

Bioeng 6460
Electrophysiology and Bioelectricity

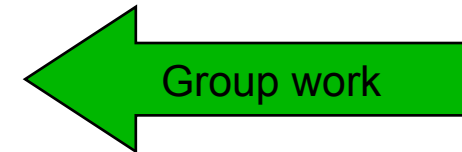
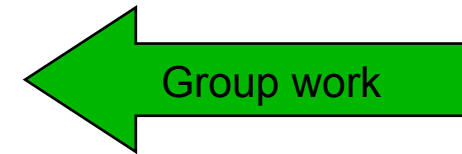
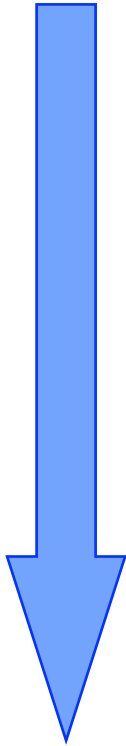
Modeling of Electrical Conduction
in Cardiac Tissue III
Arrhythmias

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Overview

- Simulation of Arrhythmias
 - Protocols and Models
 - Examples
- Cellular Automata
 - History
 - Introduction
 - Implementation
 - Examples
- Summary



Simulation of Arrhythmia: Protocol Design and Models Choice

Protocols similar as in experimental and clinical studies

Abnormal impulse initiation

- Stimuli
 - Intra-/extracellular
 - Timing
- Cellular electrophysiology
 - Density and gating of ion channels
 - Ion concentrations

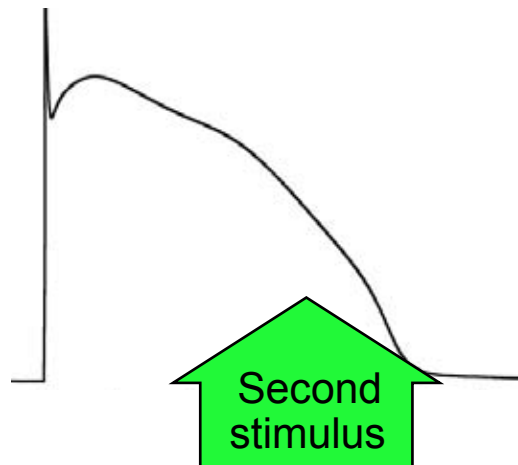
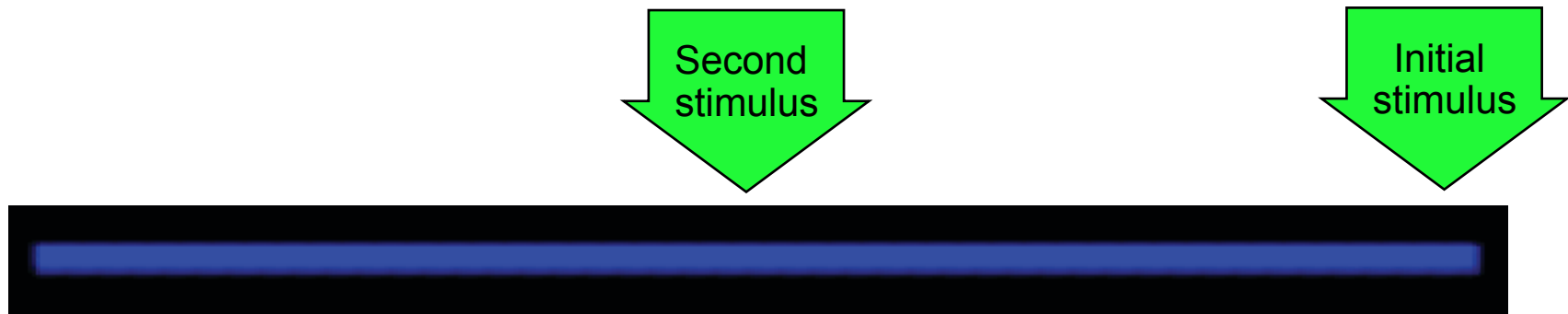
Abnormal conduction

- Tissue geometry
- Substrate properties
 - Conductivities
 - Cellular composition and electrophysiological properties

Challenges

- Realism - dynamical remodeling, multiscale and multiphysics process
- Computational demands

Unidirectional Block – 1D Monodomain Homogeneous Model



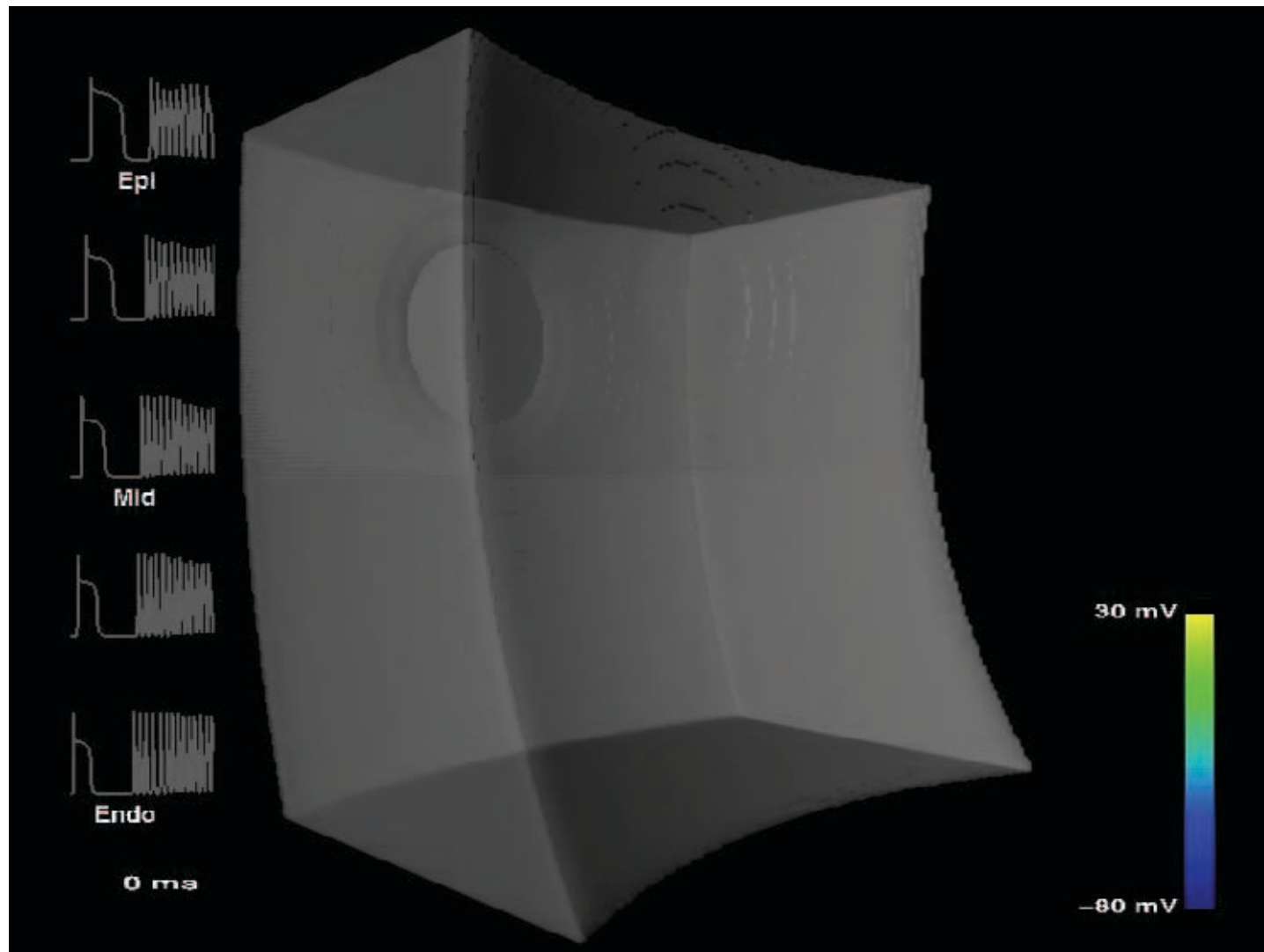
Unidirectional Block – 2D Monodomain Homogeneous Model



