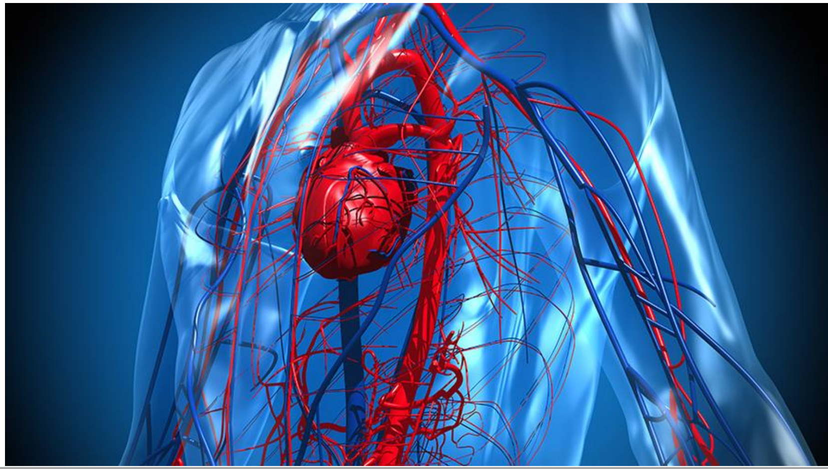
Modeling Biological Systems (In Silico) With Simulink



Pourash Patel

Sr. Application Engineer | MathWorks

Agenda

- Introduction – in silico medicine
- Case study: a novel method for validation of cardiac devices
- Additional use case examples

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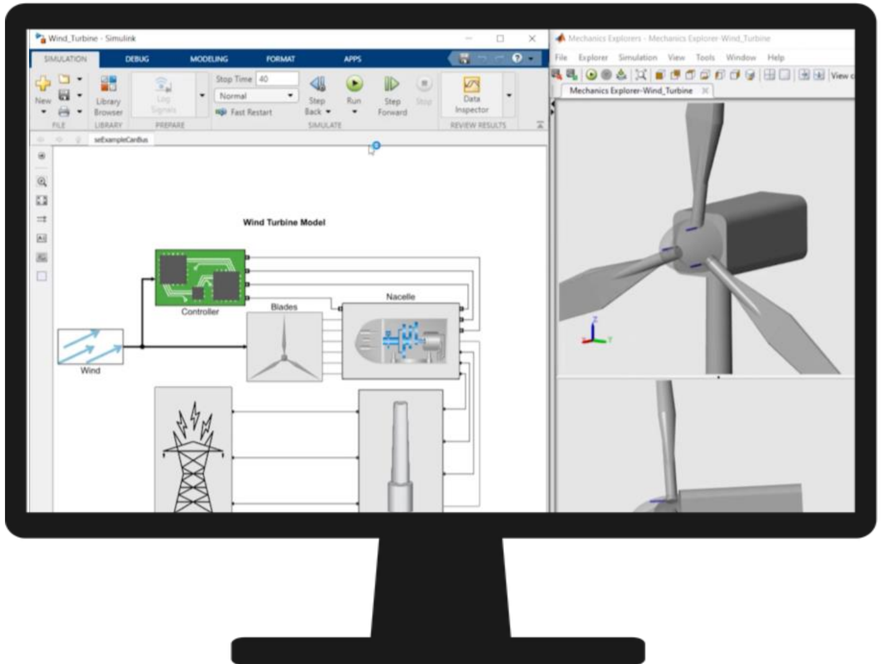
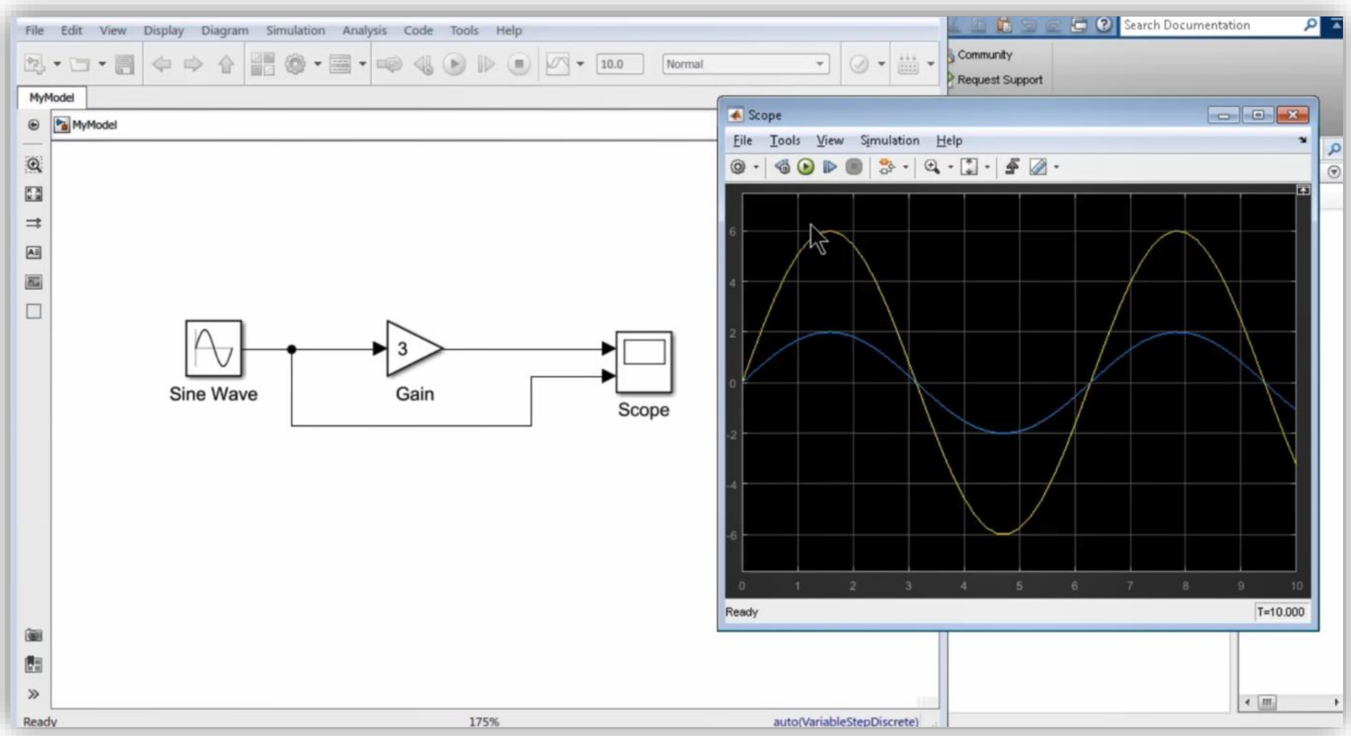
Simulink

Simulink: simulation & model based design

- dynamic system and control
- optimized model development
- grid design/integration
- code generation

Transforming the way Engineers work.





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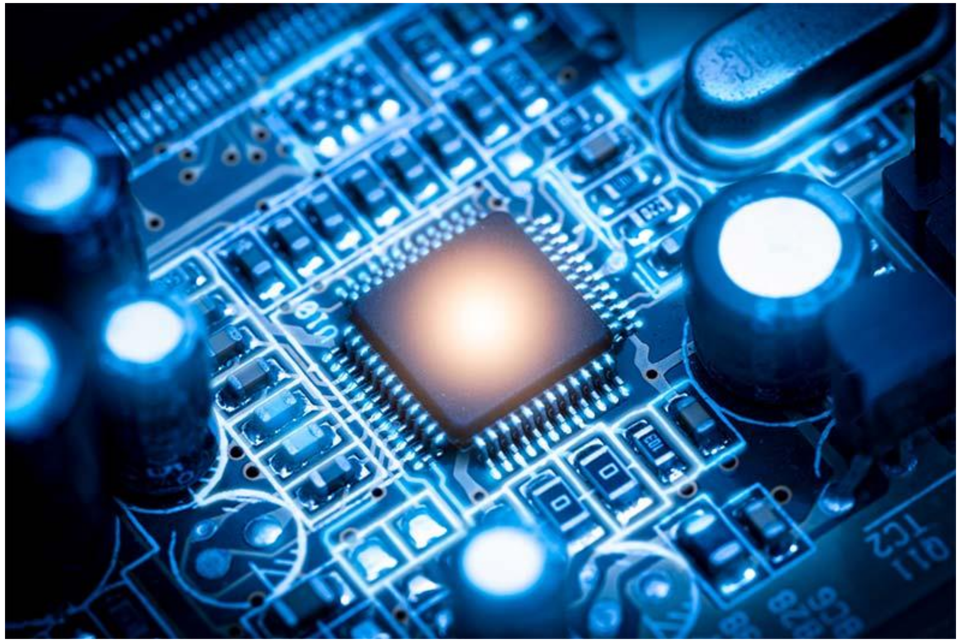
What is in silico medicine?

