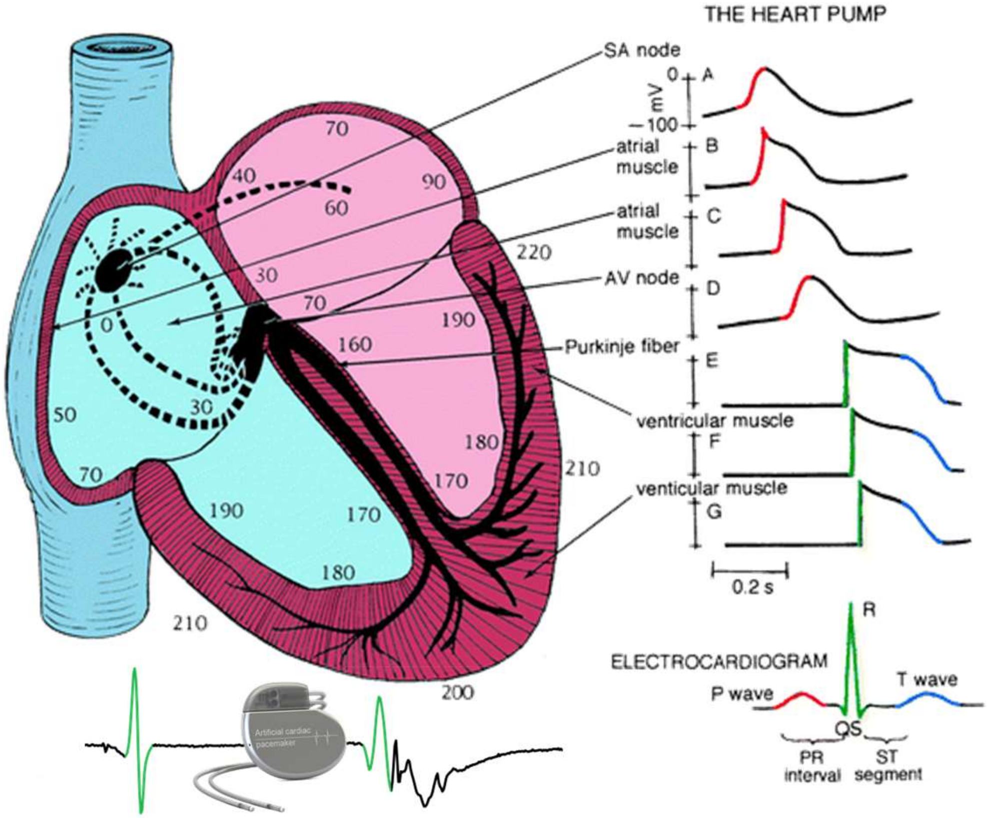
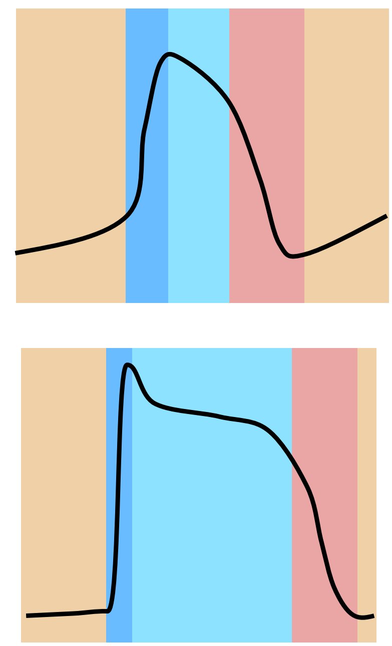
A heart model needs to capture a complete timing sequence and variable signal features

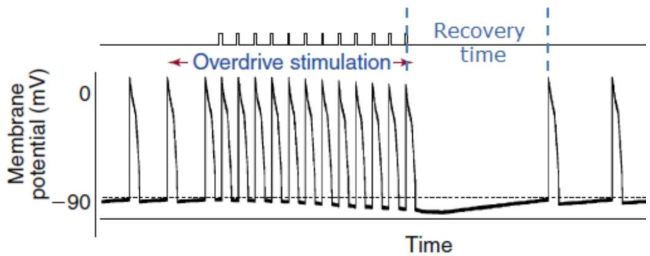


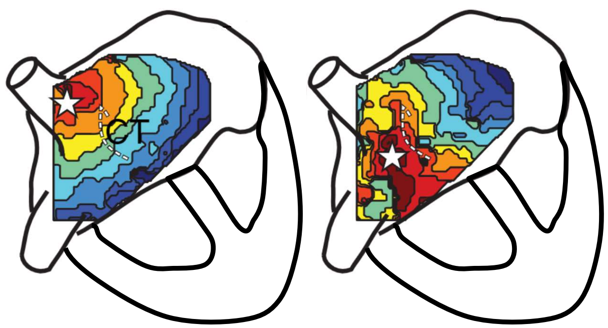
Iaizzo et al. Anatomy and physiology of the cardiac conduction system. Springer. 2010.



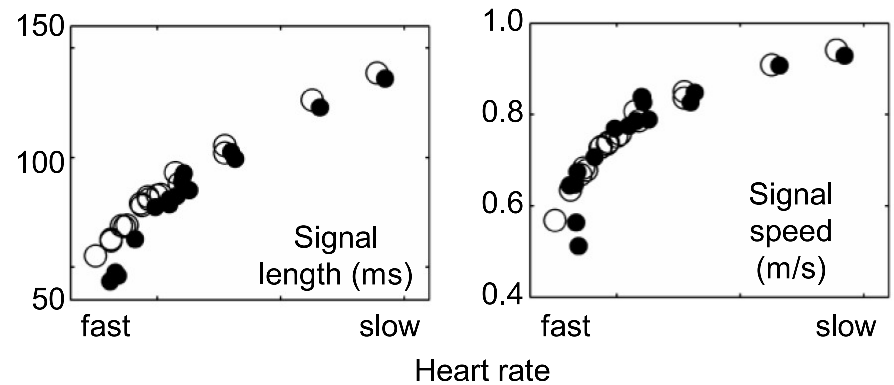
A heart model needs dynamic signals that respond to drive, heart rate and history

Ai et al. A parametric computational model of the action potential of pacemaker cells. *IEEE TBME*. 65, 123, 2017.

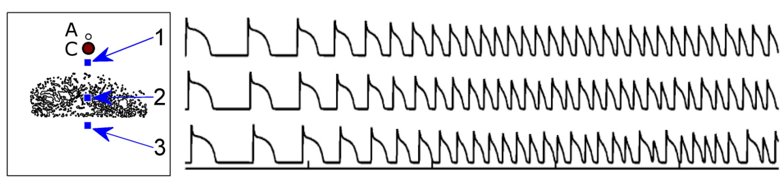


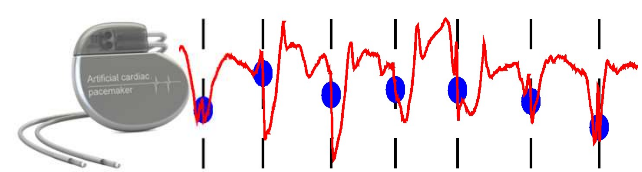


Ashton et al. Shift of leading pacemaker site during reflex vagal stimulation. *J Physiol*. 597, 3297, 2019.



Engelman et al. Structural heterogeneity alone is a sufficient substrate for dynamic instability. *Circ Arrhy Electrophys*. 3, 195, 2010.





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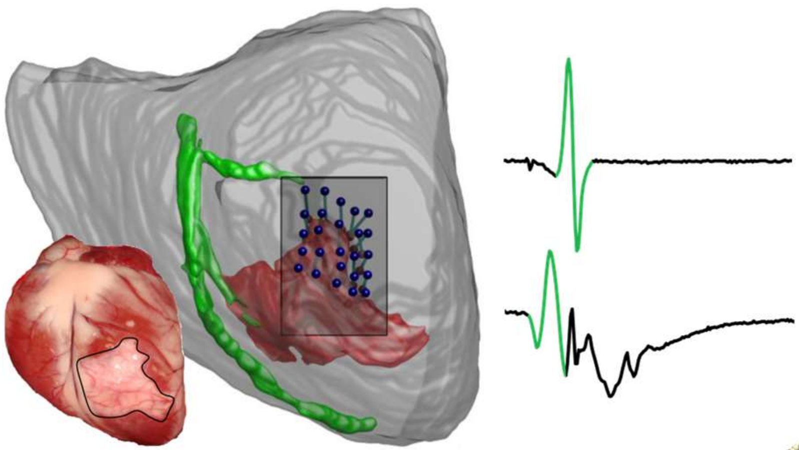
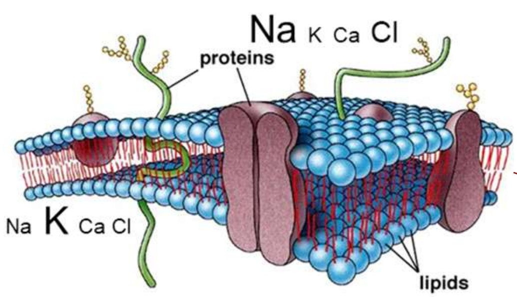
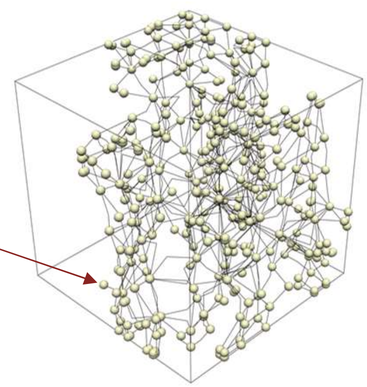
A heart model needs to enable multiple disease states, function in real-time and interact in closed-loop