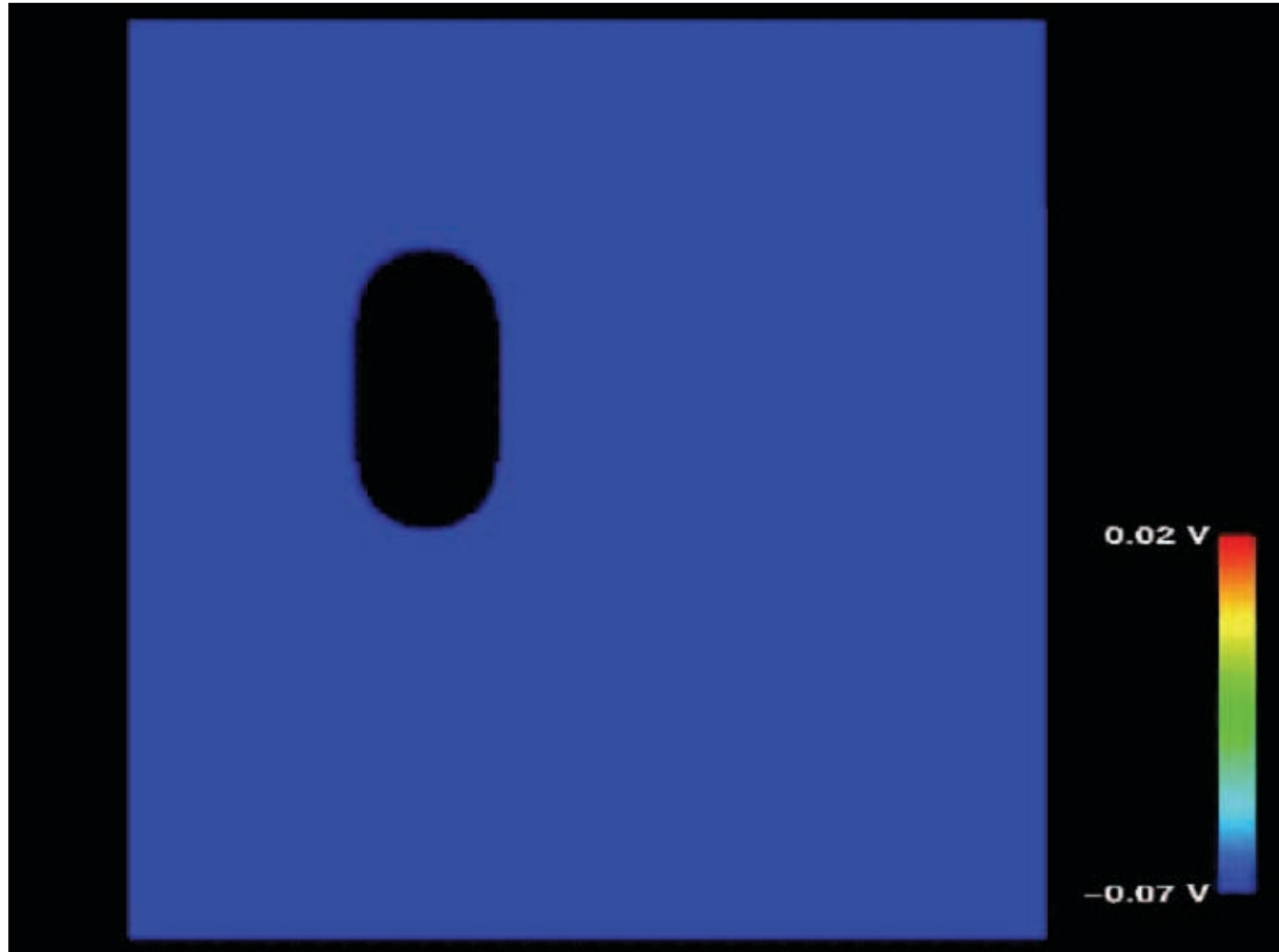
Unidirectional Block – 3D Monodomain Homogeneous Model