- **In silico medicine** uses computational modelling and simulation (CM&S) to replicate humans and medical devices

- **Virtual patients and organs** (aka digital twins) are utilised in R&D

- **Applications in medical devices:**
  - Design and verification
  - Clinical evaluation
  - Performance testing
  - Regulatory evidence



Benefits to all healthcare stakeholders

- Regulators see CM&S as a way to **provide supportive regulatory evidence**
  – Submission of virtual patient data

- Companies can use virtual human and organ models to **accelerate device development and testing**
  – Shorter time-to-market
  – Reduced R&D costs

- Patients benefit from **safer medical devices**
  – *In Silico Clinical Trials* with larger and more diverse patient cohorts

CM&S framework for medical devices

Medical device model

+

Physiological/anatomical model

+

Simulation

=

In silico medicine

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Case study: a novel method for validation of cardiac devices

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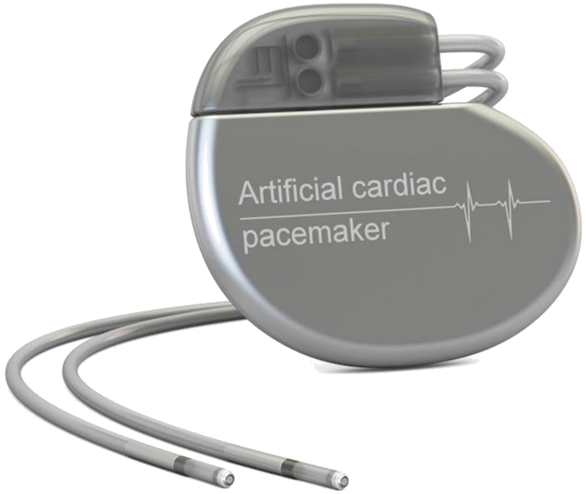
A Simulink® heart model for analyzing implantable pacemakers in closed loop



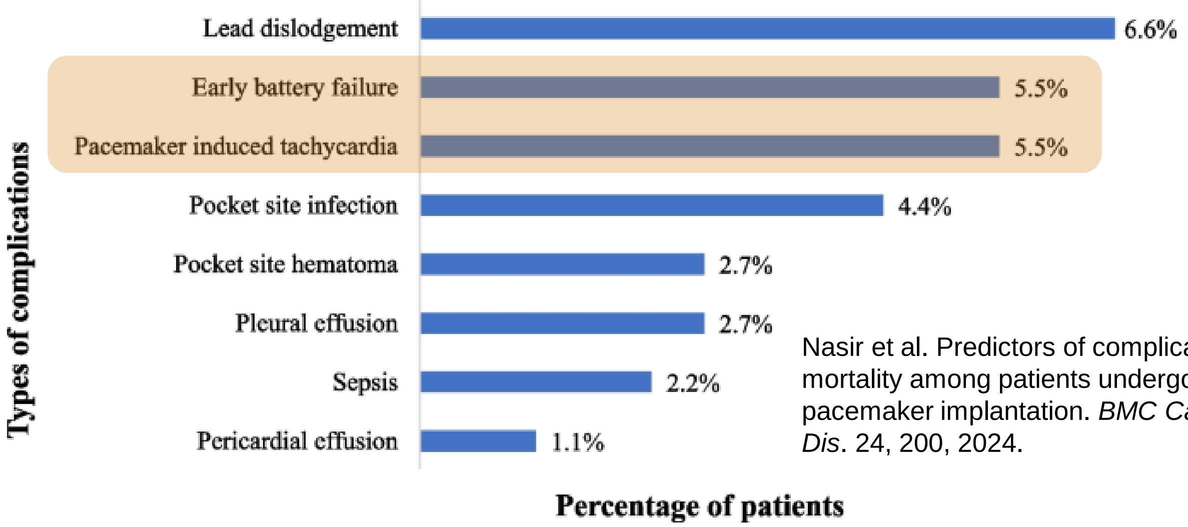
PACE
PACING AND CLINICAL ELECTROPHYSIOLOGY

DEVICE ROUNDS | Full Access

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

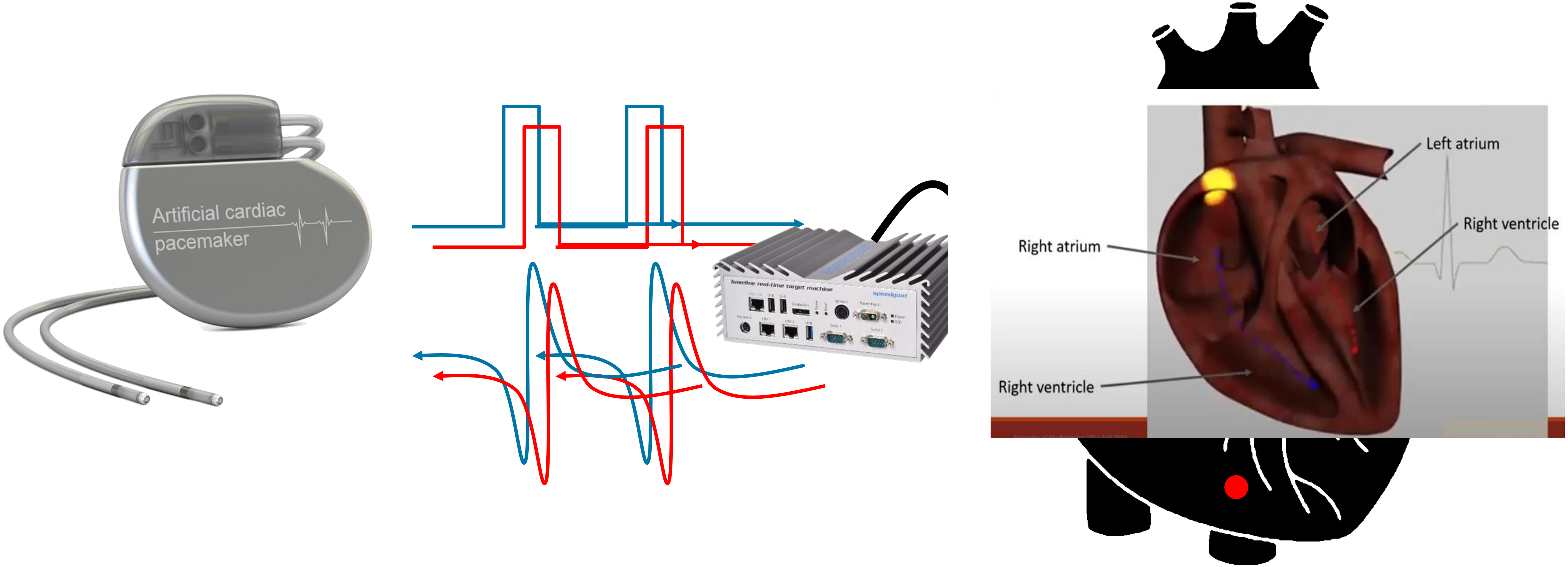
Christopher Monkhouse BSc, Alex Cambridge BSc, Anthony W.C. Chow MD, Jonathan Behar MBBS, BSc, PhD

2021.