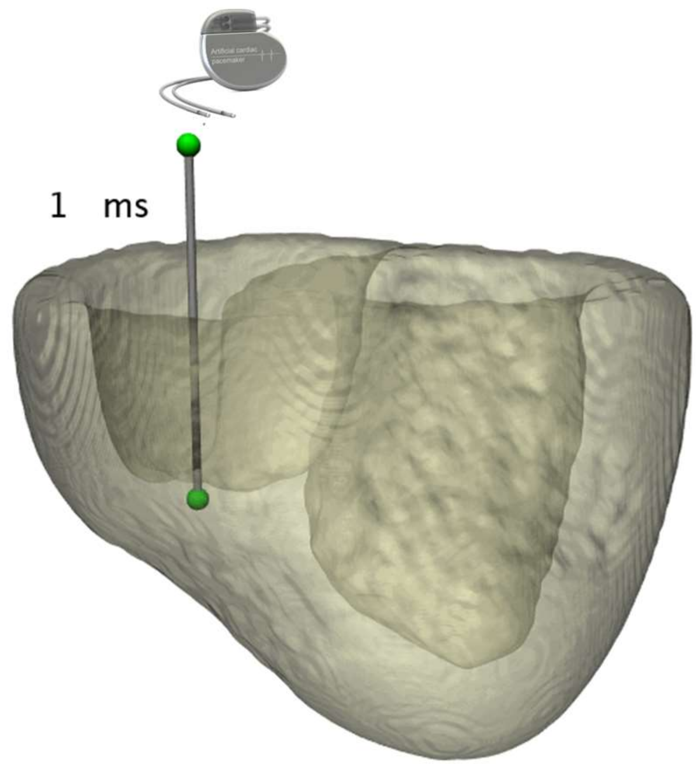
Trew et al. Cardiac intramural electrical mapping…in the peri-infarct region. *AJP Heart Circ Phys*. 317, H743, 2019.



Rutherford et al. High-resolution 3D reconstruction of the infarct border zone. *Circ Res*. 111, 301, 2012.

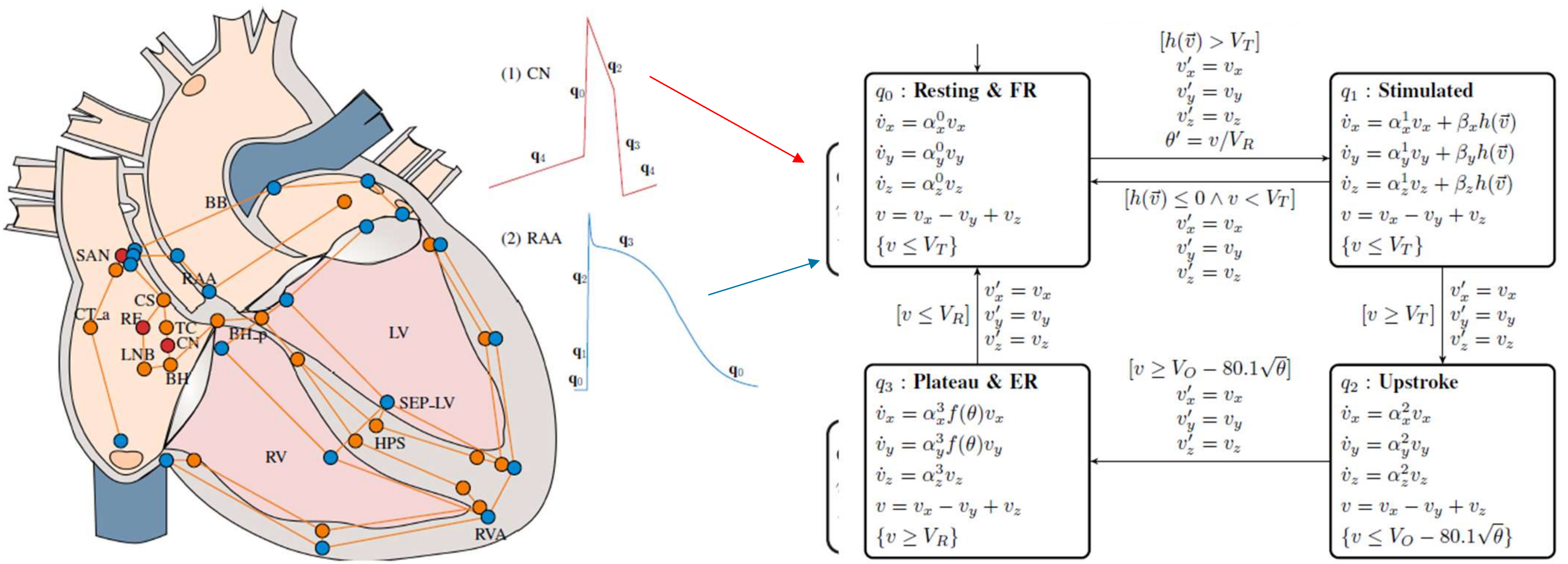




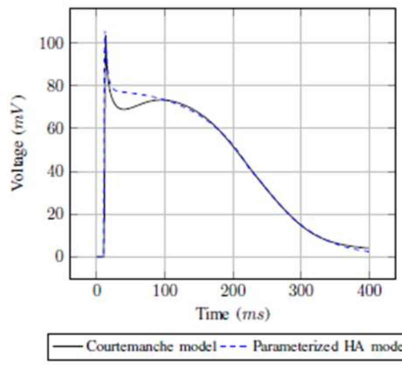


Hussan et al. A clustering method for calculating membrane currents. *Cardiovasc Eng Tech*. 3, 3, 2012.

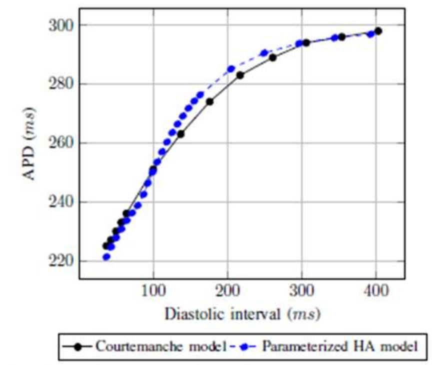
Hybrid Input/Output Automaton (HIOA) model hybrid systems as a combination of discrete and continuous behavior



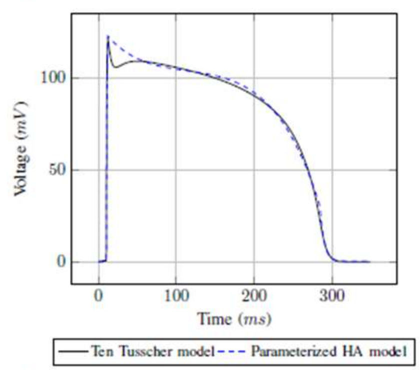
An HIOA model can be parameterized to capture regional electrical heterogeneity and dynamics



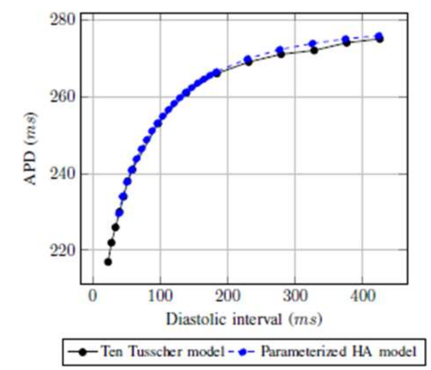
(a) The action potentials produced by the Courtemanche model and the parameterized HA model.