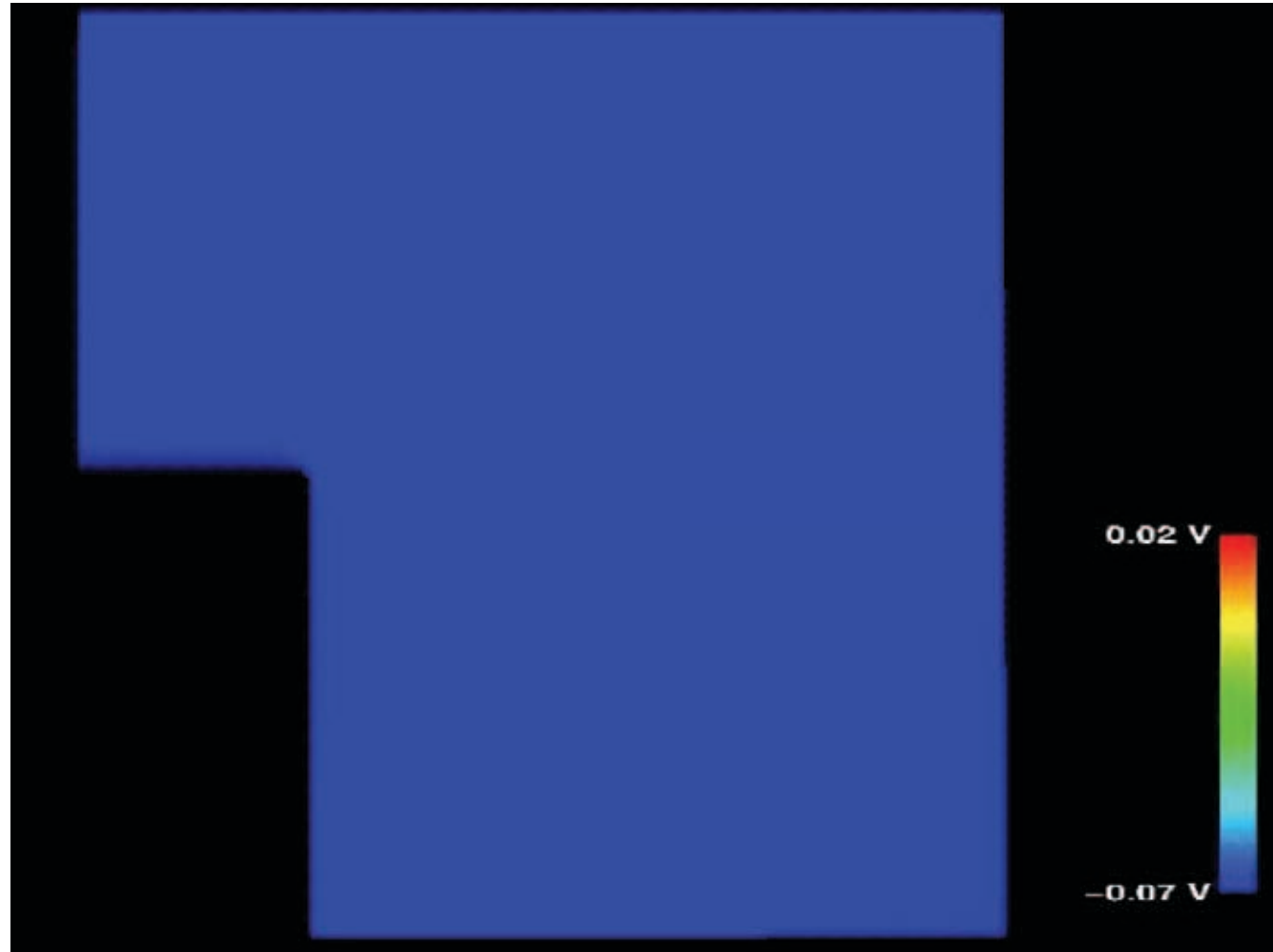
Rotor in Static Myocardial Area



Unidirectional Block – Rotating Wave Around Obstacle

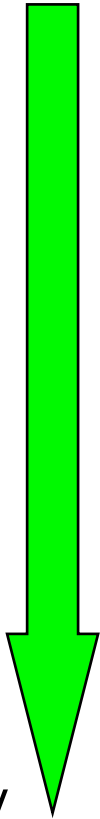


Heterogeneity of Source-Sink Relation



Cellular Automata of Cardiac Excitation Propagation

1946



- Wiener, Rosenblueth
- Moe, Rheinboldt, Abildskov
- Eiffler, Plonsey
- Adam
- Killmann, Wach, Dienstl
- Saxberg, Cohen
- Wei, Okoazaki, Harumi, Harasawa, Hosaka
- Siregar, Sinteff, Chadine, Le Beux
- Werner, Sachse, Dössel
- Siregar, Sinteff, Julen, Le Beux
- ...

2D sheets

Atria (2D sheet)

Ventricular myocardium (2D sheet)

Human ventricles (ellipsoids)

Human heart (from drawings)

Myocardium

Human ventricles (Anisotropic)

Human heart (2D)

Human heart (Anisotropic)

Human heart (CAD)