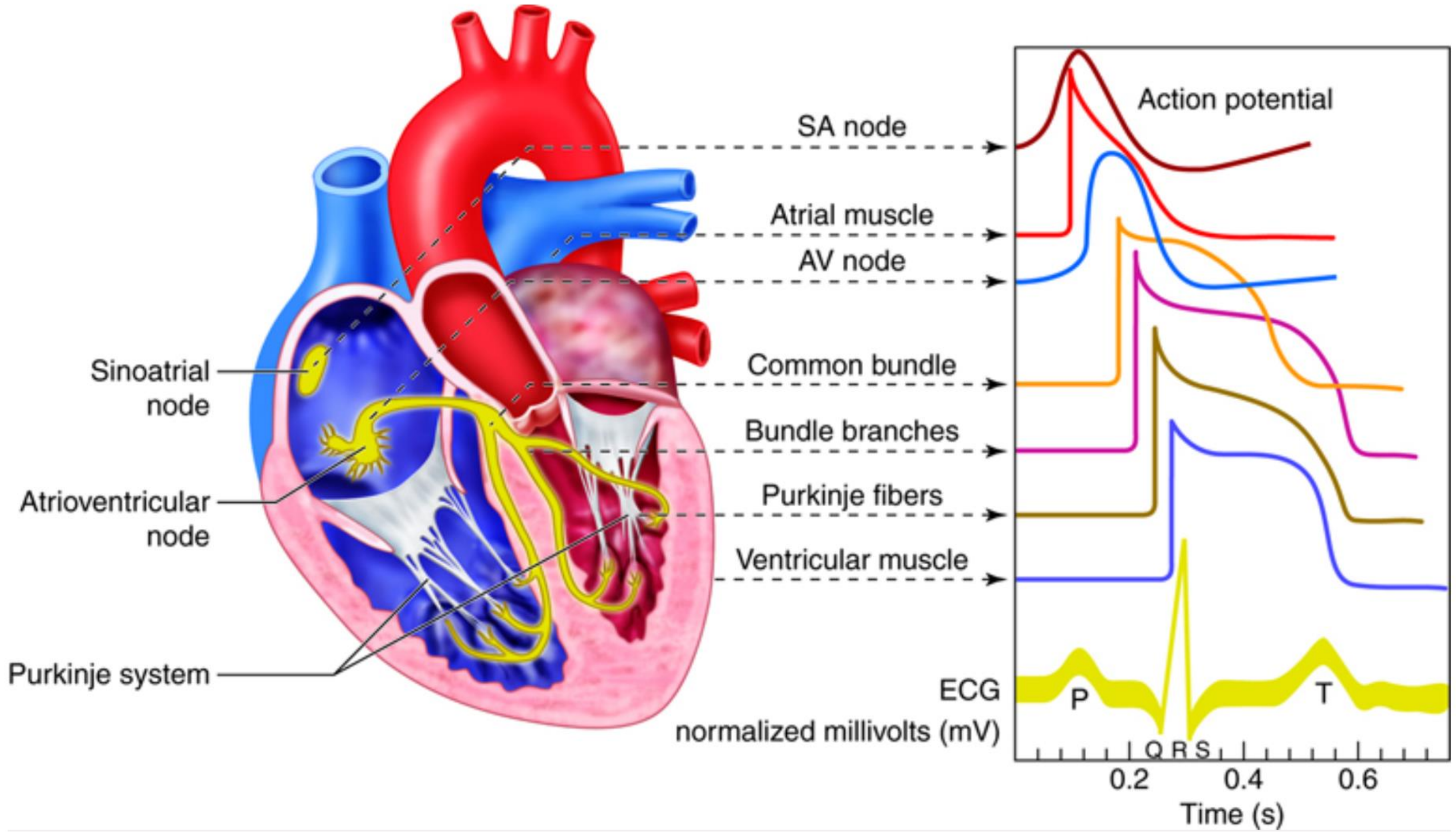


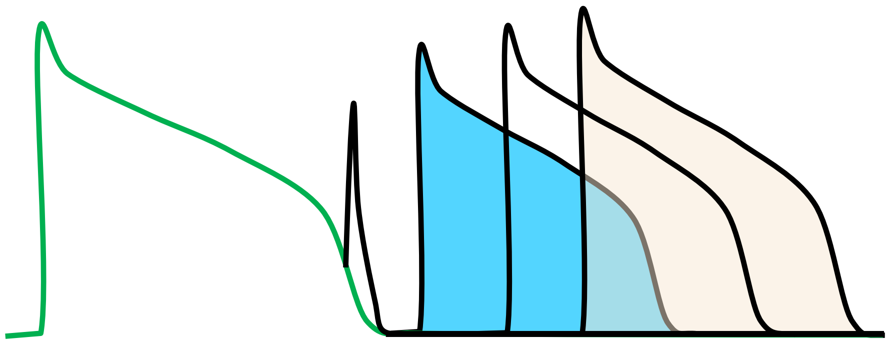
Nasir et al. Predictors of complications and mortality among patients undergoing pacemaker implantation. *BMC Cardiovasc Dis*. 24, 200, 2024.

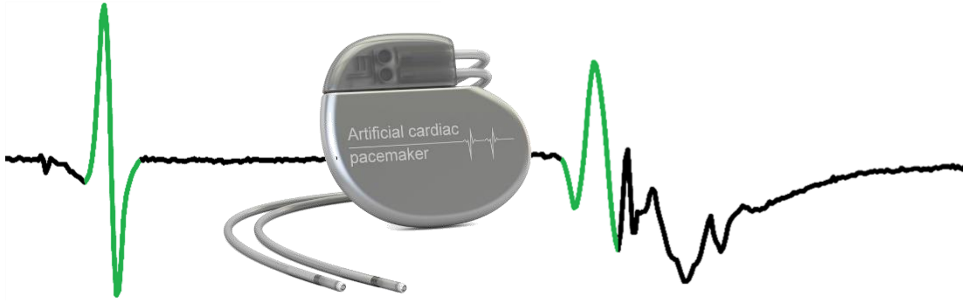
A Simulink® heart model for analyzing implantable pacemakers in closed loop



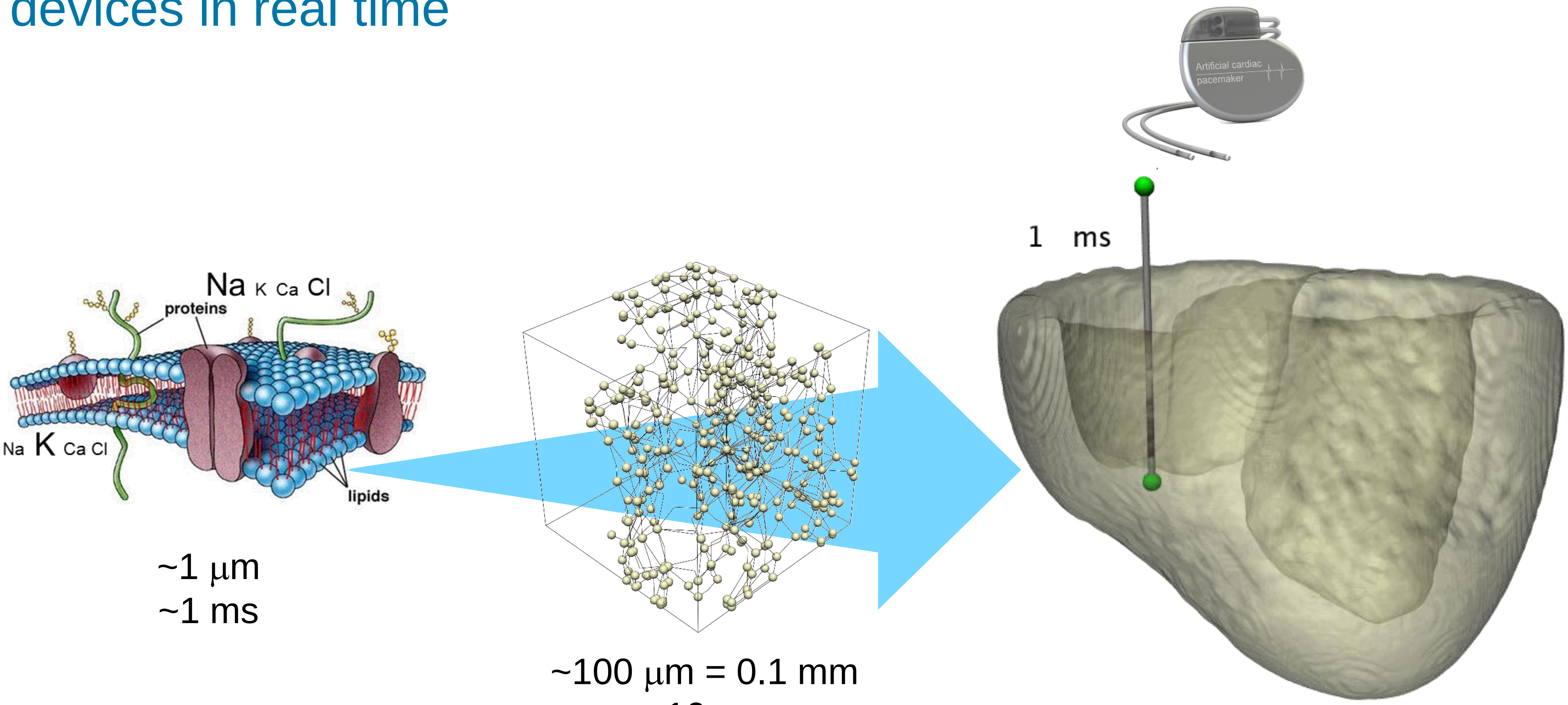
Heart models should generate signals that vary in space, time and with heart rate







In silico hearts with cell-to-organ biophysics cannot interact with devices in real time