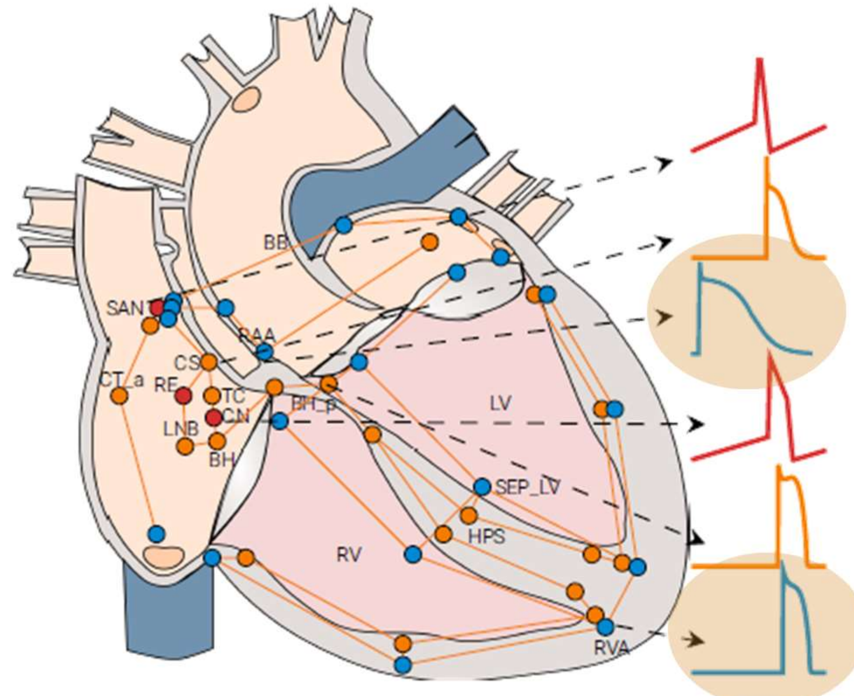
(b) The restitution curves of the Courtemanche model and the parameterized HA model.



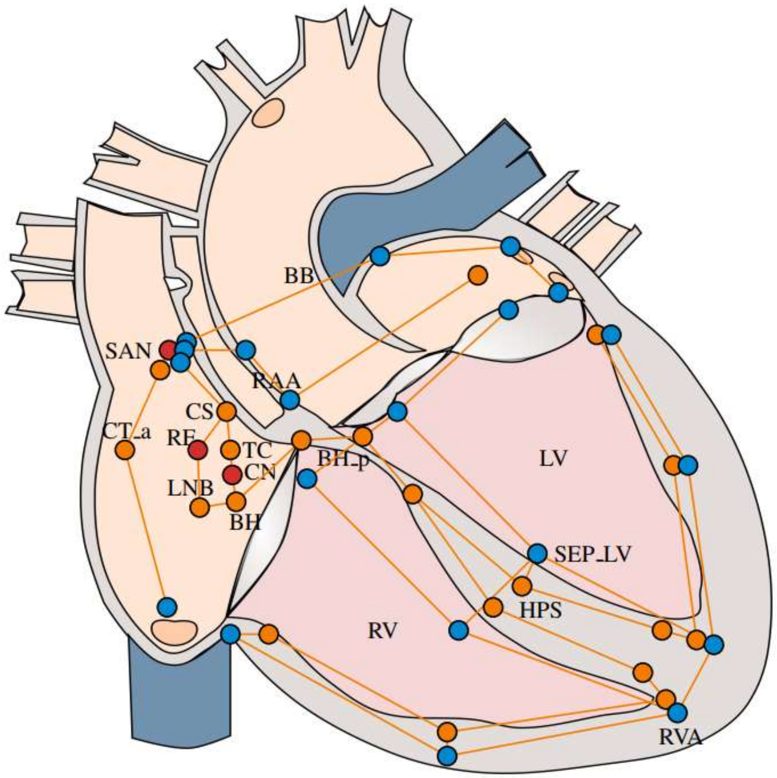
(c) The action potentials produced by the Ten Tusscher model and the parameterized HA model.

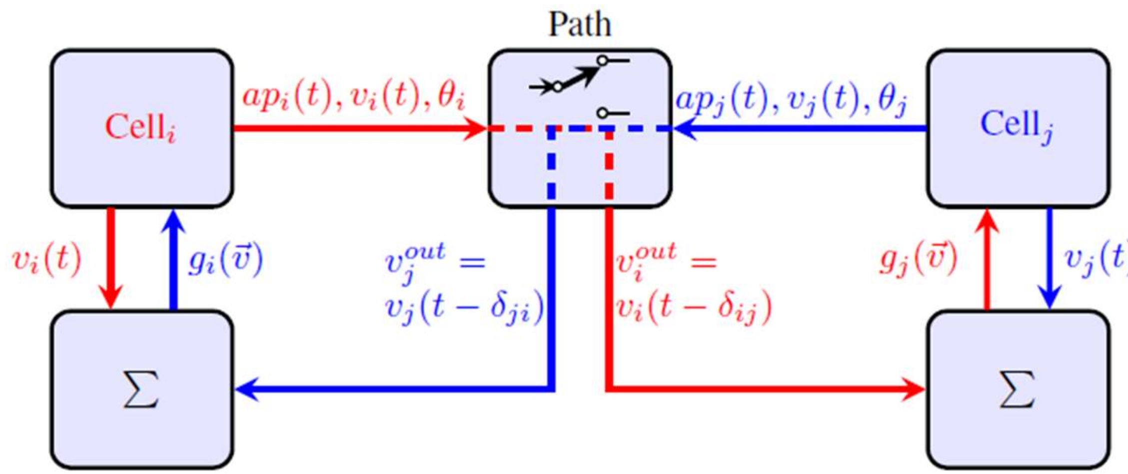


(d) The restitution curves of the Ten Tusscher model and the parameterized HA model.

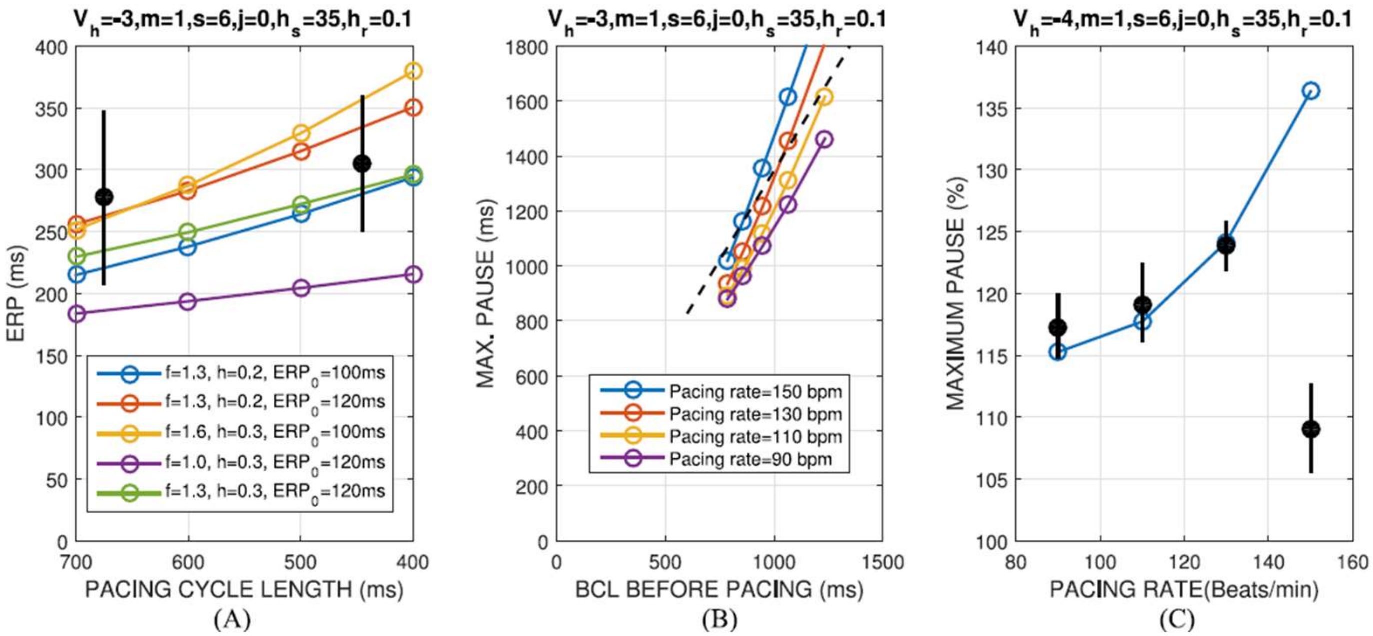


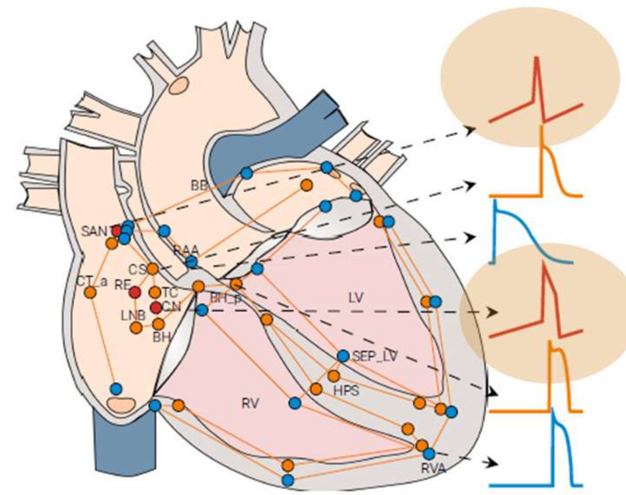
HIOA favours compositional design by supporting communication and concurrency between components