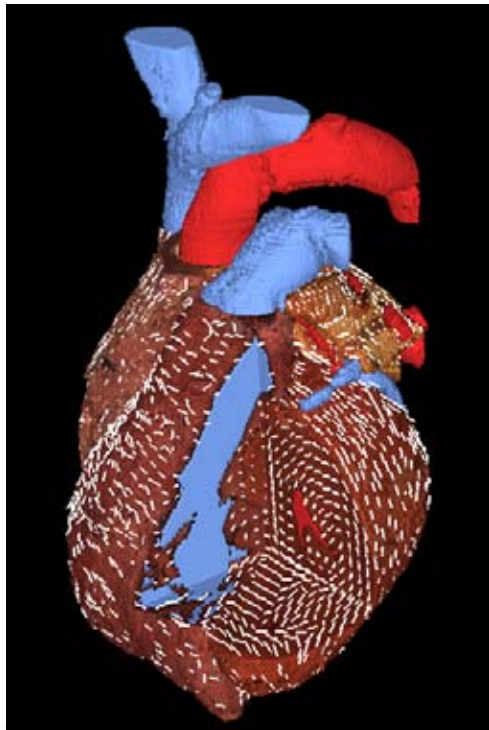
today



CVRTI

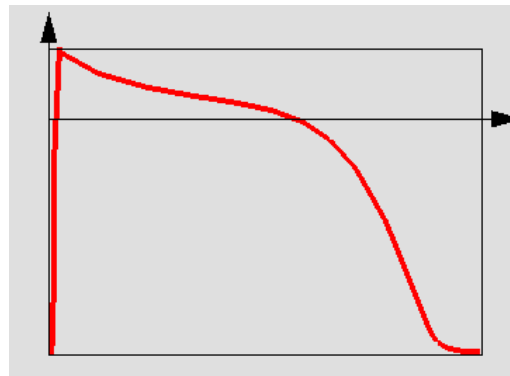
Cellular Automaton: Basics

Anatomical Model

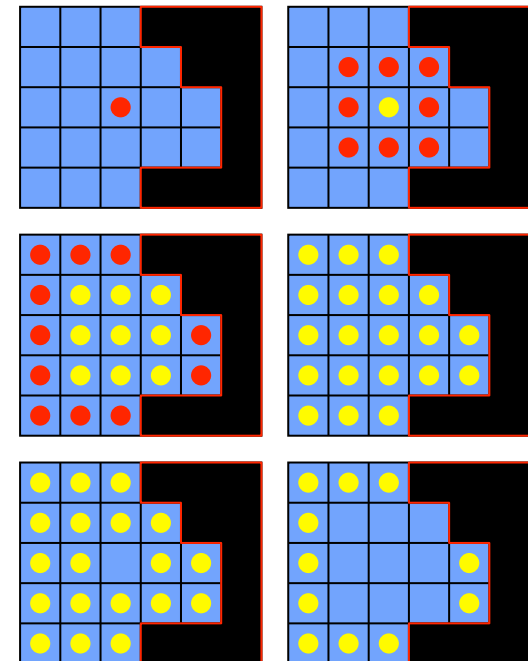


Physiological Parameters

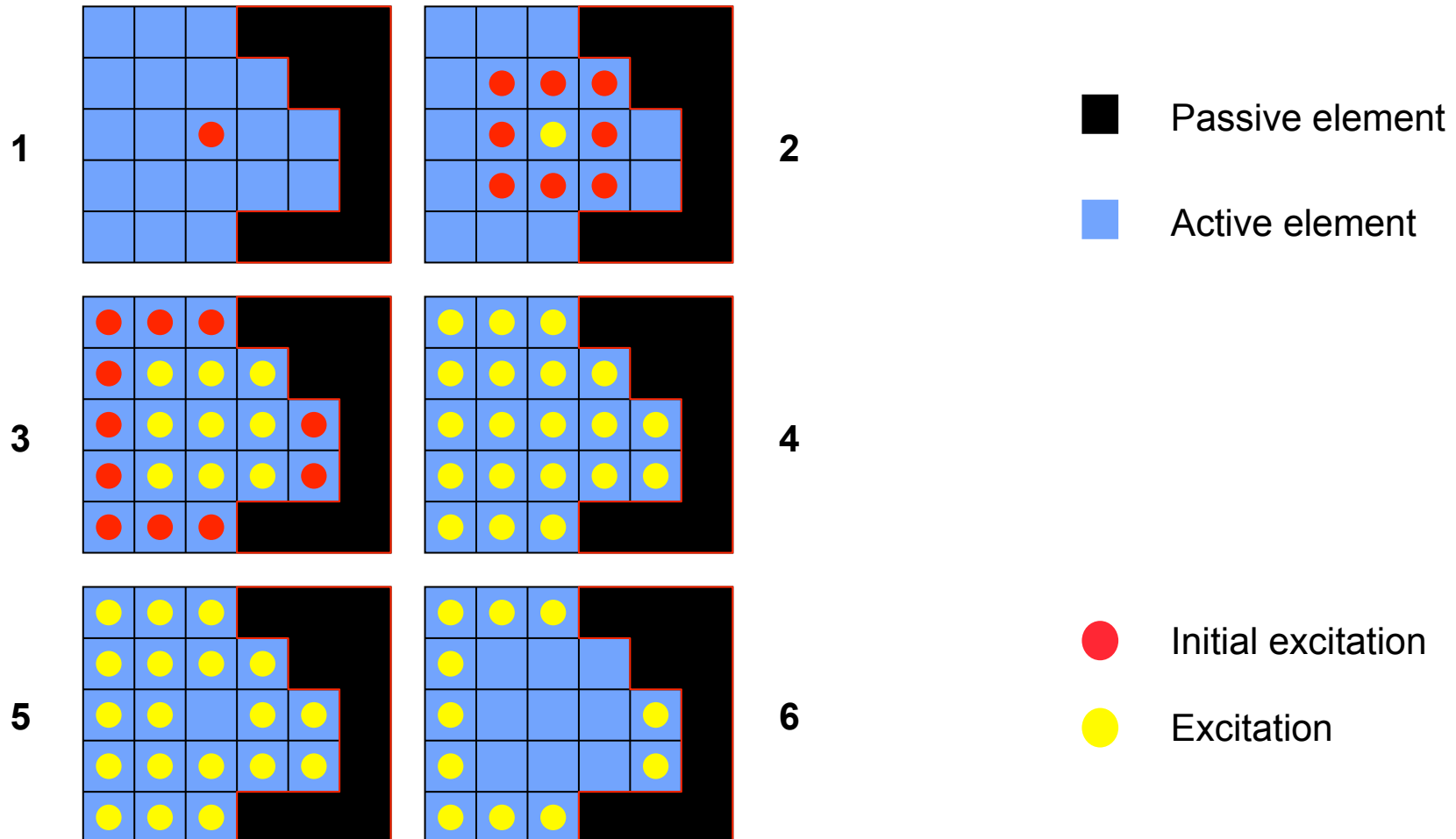
- Autorhythmicity
- Transmembrane voltage
- Conduction velocity
- Refractory period



Cellular Automaton



Cellular Automaton: Modeling of Propagation



Anatomical Model of Heart: Requirements

Necessary: Anatomical model of all excitation triggering and conductive components

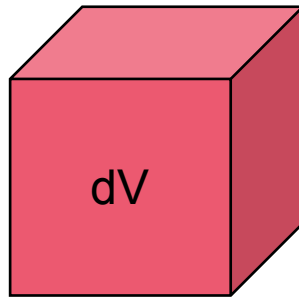
Example: Components in model of Werner et al.:

Image segmentation	Manual/rule-based definition
<ul style="list-style-type: none">• left atrial myocardium• right atrial myocardium• left ventricular myocardium• right ventricular myocardium	<ul style="list-style-type: none">• Sinus node• AV node• His bundle• Tawara bundle branches• Purkinje fibers• Fiber orientation

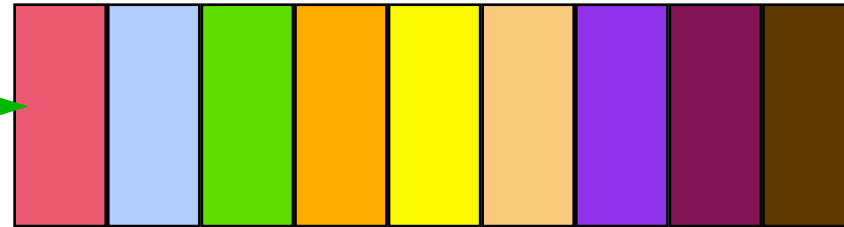


Parameters for Simulation: Lookup Tables

Known per
volume element dV
and for time t



- Time since activation t_s
- Stimulus frequency f
- Tissue type
- Fiber orientation



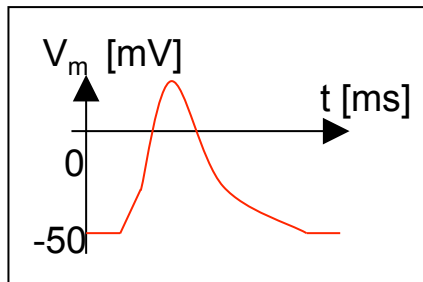
- Transmembrane voltage (t_s)
 - Refractory period (t_s)
 - Autorhythmicity (t_s)
 - Conduction velocity (f)
 - Excitable neighborhood
(constant)



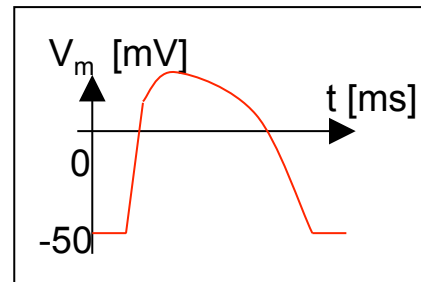
Cellular Automaton: Parameter - Transmembrane Voltage

Course of transmembrane voltage is dependent on tissue type and stimulus frequency.

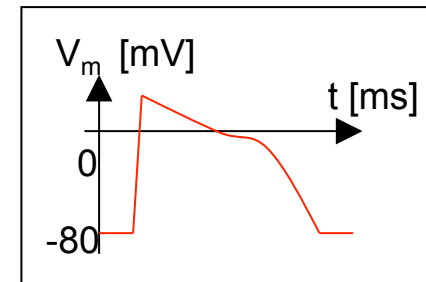
Activation is only possible outside of absolute refractory time.