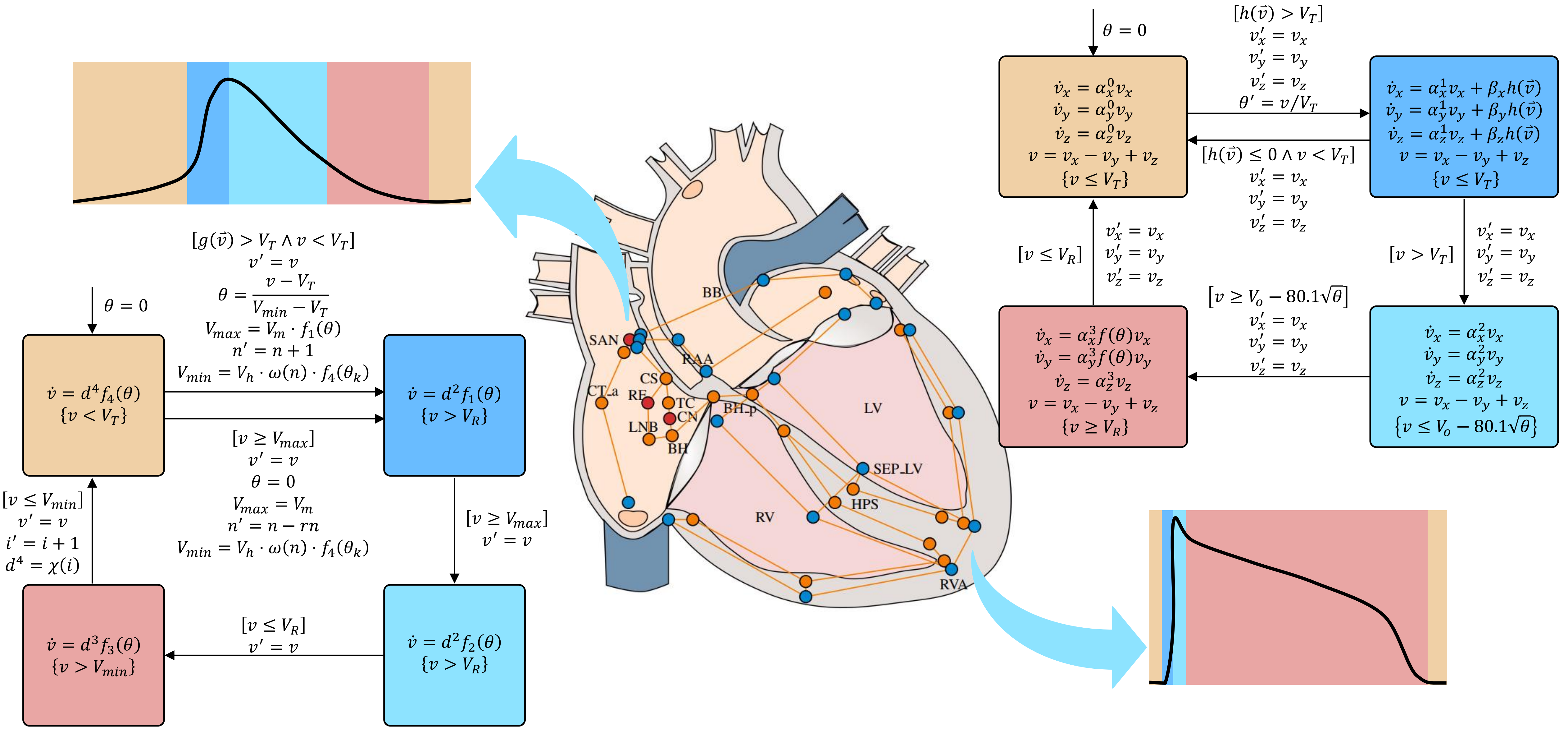


~1 μm
~1 ms

~100 μm = 0.1 mm
~10 ms

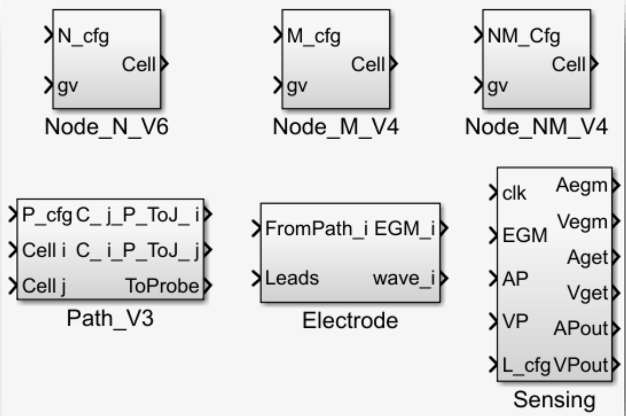
~1000+ μm = 1-10 mm
~1000 ms = 1 s

An effective solution is an abstracted heart model

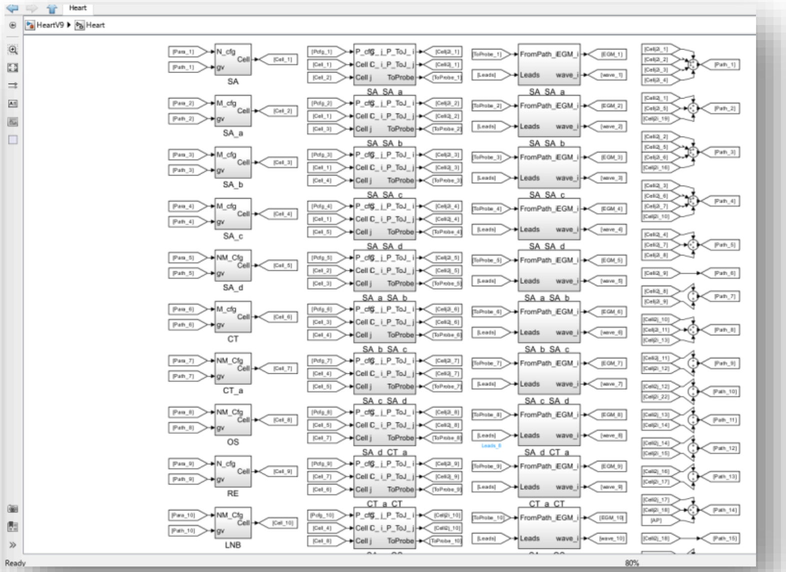


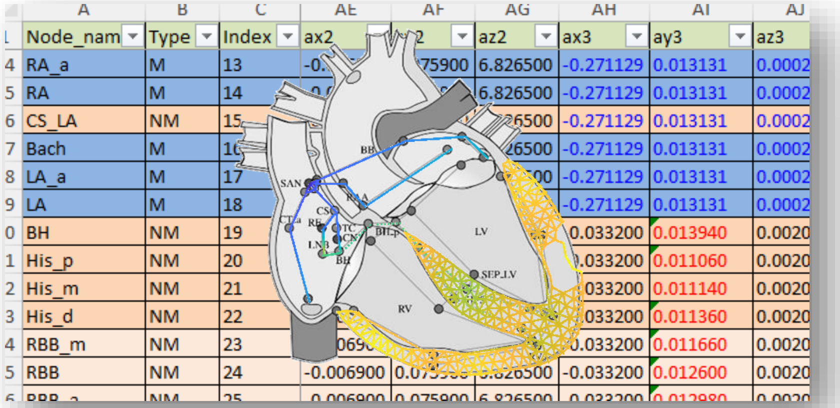
Case study: heart model parameters are combined with a Simulink® library to automatically build heart model

Simulink® library

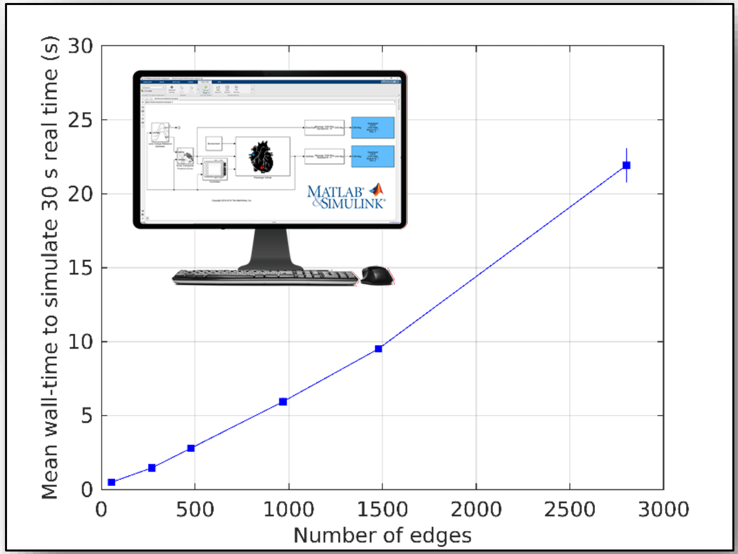


Simulink® heart model

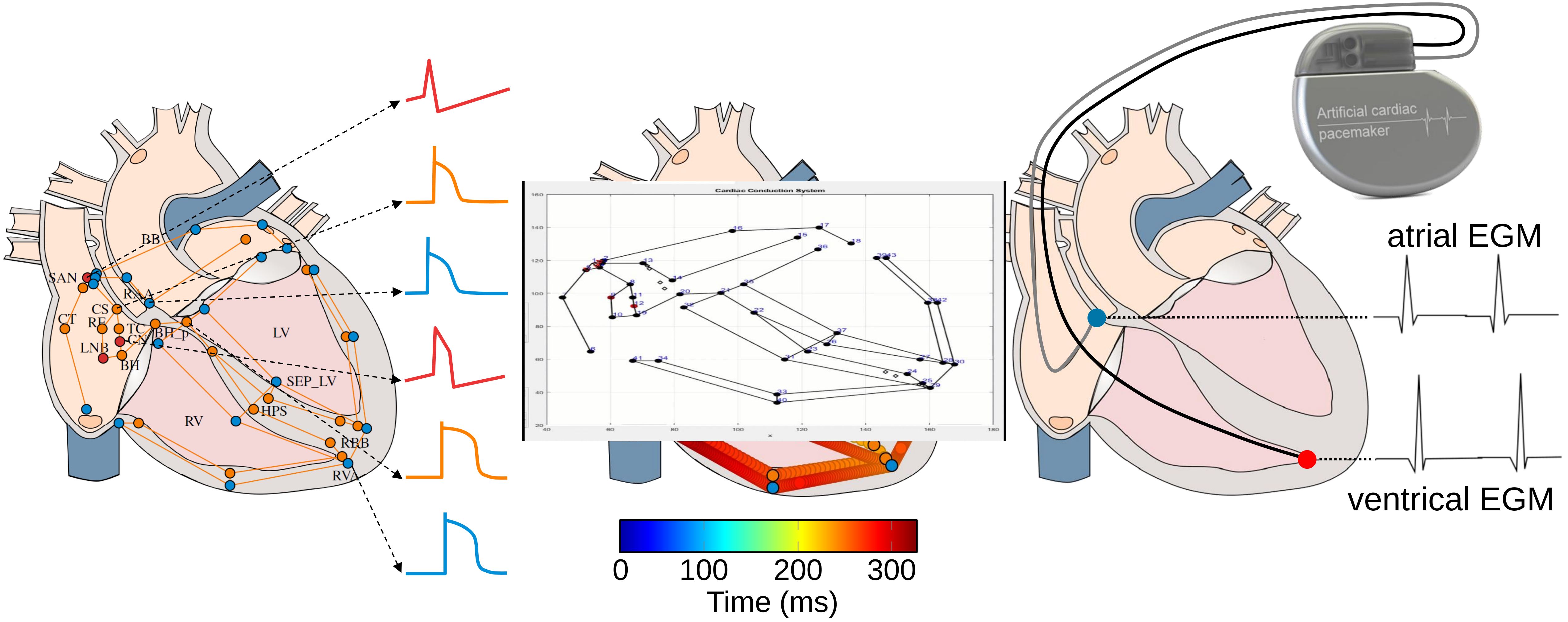




Heart model parameters



Case study: the abstracted model generates accurate timing and signals that directly link to a pacemaker