Our novel parametric HIOA model captures rate-dependent dynamics of important pacemaker cells





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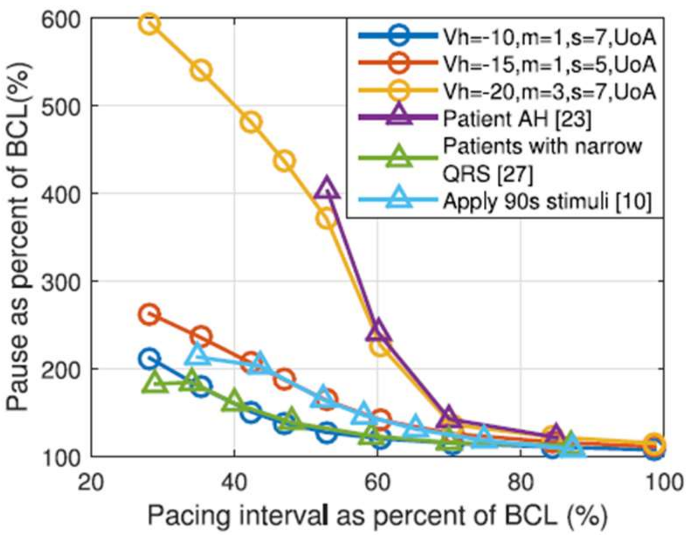
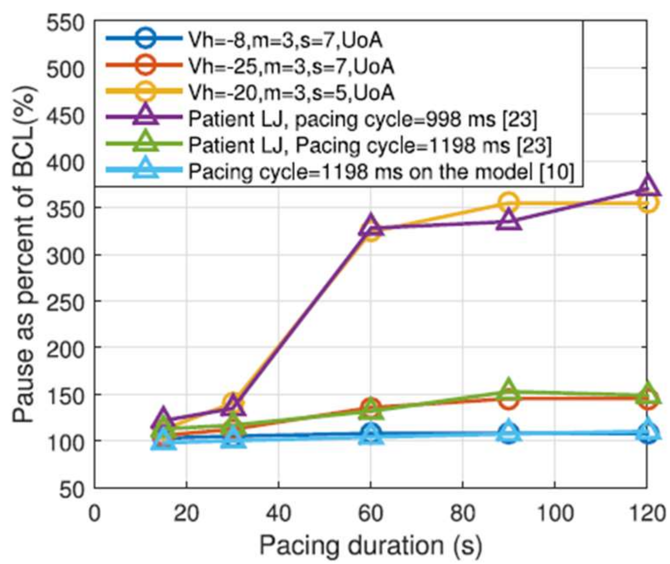
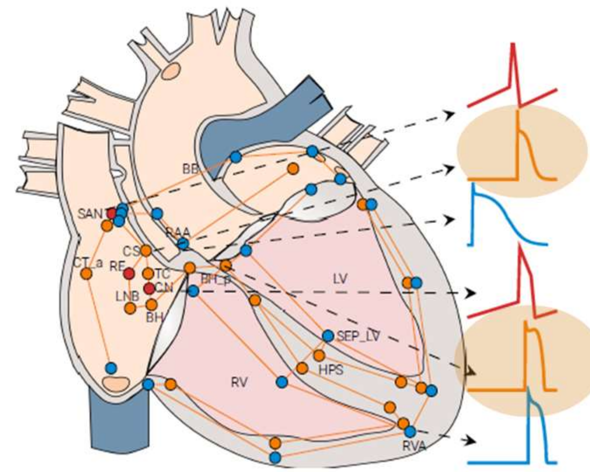
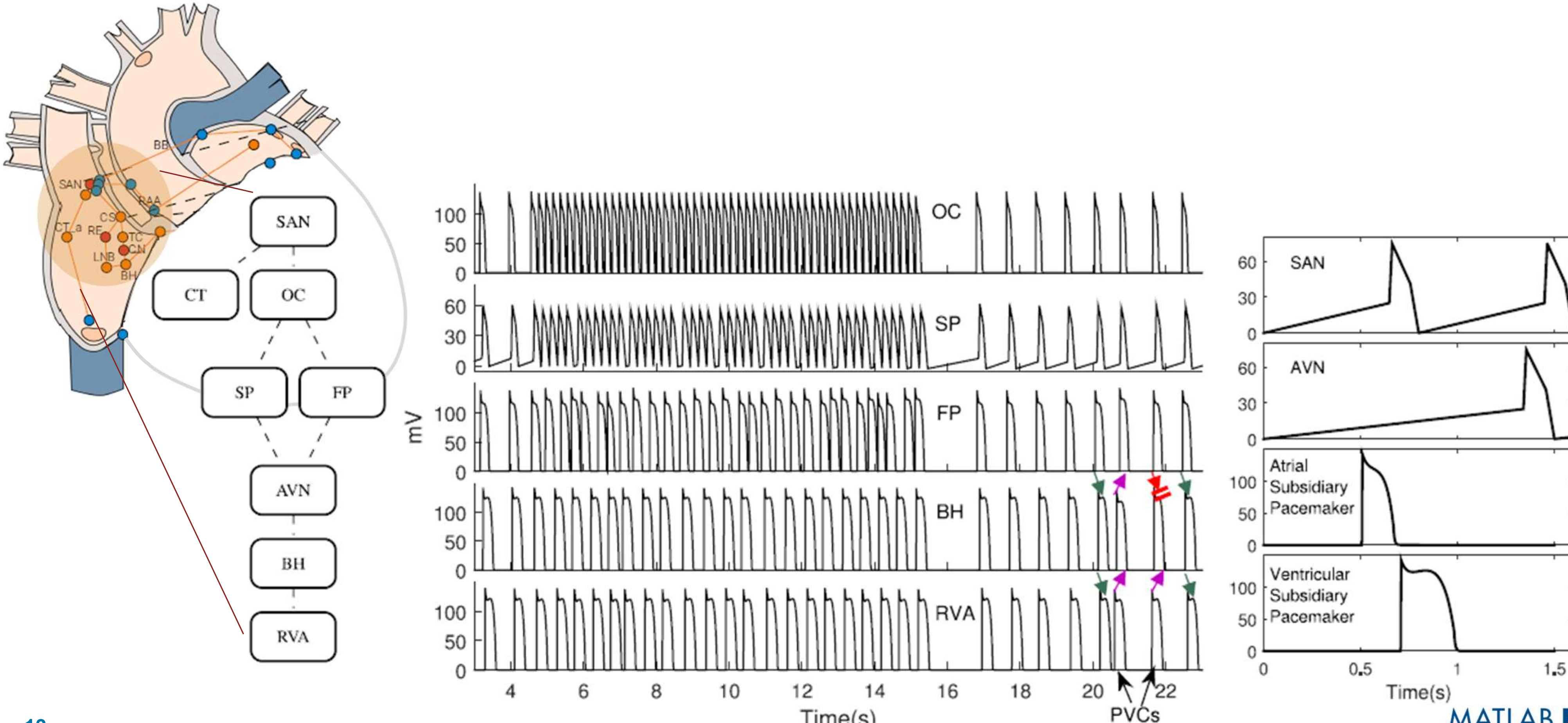
Our novel parametric HIOA model captures rate-dependent dynamics of important pacemaker cells







The compositional model produces atrio-ventricular node (AVN) filtering and escape ectopic automatic rhythms



Our heart model simulates normal activation sequences that match known literature values