Sinus node



AV node



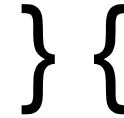
Atrial myocardium

Most cellular electrophysiological properties, e.g. ion and transmitter concentrations, nervous influences, extracellular potentials etc. are neglected!

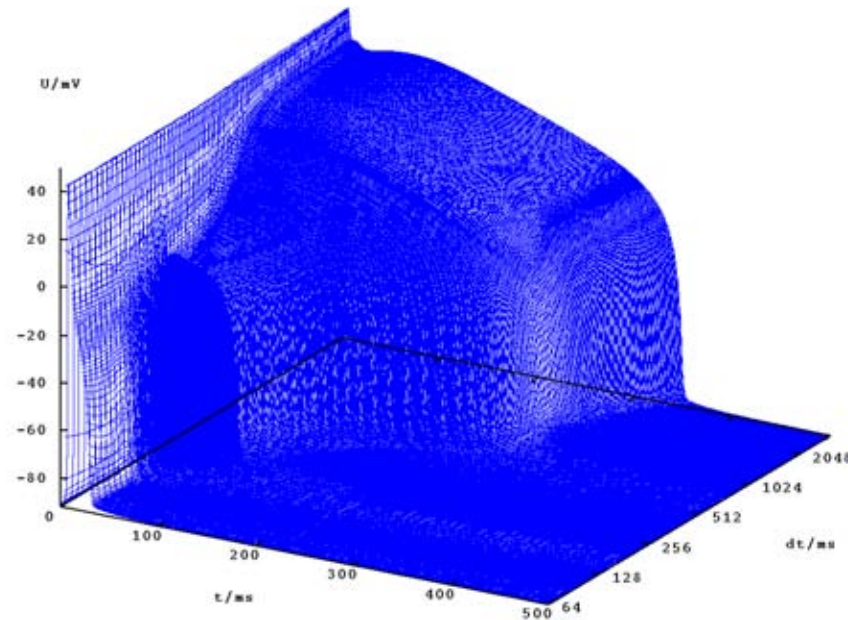


Cellular Automaton: Parameterization

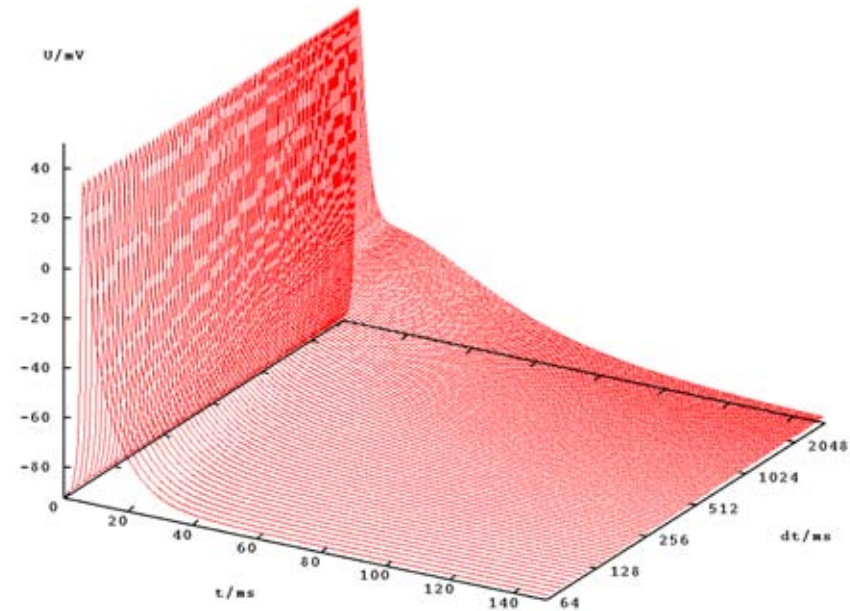
Course of transmembrane voltage
Longitudinal/transversal propagation velocity