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

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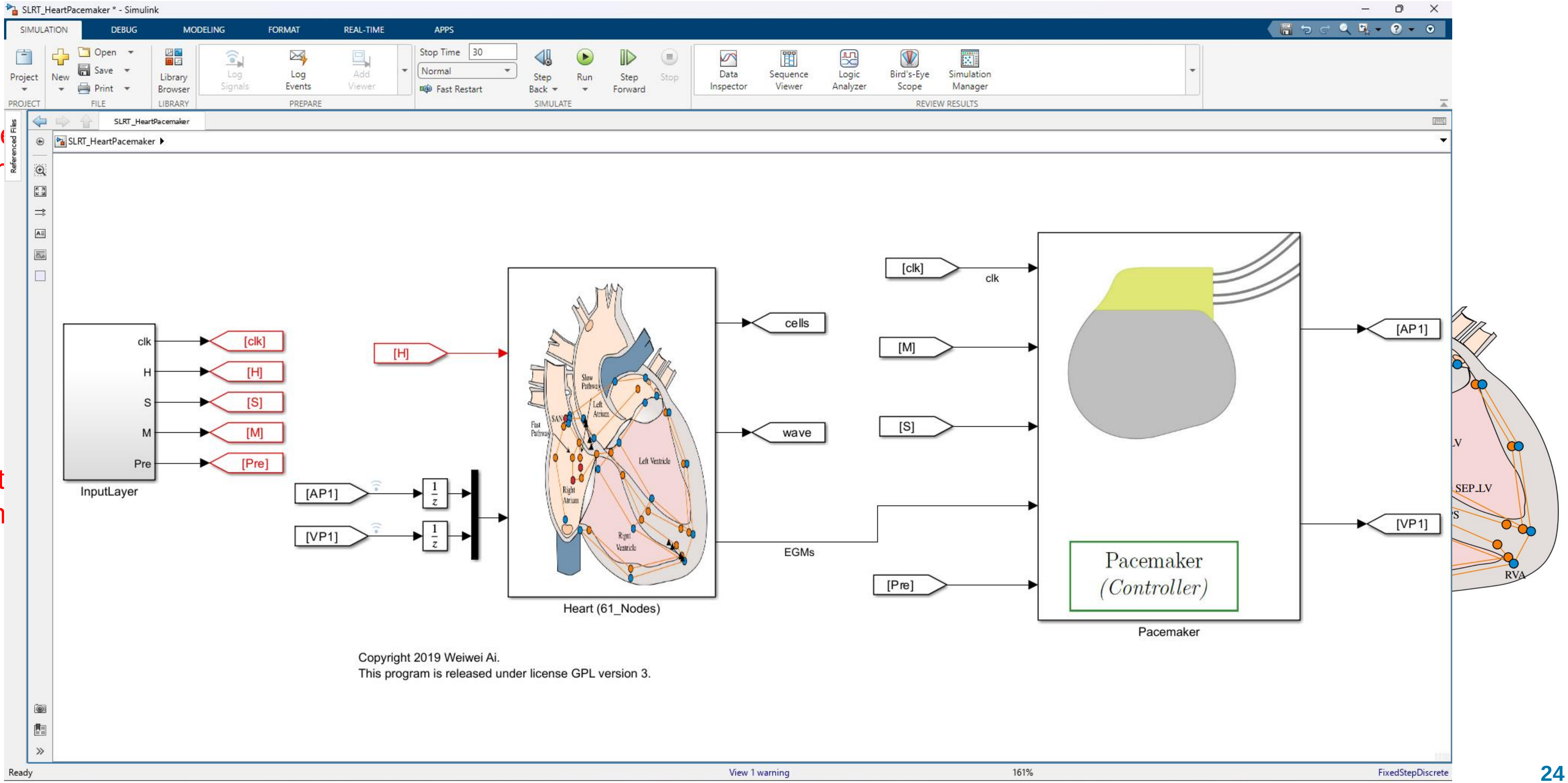
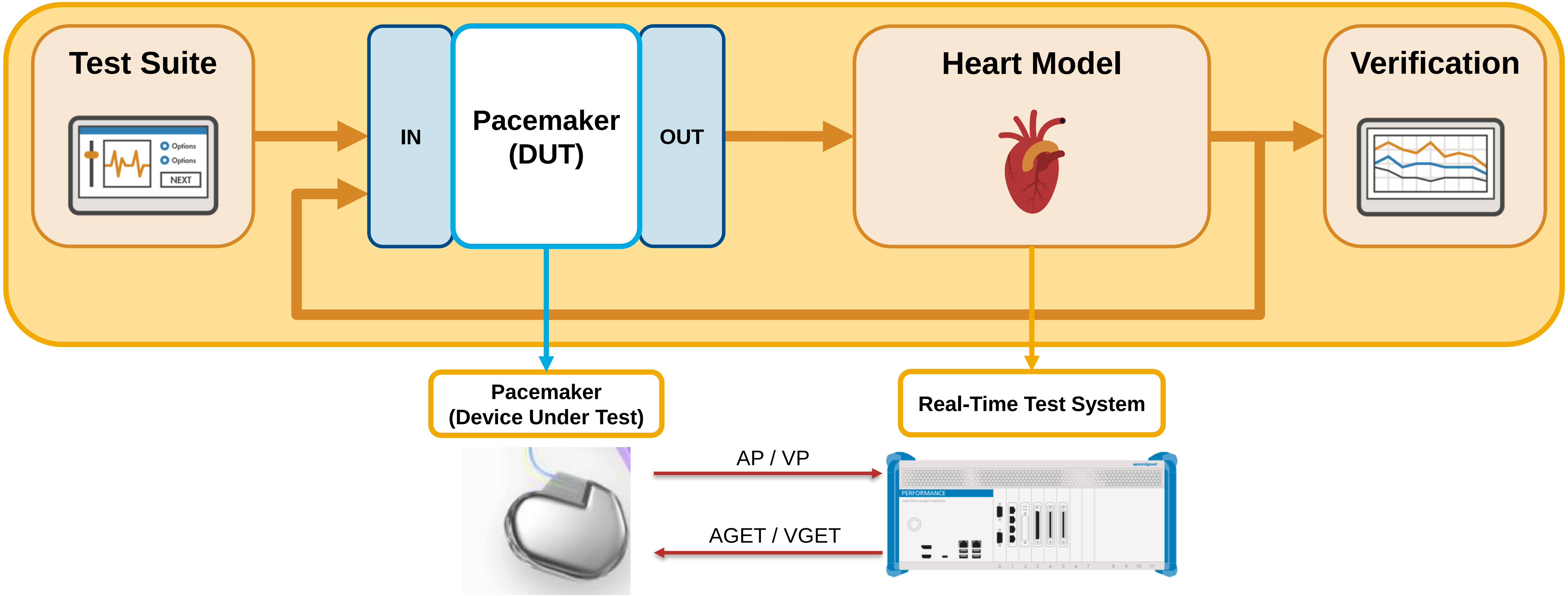
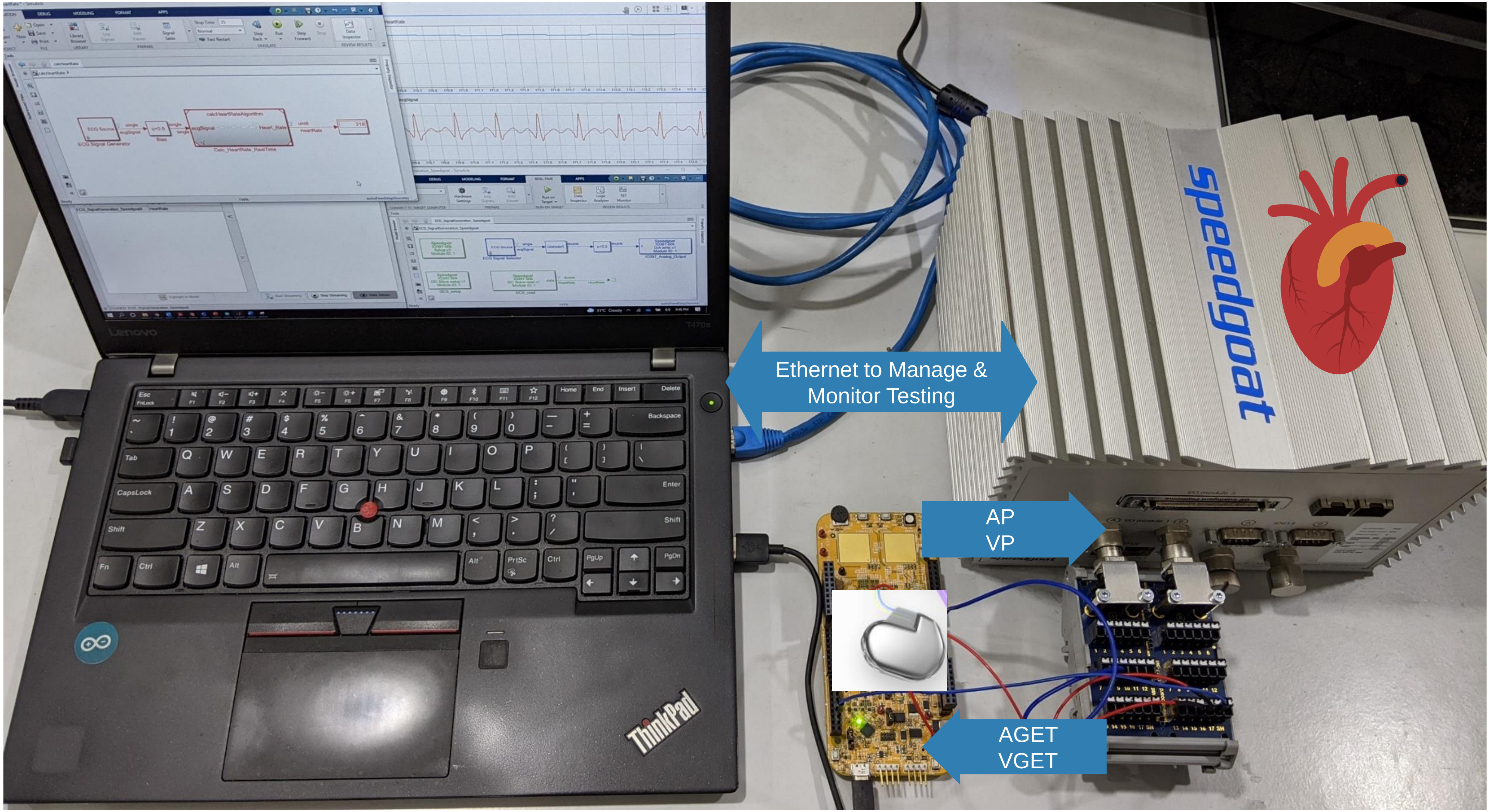