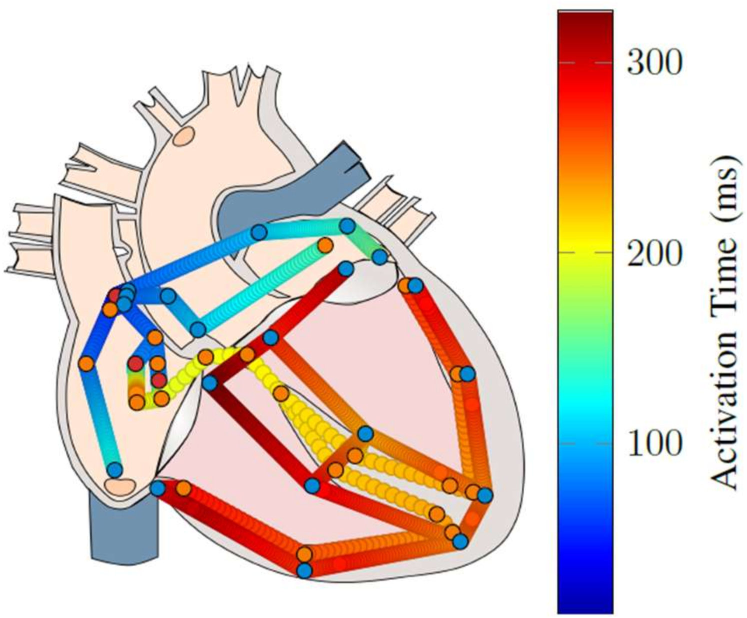
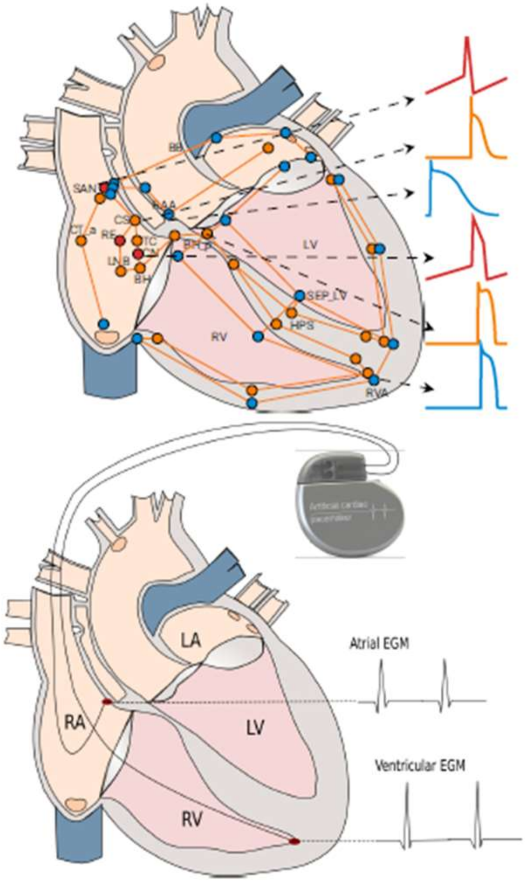
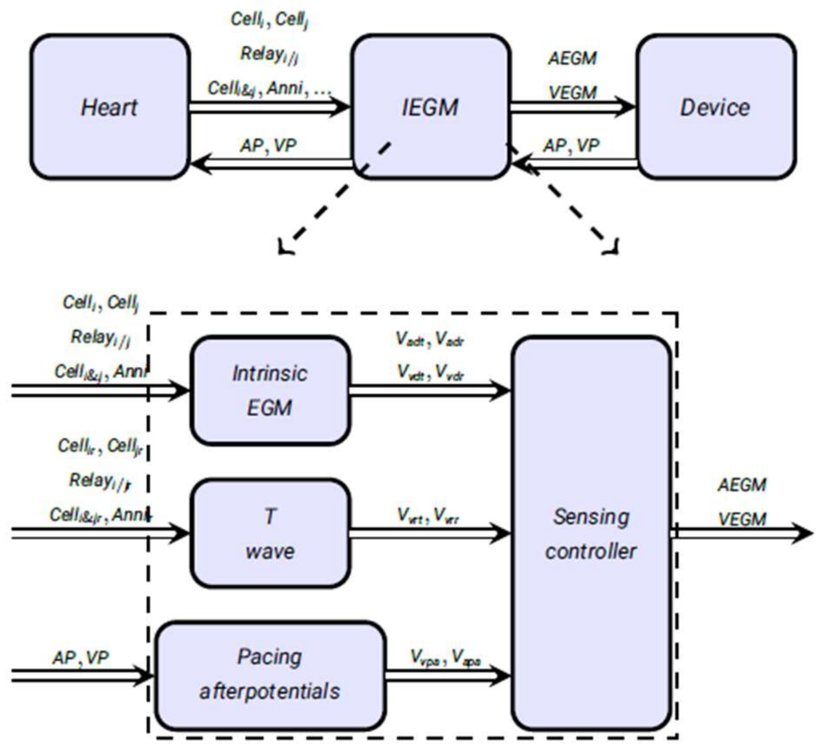


TABLE I: Normal activation sequence.

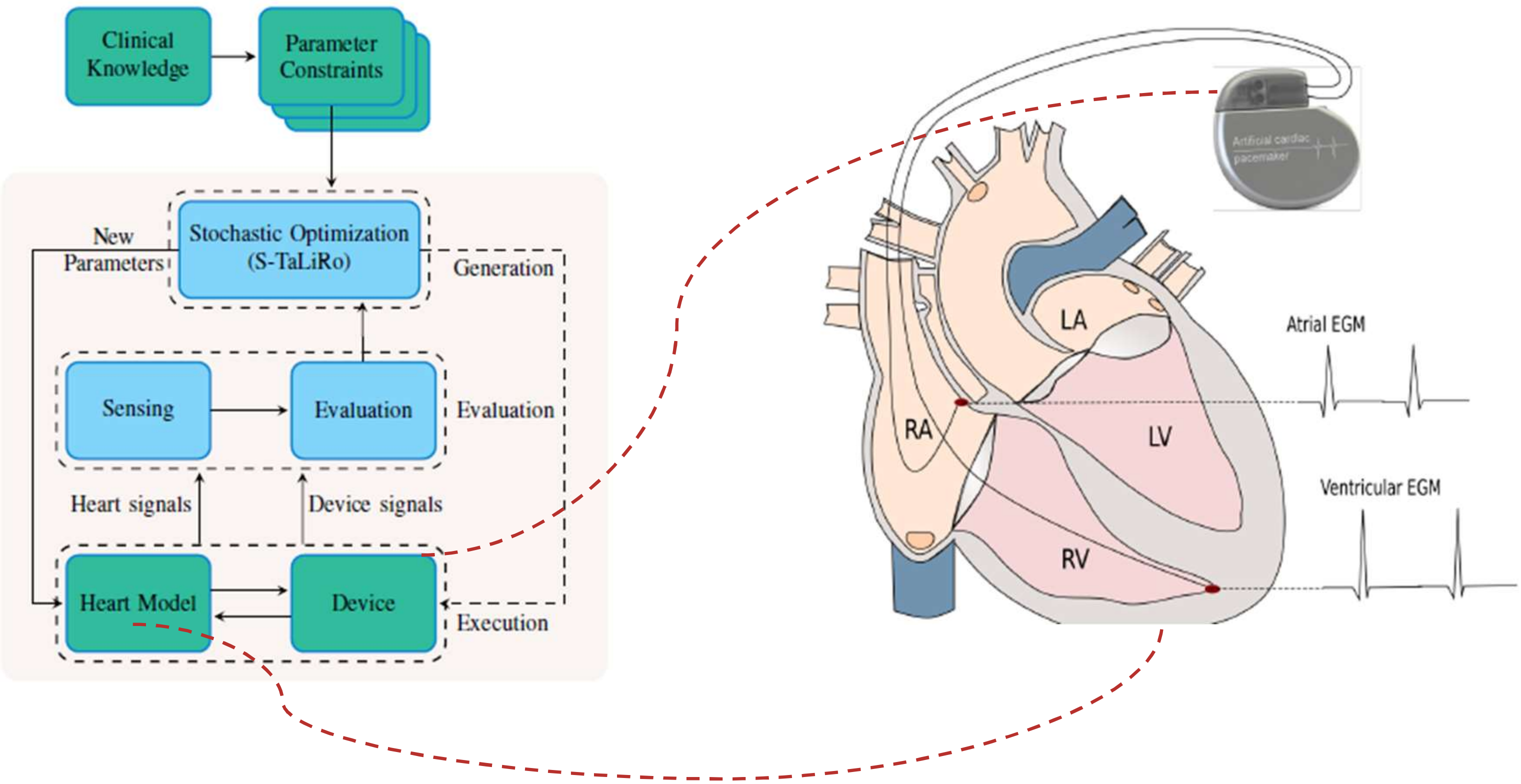
Conduction time	Experimental data	Simulation
SACT	82 ± 17 ms [20]; 65 ms [21]; 45-125 ms [38];	58 ms
BB activation	31 ± 13 ms [37];	46 ms
RA activation	93 ± 17 ms [37];	75 ms
LA activation	116 ± 18 ms [37];	103 ms
AV interval	200 ms [23]; 120-200 ms [39];	152 ms
from HPS to Ventricular activation	50 ms [26], [40]; 35 to 55 ms [39]	37 to 49 ms
HPS activation	90 ms [26], [40];	91 ms
Ventricular activation	100 ms [26], [40];	97 ms
LV and RV activation difference	RV activation is 5 to 10 ms later than LV [26], [40];	12 ms