Measurements
Numerical experiments



Ventricle: Noble-Varghese-Kohl-Noble 98



Atrium: Earm-Hilgemann-Noble 90

Group Work

Example

6	5	4	3	4	5	6
3	2	1	*	1	■	9
6	5	4	3	4	5	6

*: Stimulus site

■: Obstacle

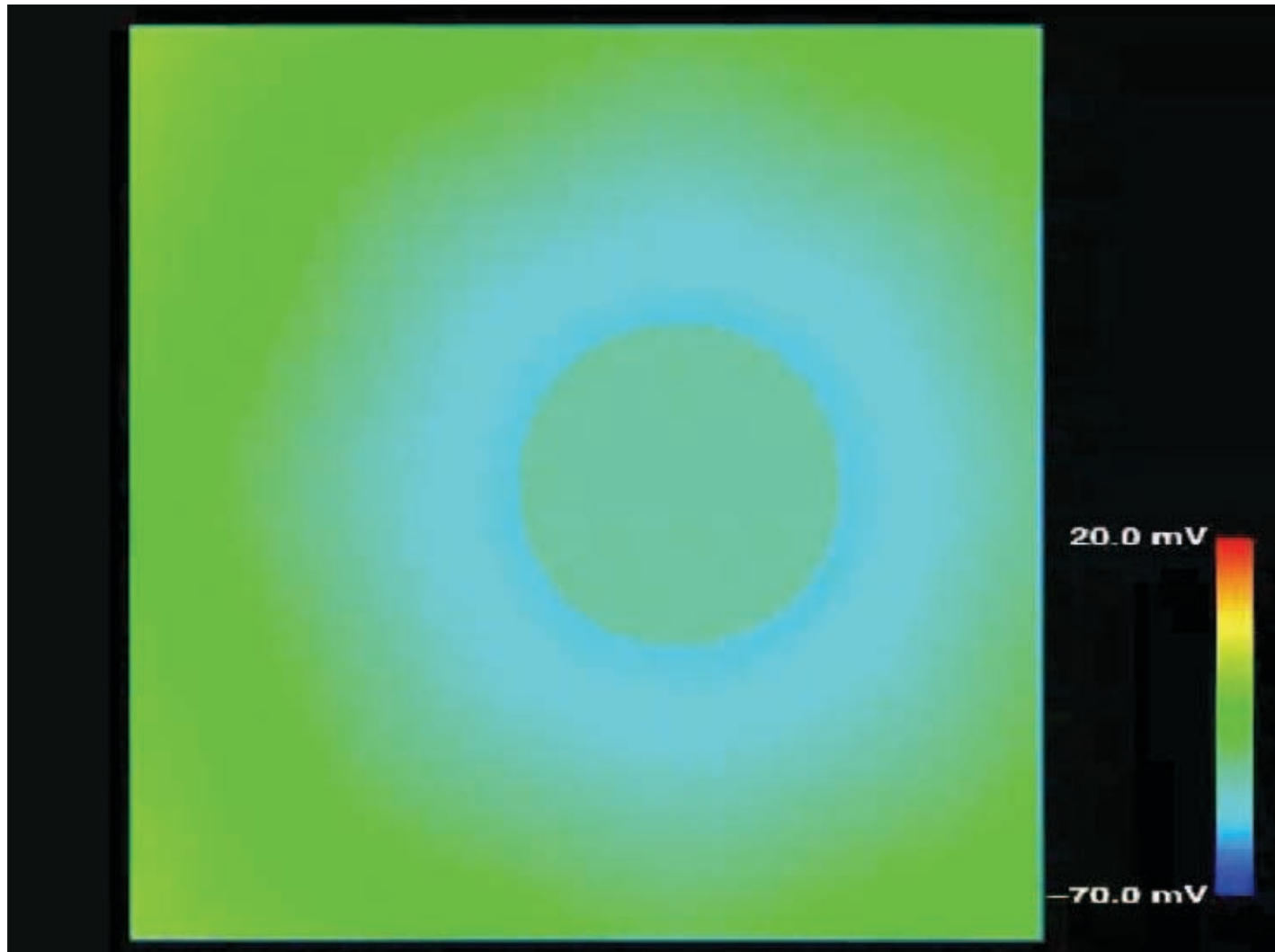
Connection: 4-neighborhood

Δt in x-direction: 1