Hardware-in-the-loop testing of pacemaker devices

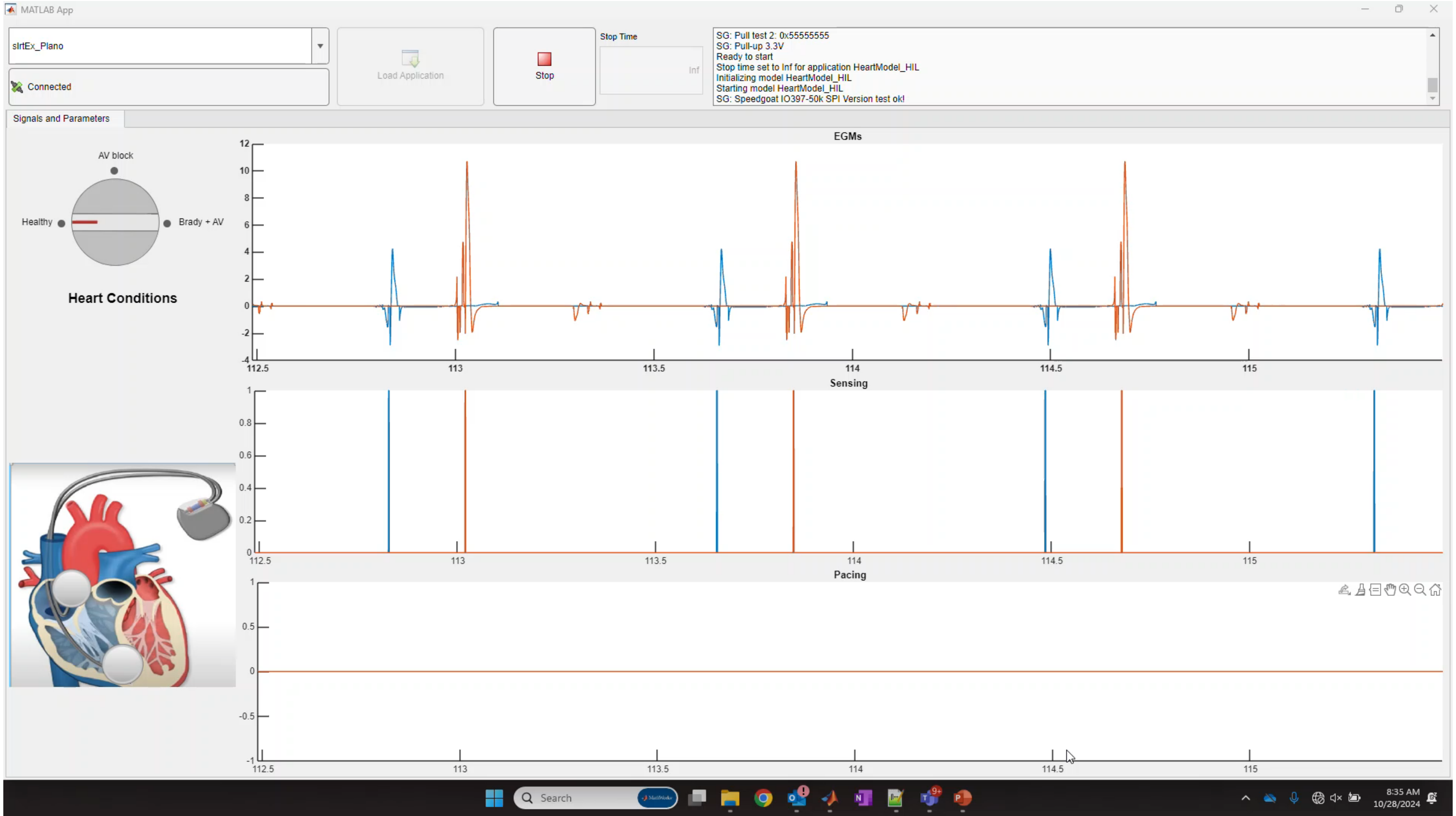
- Closed-loop testing of pacemaker (DUT)
- Test different heart conditions and device failure modes
- Automate testing and reporting for certification