A model of electrograms (EGM) bridges the virtual heart and the physical device

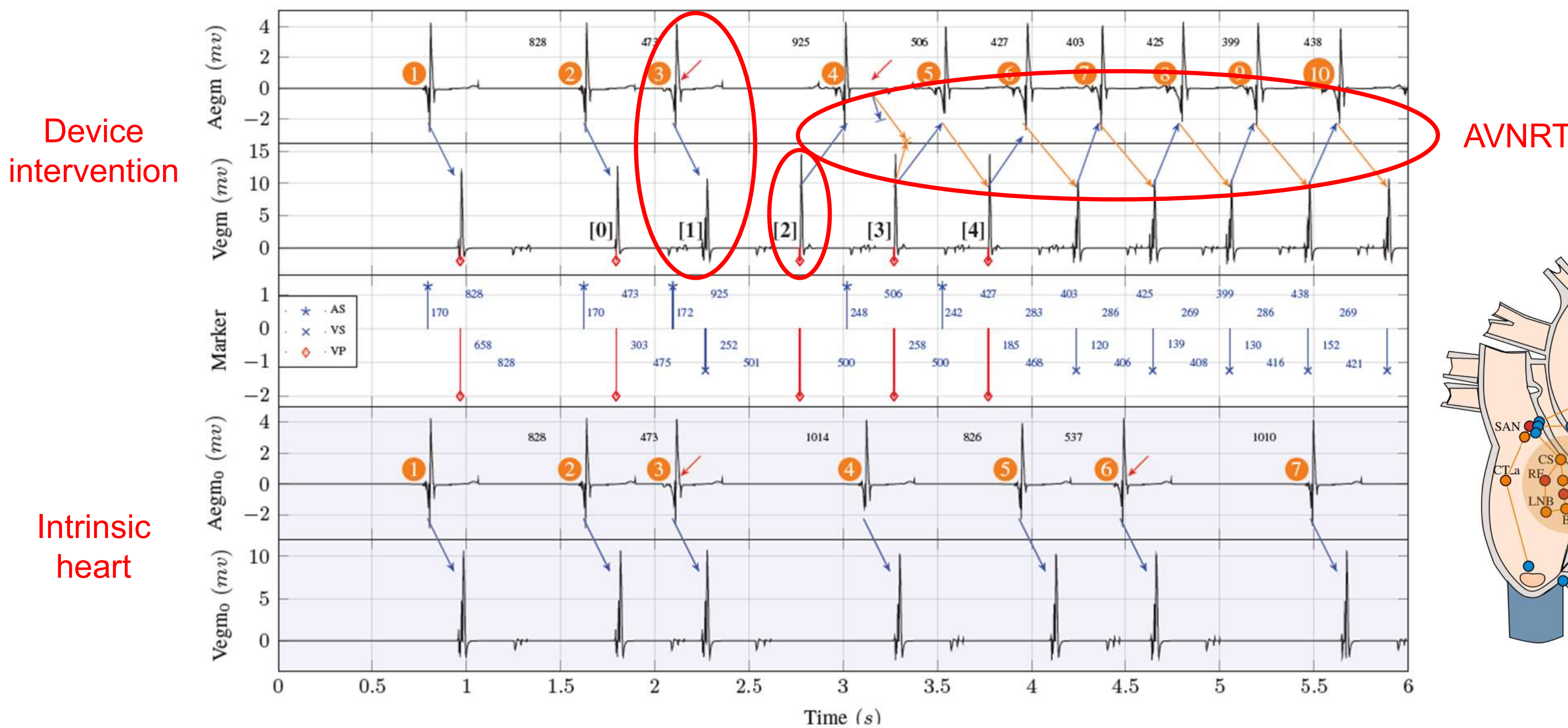


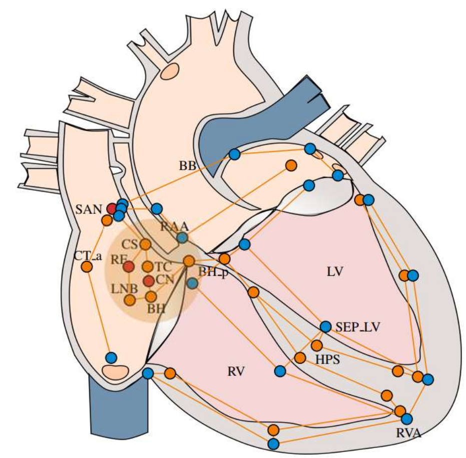


Used in a closed-loop system our heart model automates device validation in a physiologically relevant context



The closed-loop model system shows how a dual chamber pacemaker can cause atrioventricular nodal reentry tachycardia (AVNRT)





DEVICE ROUNDS

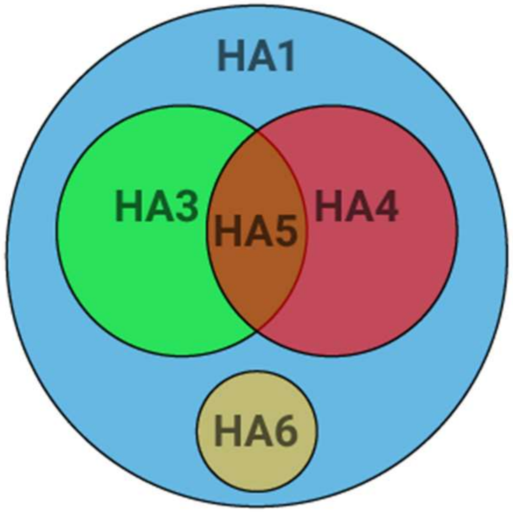
Managed Ventricular Pacing Facilitating Atrioventricular Nodal Reentrant Tachycardia

DANIEL R. FRISCH, M.D.,* ANAND S. KENIA, M.D.,* PAUL WALINSKY, M.D.,* and JOSHUA BALOG, M.D.†

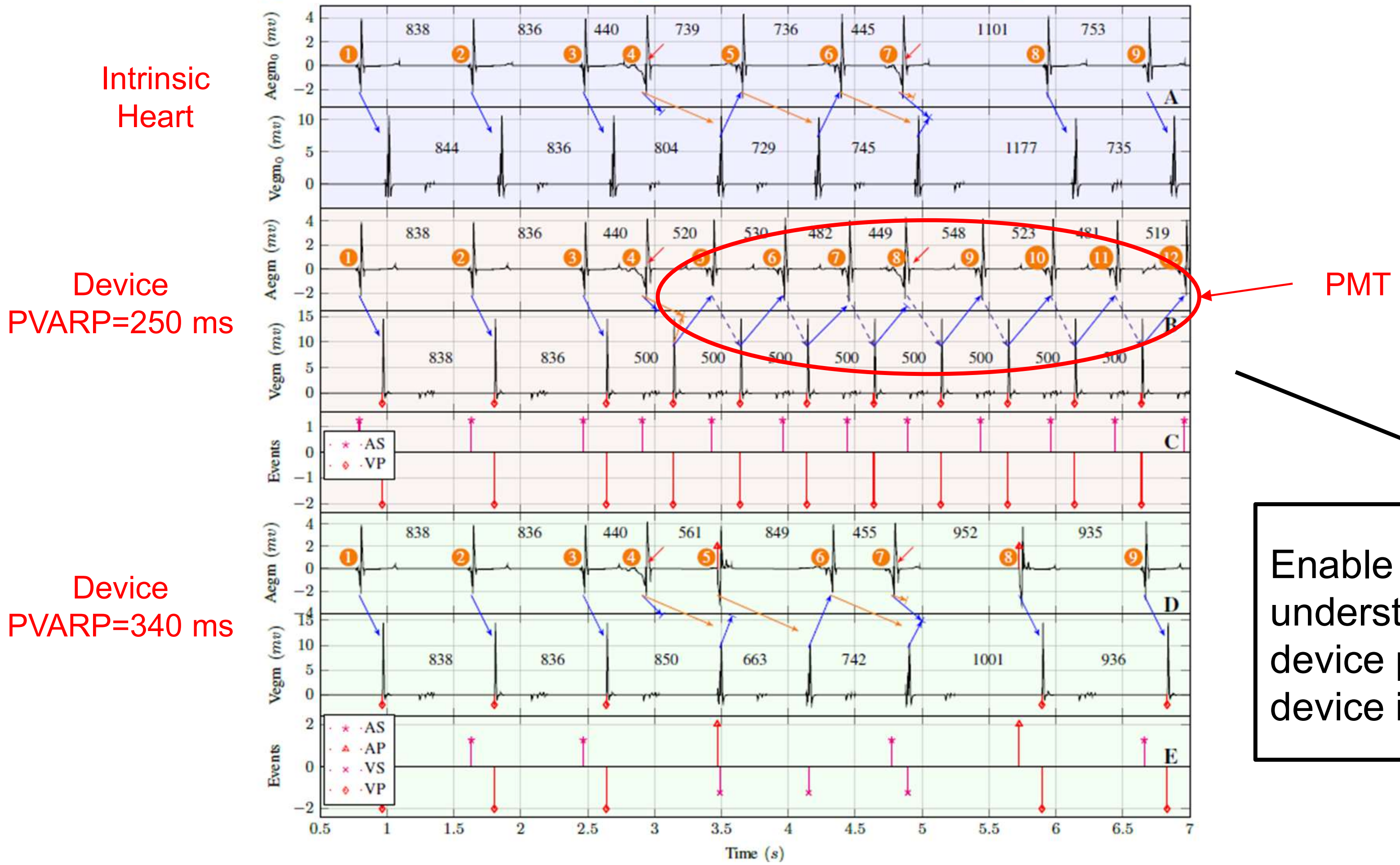
From the *Thomas Jefferson University Hospital, Jefferson Heart Institute, Philadelphia, Pennsylvania; and †Robert Wood Johnson University Hospital, New Brunswick, New Jersey