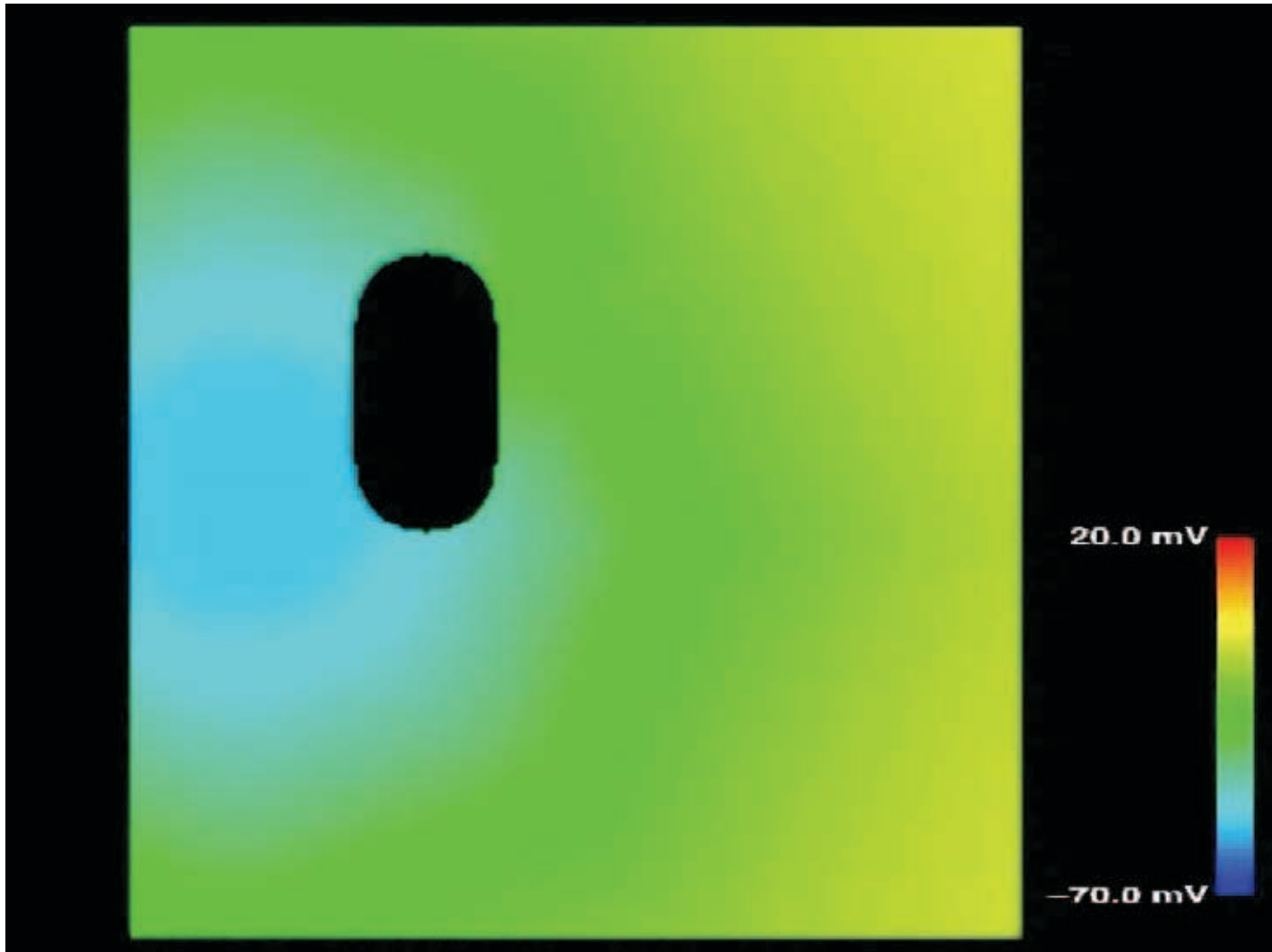
Δt in y-direction: 3

	■						
■							
			*	■	■	■	
				■	■	■	
				■	■	■	
*							

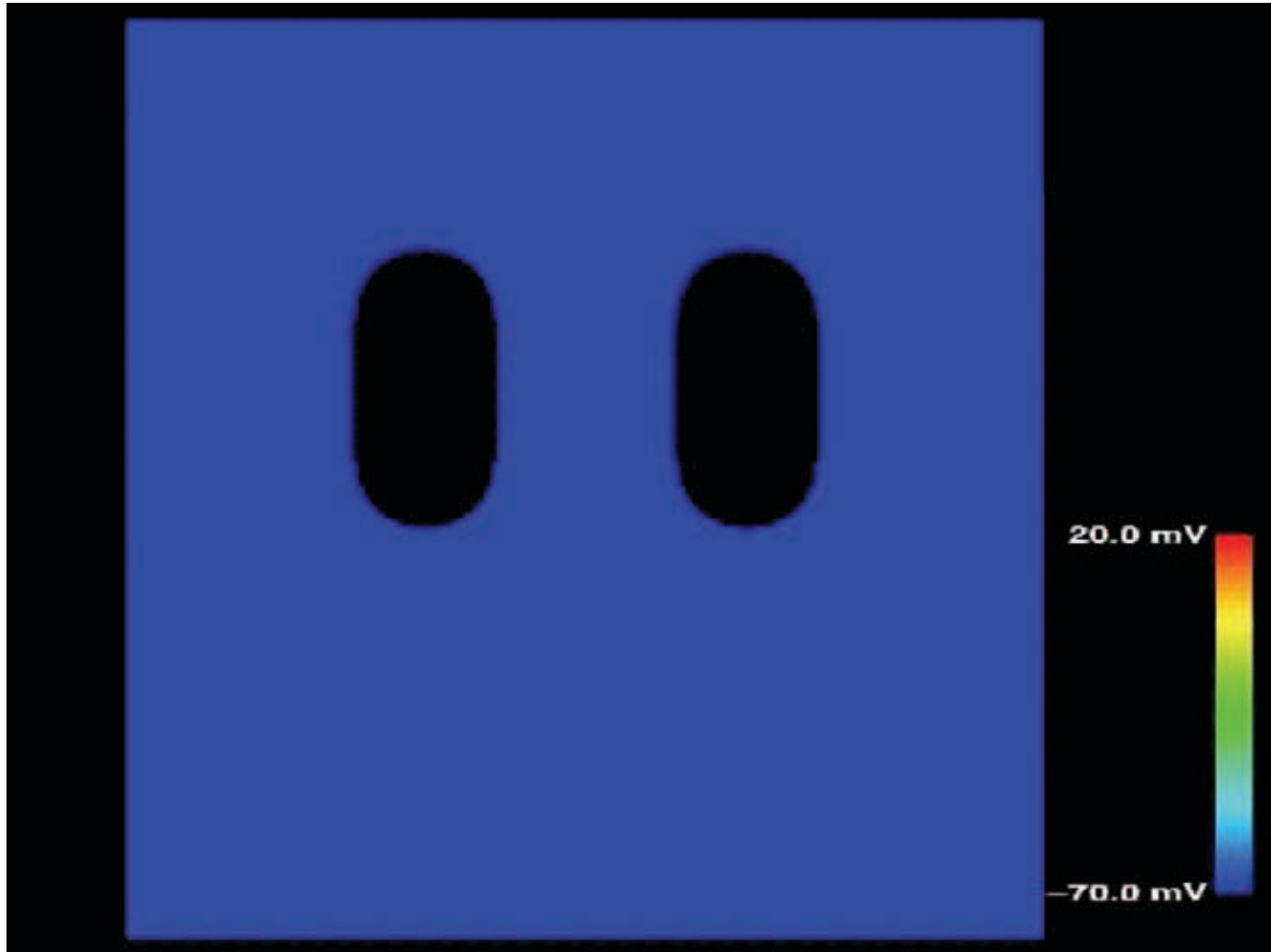
Unidirectional Block in Homogeneous Slice (2D)



Unidirectional Block - Rotating Wave Around Obstacles (2D)



Unidirectional Block - Rotating Wave Around Obstacles (2D)