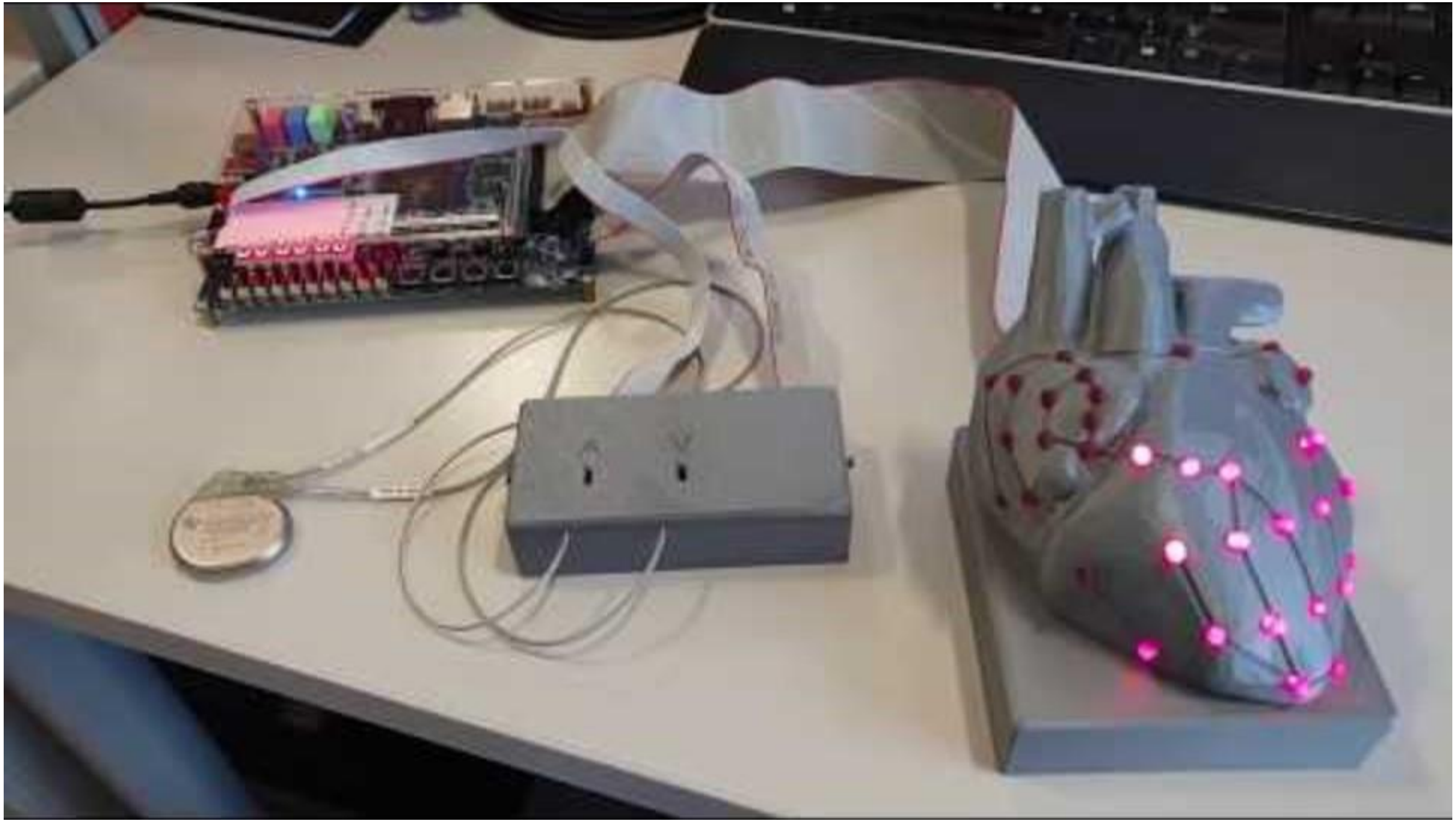
Hardware setup



Real-time simulation



Hardware-in-loop testing



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Additional use case examples

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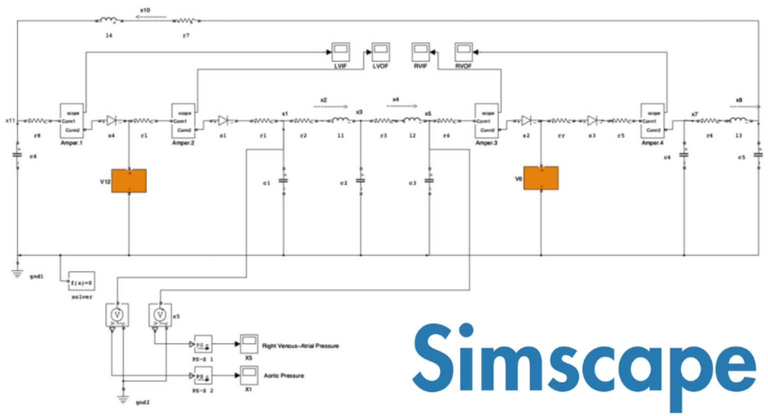
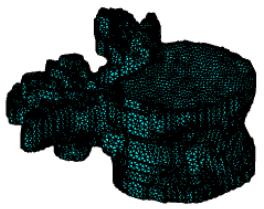
MathWorks solutions for in silico medicine

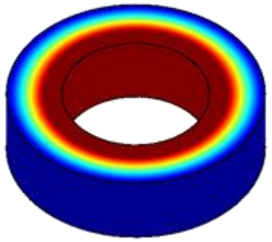
Electrical/fluid models



Simscape

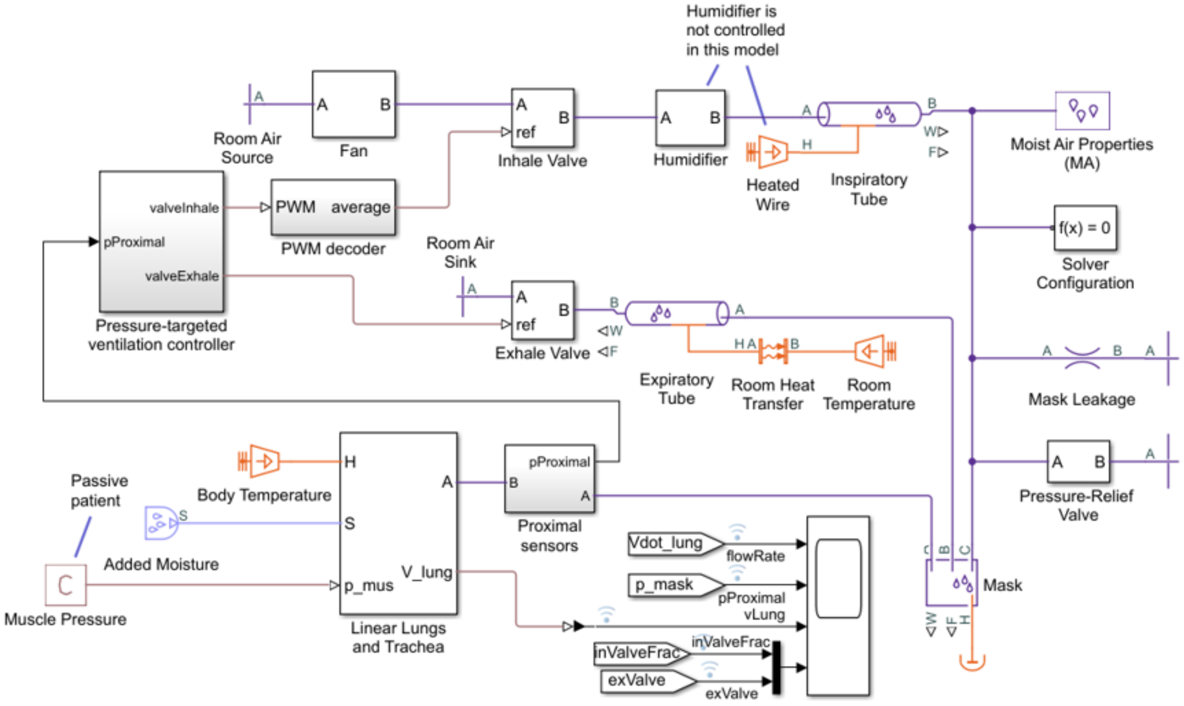
Thermal/structural/electromagnetic models





MATLAB®

Medical device models

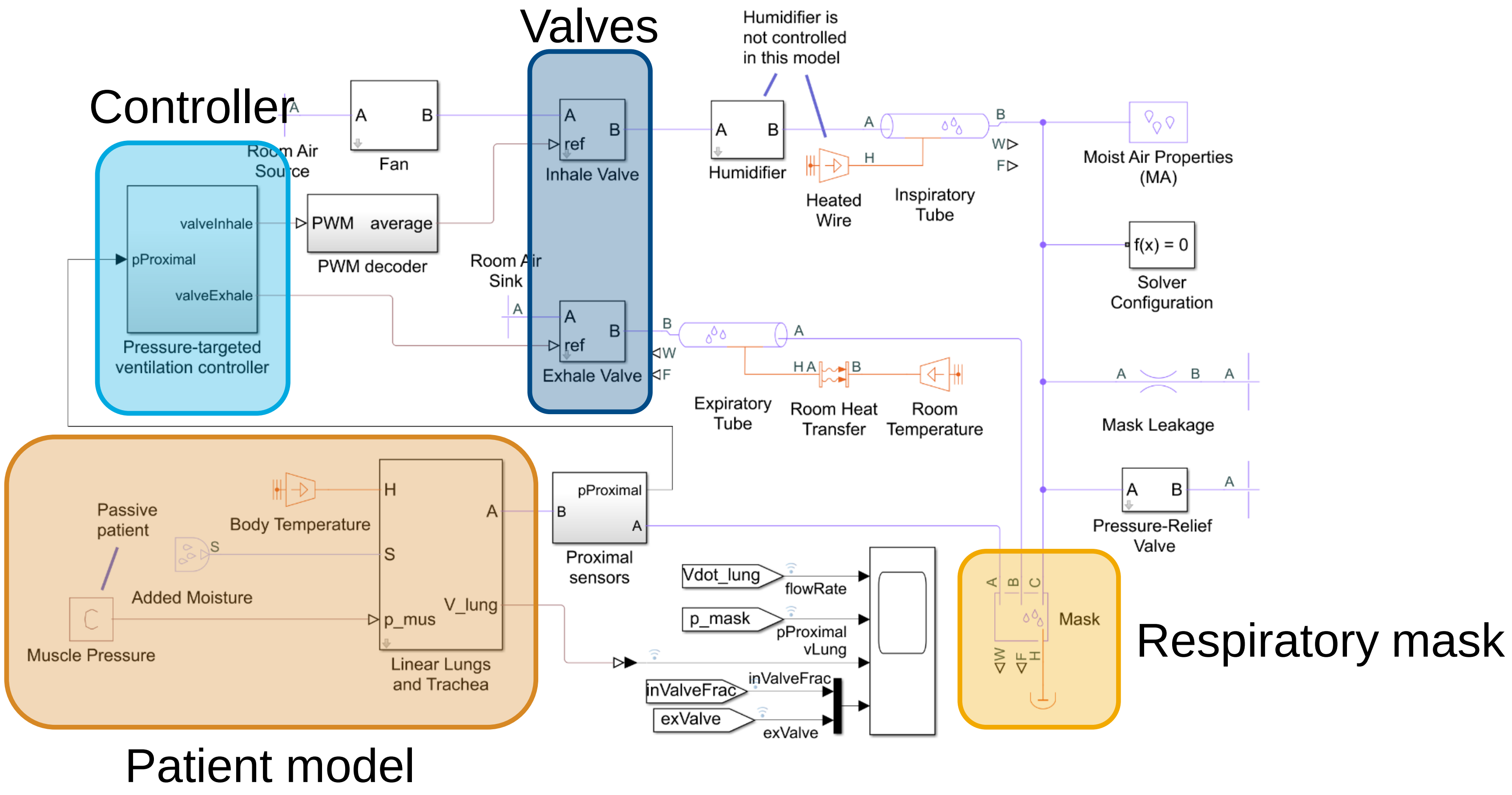


SIMULINK®

Case study: simulating a medical ventilator

- **Medical ventilator**
  - Replaces respiration by automatically moving air in and out of your lungs
- **FDA Class II device**
- **Simulation goals:**
  1. Create and tune a closed-loop control system for ventilation
  2. Generate certifiable embedded code for a production device