The closed-loop model system enables pacemaker mediated tachycardia (PMT) risk assessment

Para. Ranges	SA Rate (bpm)	APC	AV de-lay	PVC	VA con-duc-tion	PMT
HA1	30-150	Yes	Yes	Yes	Yes	45.77%
HA2	30-74	Yes	Yes	Yes	Yes	27.76%
HA3	30-74	Yes	Yes	No	Yes	6.69%
HA4	30-74	No	Yes	Yes	Yes	30.6%
HA5	30-74	No	Yes	No	Yes	0%
HA6	30-74	Yes	Yes	Yes	No	0%



The closed-loop model system shows how pacemaker programing causes a dangerous heart rhythm



Enable clinicians to understand the impact of device parameters on heart-device interactions

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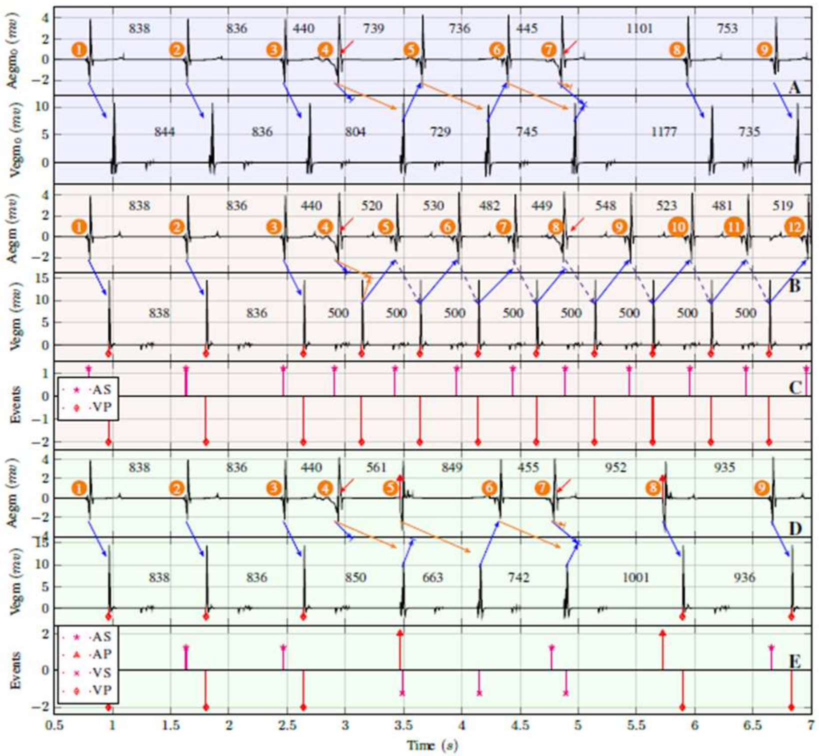
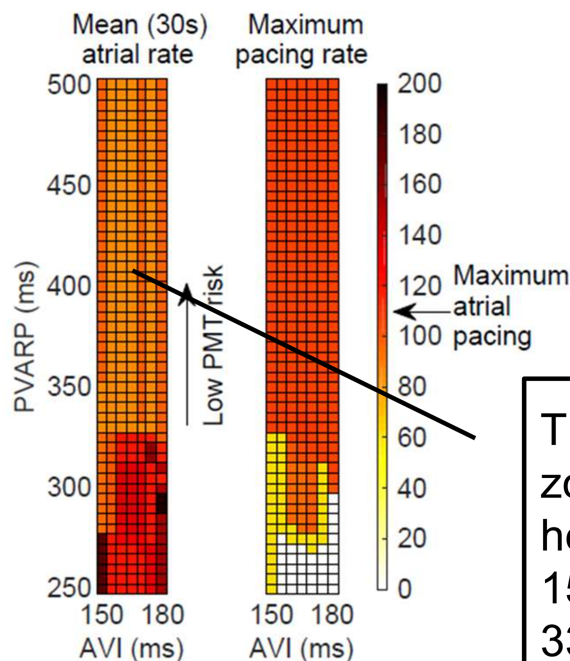
The closed-loop model system shows how pacemaker parameters are customized for safety in heart conditions





The device parameter safe zone (PMT free) for this heart condition is:

150 ≤ AVI (ms) ≤ 180

330 ≤ PVARP (ms) ≤ 500

DEVICE ROUNDS | Full Access

Pacemaker-mediated tachycardia in a dual-lead CRT-D: What is the mechanism?

Christopher Monkhouse BSc, Alex Cambridge BSc, Anthony W.C. Chow MD, Jonathan Behar MBBS, BSc, PhD

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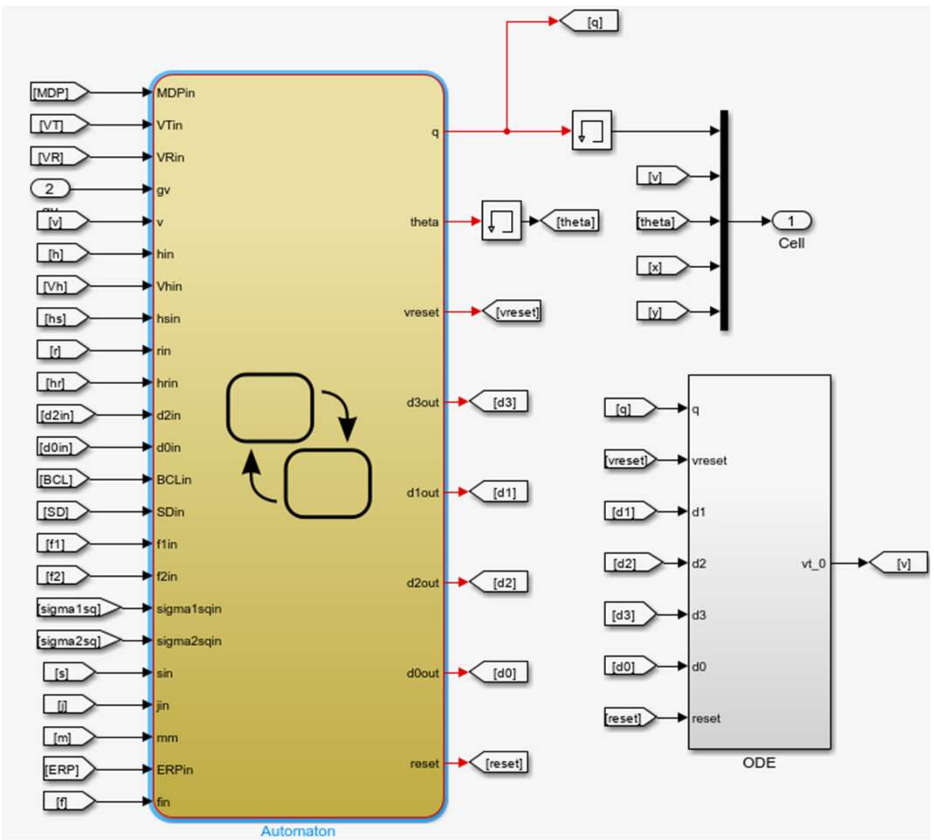
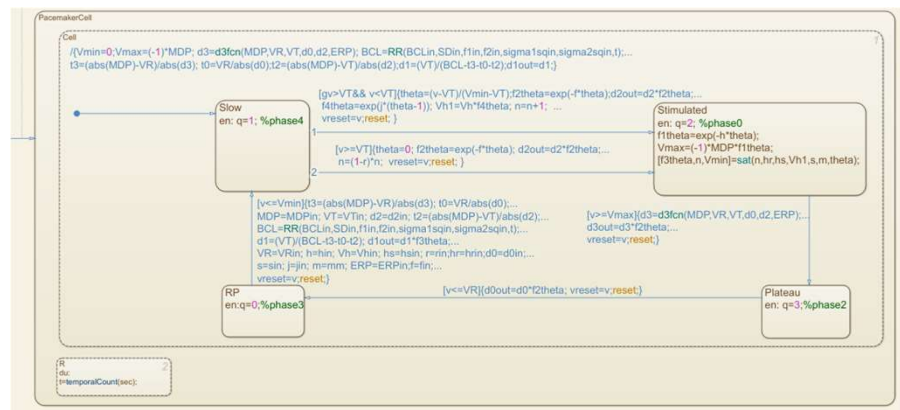
Simulink & Stateflow enable the HIOA modelling