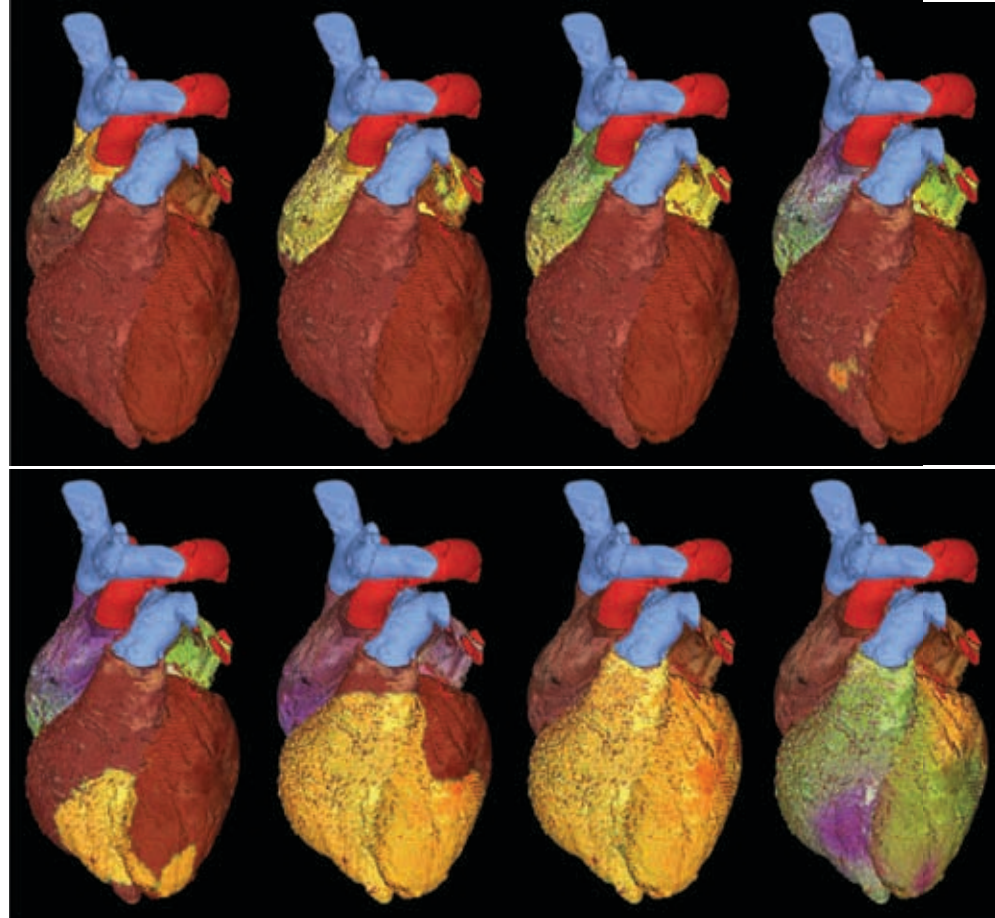


Results of Whole Heart Simulations

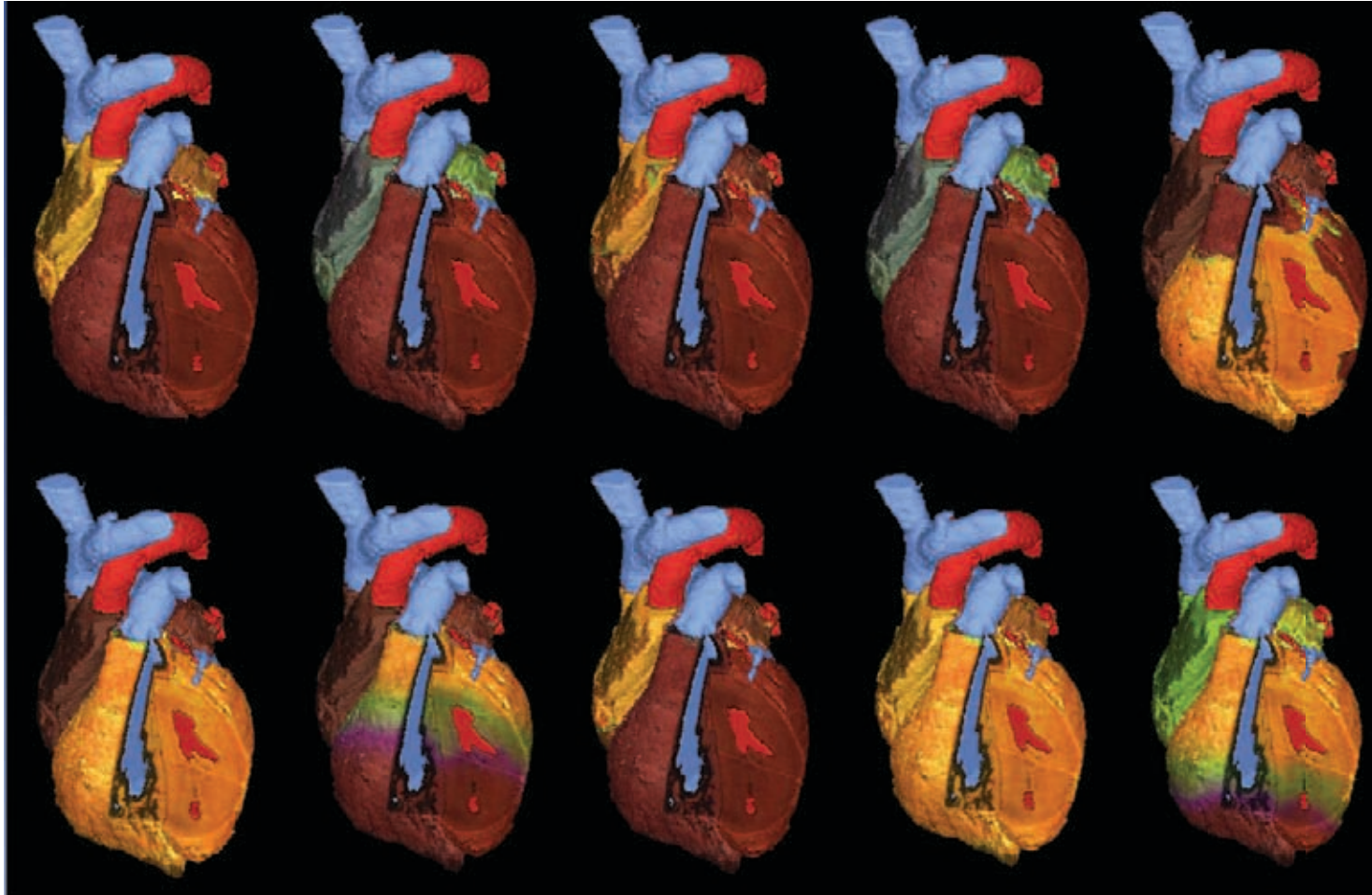
Transmembrane voltage
color-coded at heart surface
for physiological excitation
propagation

8 time steps

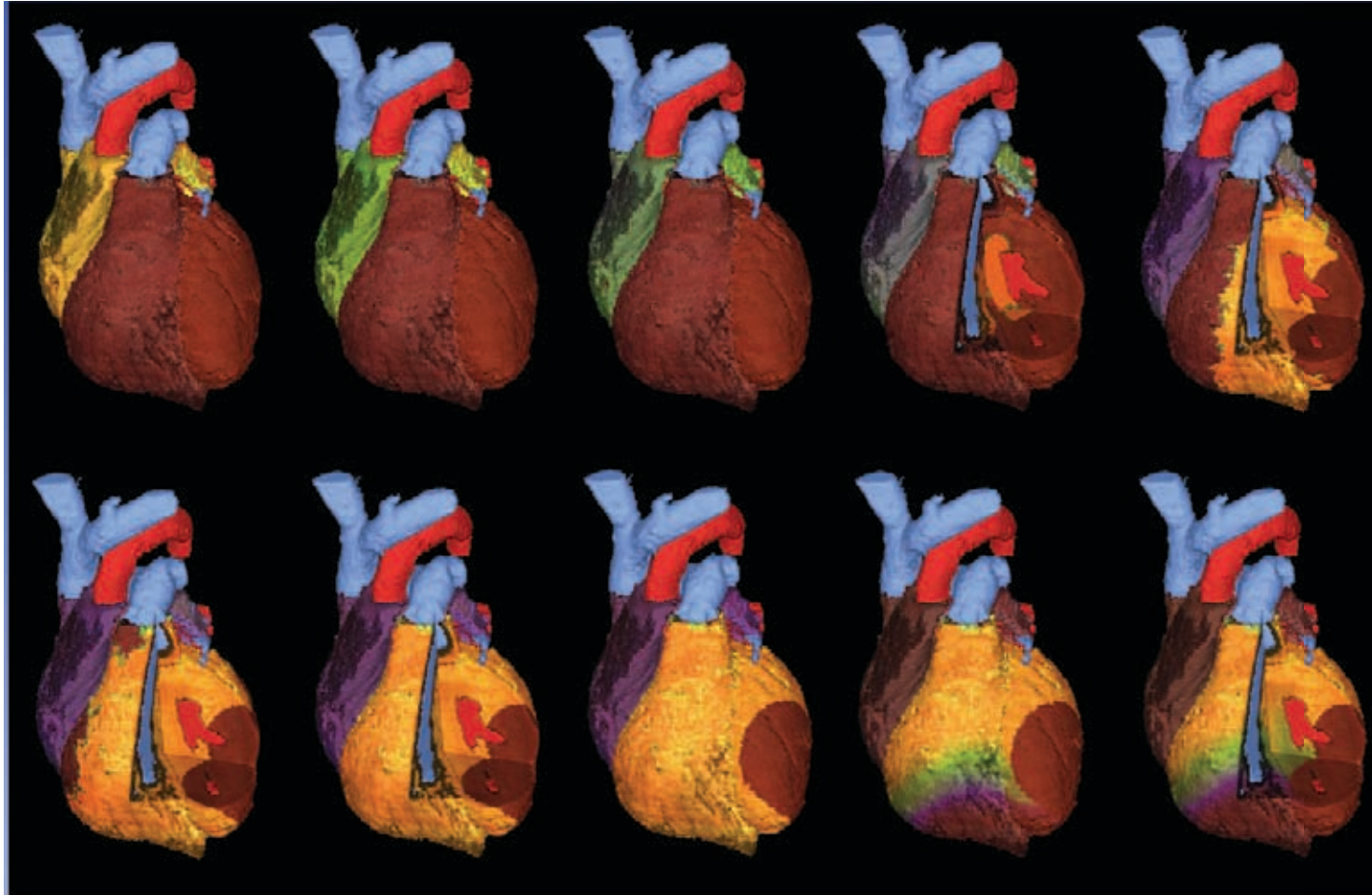
- atrial activation starting at sinus node
- ...
- atrial repolarisation
- ventricular activation starting at subendocardium
- ...
- ventricular repolarisation



Simulation of 3rd Degree AV Block



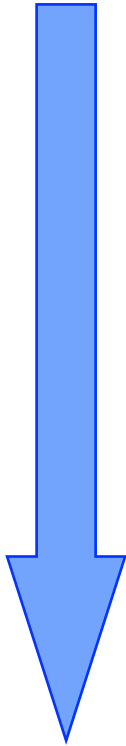
Simulation of Infarction



Group Work

Compare cellular automata with mono-/bidomain models of cardiac conduction! Apply ~5 criteria for comparison.

Summary



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