Case study: simulating a medical ventilator

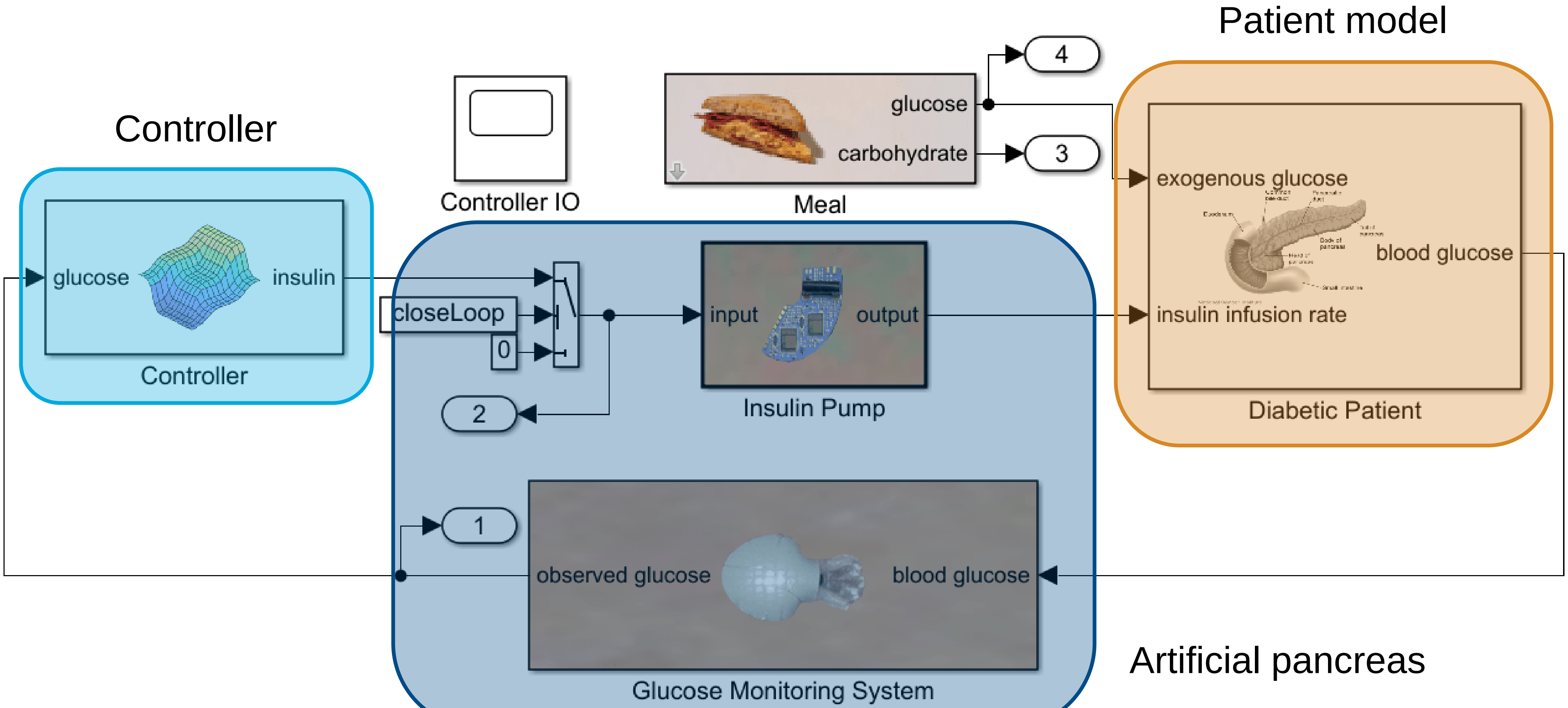


Source: Medical Ventilator Model in Simscape

Case study: simulating an artificial pancreas

- **Artificial pancreas**
  – Continuous glucose monitoring combined with insulin delivery
- **FDA Class III device**
- **Simulation goals:**
  1. Create and tune a closed-loop control system for insulin delivery
  2. Generate certifiable embedded code for production device

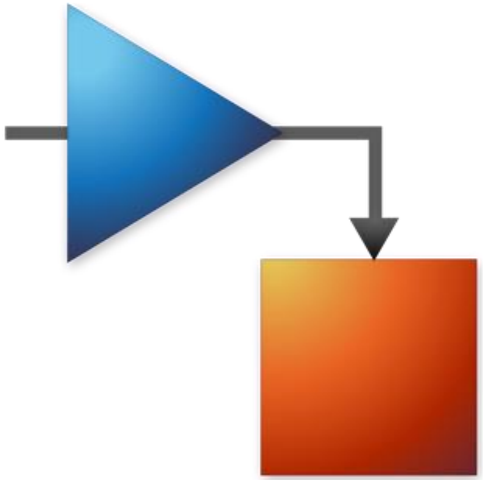
Case study: simulating an artificial pancreas



Source: [Artificial Pancreas Using Fuzzy Logic Controller]

Examples on MathWorks File Exchange

- Medical Ventilator Model in Simscape
- Cardiovascular System in Simscape with ECMO Machine
- Artificial Pancreas Using Fuzzy Logic Controller
- Dialysis Machine in Simulink
- Model-Based Design and Verification for Infusion Pump



Learn more

- [Learn more]about in silico medicine
- [White paper]on in silico medicine
- [Case studies]from the industry

Email: medical@mathworks.com

MathWorks
Accelerating the pace of engineering and science

How In Silico Medicine Can Accelerate Innovation in Medical Devices

Dr. Visa Suomi, Medical Devices Industry Manager at MathWorks, explains how virtual human simulation models can benefit the development of next-generation medical devices.

From Physical to Virtual Humans

Modern medical devices are becoming ever more complex with better functionality, which provides patient benefit but also increases the risk of design errors. Therefore, it is important that new medical devices are tested for safety and efficacy several times throughout the development cycle. The validation and clinical evaluation of medical devices can be performed using living animals or humans, but this is expensive, time-consuming, and sometimes even risky to the test subjects. Alternatively, the testing can be conducted with tissue-mimicking phantoms or *in vitro*, which can reduce time and costs but does not accurately reflect a real human.

The question then arises: is it possible to eliminate the drawbacks of time, costs, and possible safety risks while maintaining the advantages of *in vivo* evaluation? One way to do this could be *in silico medicine*, which refers to the use of virtual human models to replace their physical counterparts in testing of new medical devices. The aim of these virtual humans is to replicate human anatomy and physiology so accurately that they can be used

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Resources and Training

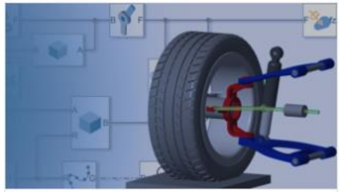
- https://www.mathworks.com/services/training/courses.html

Predictive Maintenance with MATLAB

Learn the analytics, signal processing, and machine learning techniques needed for predictive maintenance and condition monitoring workflows.

Real-Time Testing with Simulink Real-Time and Speedgoat Hardware

Configure Simulink models for rapid control prototyping and hardware-in-the-loop simulation, interface with an external motor and microcontroller hardware, and simulate and test against requirements in real time.



Modeling Multibody Mechanical Systems with Simscape

Model multibody mechanical systems; create custom geometries and compound bodies; assemble, guide, and verify mechanisms; and import CAD files.

Simulink Onramp

14 modules | 2 hours | Languages

Get started quickly with the basics of Simulink.

Circuit Simulation Onramp

7 modules | 2 hours | Languages

Learn the basics of simulating electrical circuits in Simscape.

Simscape Onramp

9 modules | 1.5 hours | Languages

Learn the basics of simulating physical systems in Simscape.

Stateflow Onramp

12 modules | 2 hours | Languages

Learn the basics of creating, editing, and simulating state machines in Stateflow.

Control Design Onramp with Simulink

7 modules | 1 hour | Languages

Get started quickly with the basics of feedback control design in Simulink.

Start the project with the right support

- ► Trials and evaluations
- ► Consulting services
- ► Training services
- ► Technical support

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