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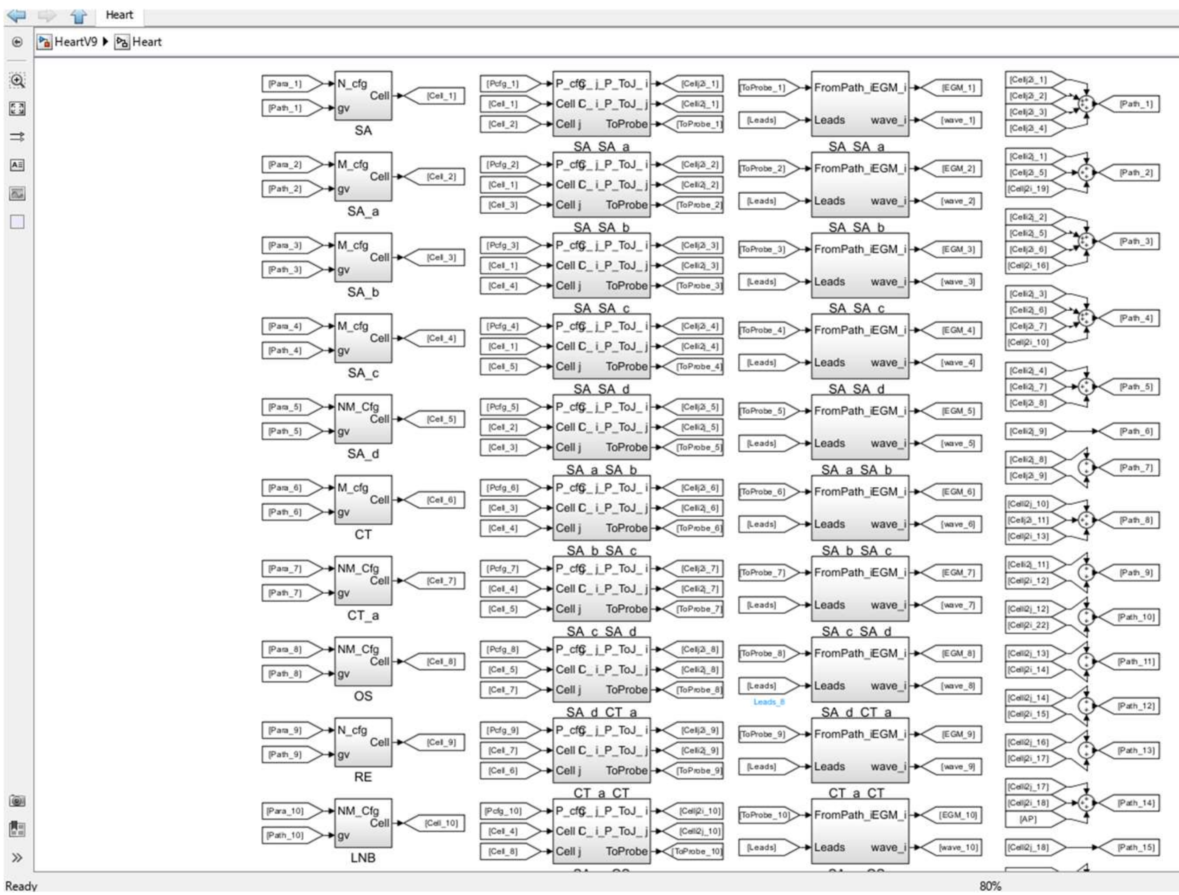
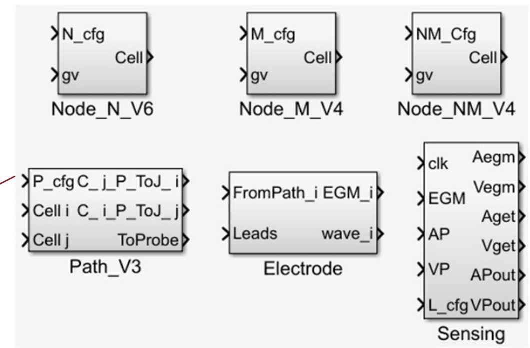
Simulink Library facilitates the model composition



Library



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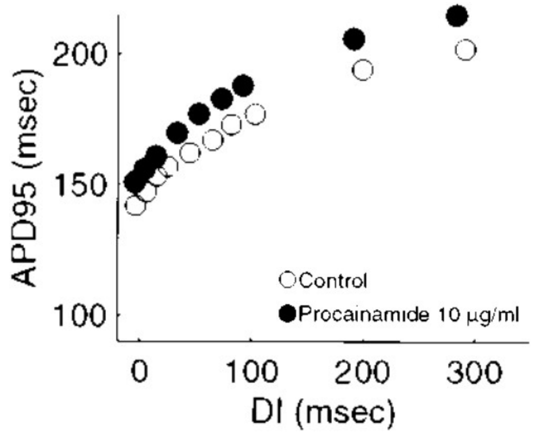
5	RA	M	14	-0.006900	0.075900	6.826500	-0.271129	0.013131	0.0002
6	CS_LA	NM	15	-0.006900	0.075900	6.826500	-0.271129	0.013131	0.0002
7	Bach	M	16	-0.006900	0.075900	6.826500	-0.271129	0.013131	0.0002
8	LA_a	M	17	-0.006900	0.075900	6.826500	-0.271129	0.013131	0.0002
9	LA	M	18	-0.006900	0.075900	6.826500	-0.271129	0.013131	0.0002
0	BH	NM	19	-0.006900	0.075900	6.826500	-0.033200	0.013940	0.0020
1	His_p	NM	20	-0.006900	0.075900	6.826500	-0.033200	0.011060	0.0020
2	His_m	NM	21	-0.006900	0.075900	6.826500	-0.033200	0.011140	0.0020
3	His_d	NM	22	-0.006900	0.075900	6.826500	-0.033200	0.011360	0.0020
4	RBB_m	NM	23	-0.006900	0.075900	6.826500	-0.033200	0.011660	0.0020
5	RBB	NM	24	-0.006900	0.075900	6.826500	-0.033200	0.012600	0.0020

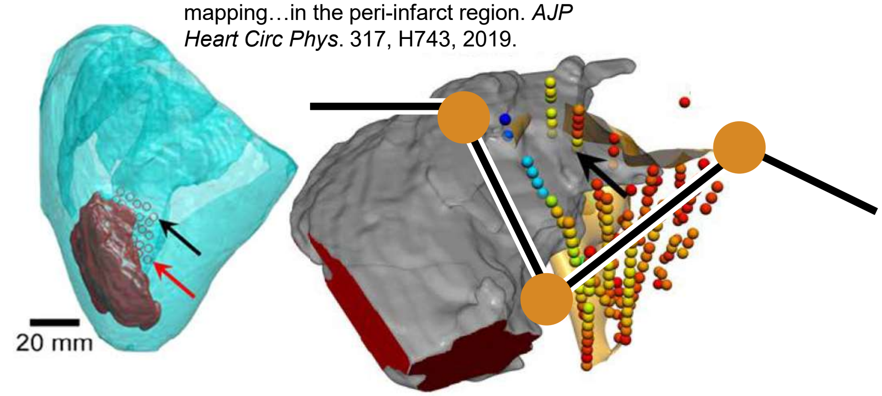
Parameters

On the horizon, our heart model has built in expansion capacity

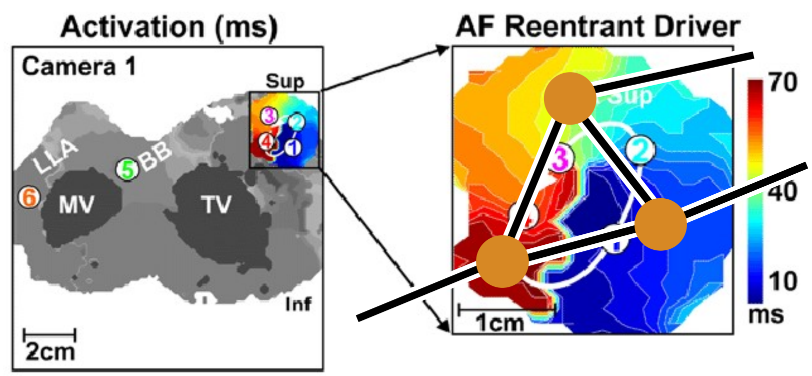


Riccio et al. Electrical restitution and spatiotemporal organization. *Circ Res*. 84, 955, 1999.

Trew et al. Cardiac intramural electrical mapping…in the peri-infarct region. *AJP Heart Circ Phys*. 317, H743, 2019.



Li et al. Adenosine-induced atrial fibrillation. *Circulation*. 134, 486, 2016.



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We have developed a heart model with adaptive capacity that interacts with medical devices in real-time

Heart model packaged as a robust teaching and demonstration tool

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Thank you

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